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Social Network Drivers of Agroecological Practices: Study of the Avocado Multi- stakeholder Platform

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Abstract

Smallholder farmers increasingly adopt agroecological practices to enhance productivity, eficiency, and market access while addressing climate vulnerabilities, market uncertainties, and financial instability. However, the role of social network drivers in fostering on-farm resilience practices remains underexplored. This study investigates the social network drivers supporting avocado agroecological practices among producers in Kenya, focusing on a multi-stakeholder platform. Using the social network analysis (SNA), the study identifies connections and centrality measures within production, market, and information exchange networks. Data were collected through farmer interviews and analyzed using a multiple linear regression model to assess the influence of network centrality metrics, sociodemographic factors, and farm attributes on agroecological techniques. The findings reveal that market centrality and information exchange networks influence agroecological practices more than production networks. The key factors such as farmers' age and education level play a critical role in adoption, while farm size and gender show limited impact. The study highlights the importance of multi-stakeholder strategies in addressing societal challenges, particularly in the avocado sector that underpin the value of local initiatives that engage farmers in technology innovation. By leveraging the strengths of social networks, stakeholders can enhance knowledge sharing, build trust, and promote sustainable practices, ultimately improving farm resilience and productivity. These insights contribute to the broader discourse on agroecology and the Agricultural Innovation System, offering actionable recommendations for policymakers and practitioners to support smallholder farmers in Kenya.

Keywords: Agroecology, Social Network Analysis, Multi-stakeholder Platforms, Avocado Farming, Climate Resilience, Kenya

Introduction

The agricultural sector is vital for a nation's economy, enhancing food security, employment, and rural livelihoods. Among the various agricultural commodities, avocado production has emerged as a key driver due to its high export demand and substantial economic potential [1].

Despite this growth, avocado farmers encounter numerous challenges, including climate variability, pests, and limited market access, which threaten the sustainability of their farming systems [2].

To address these issues, agroecological practices have gained traction as a promising approach to enhance farm resilience, boost productivity, and promote environmental sustainability. Agroecology integrates ecological principles into agricultural systems by fostering diversified farming practices, optimizing resource use efficiency, and strengthening social networks [3, 4]. Social networks are essential in facilitating the adoption and dissemination of agroecological practices. These networks enable farmers to exchange knowledge, resources, and innovations, enhancing their capacity to adapt to changing environmental and market conditions [5].

The Avocado Multi-Stakeholder Platform exemplifies this collaborative effort by bringing producers, researchers, policymakers, and other stakeholders. Understanding the dynamics of social networks within this platform is critical for promoting agroecological practices and scaling up sustainable farming techniques [1].

Social networks in agroecological systems facilitate innovation, knowledge sharing, and long- term territorial development [6]. Innovation in agriculture is inherently a social and interactive process, requiring the flow of information and collaboration among actors [7]. The structure of these networks significantly influences the growth and performance of agricultural innovations, making it essential to understand how information is disseminated and processed. Social network analysis (SNA), rooted in graph theory, provides a robust framework for examining relational data and identifying key actors and connections within agro-food systems [8]. Farmers are embedded in diverse networks, including family, friends, and stakeholders, which shape their practices and decision- making. Notably, rather than technical support or family networks, emphasize the significance of recognizing the role of central actors in information distribution [9, 10].

Research has shown that strong stakeholder ties enhance technology adoption and profitability among farmers [11]. Collaboration networks significantly improve the likelihood of adopting innovative farming practices. However, while knowledge flows within networks have been widely studied, there is a gap in understanding how these networks influence the adoption of agroecological practices, especially in avocado farming [12]. Agroecological practices, which aim to enhance productivity while addressing adaptation, resilience, and emissions reduction, are critical for mitigating the impacts of climate change on smallholder agriculture [13]. Smallholder farmers, highly vulnerable to climate threats such as droughts, floods, and pest outbreaks, face significant challenges in maintaining crop yields, food security, and income stability [14]. These challenges are further compounded by market volatility, environmental hazards, and financial instability, which are not adequately addressed by current interventions [15].

To address these challenges, multi-stakeholder platforms (MSPs) have emerged as a promising approach for fostering collaboration among diverse actors in the agricultural value chain. MSPs provide a structured space for stakeholders to share knowledge, resources, and strategies, thereby enhancing the resilience and sustainability of farming systems [16]. This study focuses on the role of MSPs in promoting agroecological practices among avocado producers in Kenya, the social network drivers that in fluence adoption. These drivers include network structure, information flow, trust, and social capital, learning and innovation, shared values and norms, leadership and influence, resource sharing, and policy support. Networks with dense connections and influential central nodes are more effective in disseminating agroecological knowledge and practices, while trust and social capital foster collective learning and resource sharing [17]. While previous studies have highlighted the importance of social networks in agricultural innovation, few have explored their role in agroecological practices, especially in the avocado sector. This study builds on the work of Aguilar-Gallegos et al. (2015) and Filippini et al. (2020) by examining how network structures and central actors influence the dissemination and adoption of climate-smart practices. It also extends the findings of Diaz-Sarachaga et al. (2018) and Rasch (2019) by focusing on the potential of MSPs to address complex socio-economic and environmental challenges in smallholder farming systems.

This study aims to bridge the knowledge gap regarding how social networks influence agroecological practices among smallholder avocado farmers in Kenya. It addresses three key objectives: (i) to explore the role of social network drivers in on-farm resilience practices among avocado producers, (ii) to use social network analysis (SNA) to identify connections and centrality measures in production, market, and information exchange networks, and (iii) to determine the factors influencing the adoption of avocado agroecological techniques. By integrating SNA with an analysis of socio-demographic and farm-level factors, the study provides a comprehensive understanding of the drivers of agroecological adoption. It also offers actionable insights for policymakers and practitioners seeking to promote sustainable agricultural practices and enhance the resilience of avocado farming systems. The findings will contribute to the broader objectives of the Avocado Multi-Stakeholder Platform by recommending strategies to strengthen farmer networks, improve knowledge sharing, and encourage the uptake of agroecological practices.

Methodology

Study Location

The research focused on the Upper Mara Watershed, specifically the East Bomet and Narok West Sub-County region, located in the Mau Forest Complex, at 1900-2970M elevation (Figure 1). The Upper Mara watershed, with a climate of 12°-16°C and Andosols and Nitisols soils, is primarily used for forest and agriculture. Its lowland region, encompassing grassland, livestock, and wildlife, preserves the ecosystem. However, human expansion and resource depletion have led to lower productivity. To counter this, avocado farming has been integrated into cattle rearing, preserving watersheds, and promoting cultural and economic values [18]. et al., 2023)

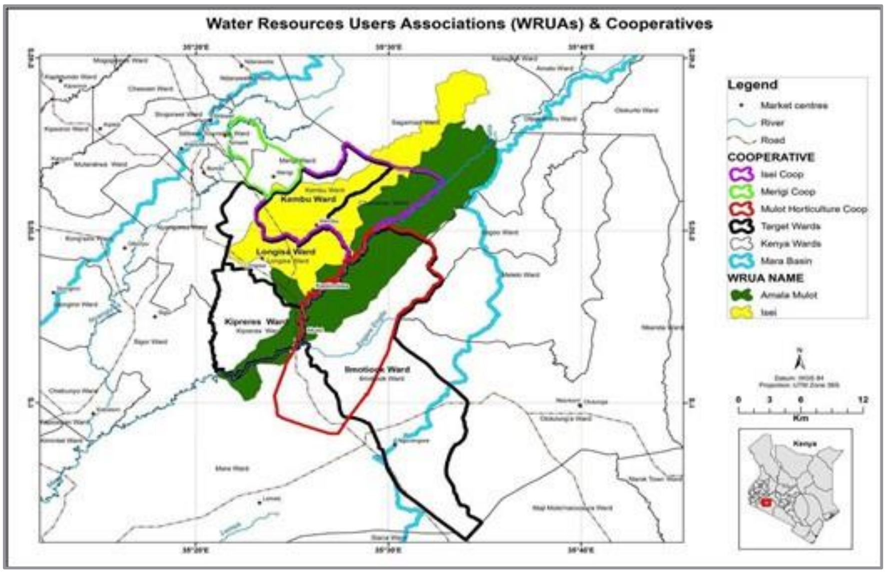

Figure 1: Map of Upper Mara Watershed of water users' associations and farmer cooperative groups. (Source: adapted from Rop et al., 2023)

Sample and Survey

The study investigated the avocado value chain in Kenya, focusing on the role of social networks in fostering on-farm resilience and agroecological practices. A total of 80 stakeholders, including representatives from cooperatives, government agencies, NGOs, and private sector actors, and 60 smallholder farmers from four avocado-producing cooperatives, were purposively sampled to ensure a comprehensive representation of the value chain. Data collection was conducted using structured surveys and semi-structured interviews to gather information on sociodemographic characteristics, challenges faced in adopting climate-smart agricultural practices, and patterns of information sharing among stakeholders within the avocado industry. The study identified and analyzed three distinct types of networks: production networks, which focus on collaborative farming activities; market networks, which examine trade and economic interactions; and information exchange networks, which explore the flow of knowledge and resources among [19]. These networks were critical for understanding how social connections influence the adoption of agroecological practices and resilience-building strategies among avocado producers.

Data Analysis

The data analysis process integrated social network analysis (SNA) and statistical modeling to address the study's objectives. First, SNA was employed to map and quantify the relationships among avocado farmers and stakeholders. A binary matrix was used to represent the presence or absence of connections between nodes (actors), and Gephi software was utilized for network visualization and analysis [20]. Key SNA metrics, including degree centrality (the number of connections a node has) and betweenness centrality (the extent to which a node lies on the shortest path between other nodes), were calculated to identify influential actors within the networks [21]. Additionally, network-level metrics such as density (the proportion of actual connections to possible connections), transitivity index (the likelihood of interconnectedness), and clustering coefficient (the degree to which nodes tend to cluster together) were used to assess the cohesion, openness, and subgroup formation within the networks [22].

Second, multiple linear regression analysis of the influence of sociodemographic factors (e.g., age, education, gender) and farm characteristics (e.g., farm size, access to resources) on agroecological techniques. This approach identifies key drivers and barriers to sustainable practices, aligning with the study's objectives [23].

Social Network Analysis and Agroecology

The study was grounded in the principles of agroecology, which emphasize ecological and social concepts to design sustainable and resilient agricultural systems [24]. Agroecology recognizes the interconnectedness of processes, human activities, and social dynamics, making it a suitable framework for analyzing the avocado value chain. By applying SNA, the study identified key actors and linkages within the production, market, and information exchange networks, highlighting opportunities for enhancing sustainability and resilience. For instance, actors with high centrality measures were found to play pivotal roles in disseminating knowledge and resources, influencing the adoption of agroecological practices [25]. Furthermore, the study acknowledged the context-specific nature of food systems, emphasizing the need for locally tailored solutions that address ecological, economic, and social constraints [26]. Through this integrated approach, the study provided insights into the diversity and complexity of the avocado value chain, offering actionable recommendations for improving its sustainability and resilience.

In graph theory, a connected component is a subgraph in which there is a path linking every pair of vertices, meaning all elements within the component are interconnected. Network analysis is a methodological approach used to study the relationships and interactions between elements within a system [27]. A connected component represents a segment of a network where every element reaches every other element through some path [27]. The largest connected component in a network is referred to as the giant component, which serves as an indicator of the network's overall connectivity and cohesion.

Assortativity, a key concept in network analysis, measures the tendency of elements (nodes) to form connections with others that are either similar or dissimilar in specific attributes, such as degree centrality [28]. Degree centrality, which quantifies the number of connections an element has, is often used to calculate and interpret assortativity. Assortativity is expressed as a correlation coefficient between the degrees of connected elements. A positive coefficient indicates that elements with similar degrees are more likely to connect, while a negative coefficient suggests a preference for connections between elements with differing degrees. This measure of assortativity provides insights into the network's structure, particularly its ability to link core and peripheral elements, thereby reflecting the network's overall connectivity and robustness [2].

Results and Discussion

The Role of Social Network Drivers in on-farm Resilience Practices Among Avocado Producers Gender and Marital Status

The survey findings highlight significant gender dynamics in avocado farming, a labor-intensive industry where roles are often divided along gender and age lines. Men dominate avocado cultivation, while women prioritize growing other food crops to ensure household food security. Gender is critical in knowledge acquisition, sharing, and decision-making, particularly in adopting climate-smart practices and managing agricultural production. Addressing gender disparities is essential for meeting societal and economic needs, promoting climate-smart agriculture, and enhancing agricultural resilience. This is especially relevant in developing countries, where women often manage farm labor and play a central role in agricultural activities [29, 30].

The study also found that 90% of respondents were married, while 3.89% were widows or widowers. Marital status significantly influences gender roles in land-use decision-making, labor allocation, and agricultural activities. Marriage often brings familial responsibilities, underscoring the importance of socioeconomic networks for accessing information and financial resources. The availability of family labor may encourage married farmers to expand crop cultivation and apply agricultural knowledge more effectively. These findings align with previous research indicating that information-sharing networks among smallholder avocado farmers vary by gender, with women often relying on close-knit networks and media for information. Balancing open communication with external sources and maintaining strong family networks is crucial for raising awareness about climate change and fostering resilience in agricultural practices.

Age and Education Level

The demographic profile of avocado growers in rural areas reveals that the majority are aged between 34 and 60 years, with younger farmers (34.4%) and older farmers (19.0%) representing distinct groups within the farming community. Age is a significant factor influencing the adoption of climate-smart avocado farming practices, the acquisition of knowledge, and adaptation strategies. Older farmers are often less likely to adopt labor-intensive and knowledge- intensive agroecological techniques than their younger counterparts, who are generally more open to innovation and change. Additionally, most avocado farmers have moderate levels of education, typically attaining primary school certificates. Education is critical in addressing farming challenges, such as pest and disease management, and is a key determinant in sustainable practices. While age may pose a barrier to technology adoption, education emerges pivotal factor in overcoming these challenges and fostering resilience among farmers.

Education level is crucial for the effective adoption of climate-smart and agroecological practices. Farmers with higher education levels are better equipped to perceive, analyze, and respond to new information, enabling them to implement innovative techniques [31]. However, even farmers with modest literacy levels can actively participate in agricultural development. Through action learning—a participatory approach to learning by doing—farmers with limited formal education can enhance their capacity for creativity and innovation within agricultural systems [32]. This approach aligns with the principles of agroecology, which emphasize context-specific, participatory, and inclusive strategies for sustainable farming. By fostering collaborative learning and knowledge- sharing networks, even farmers with lower literacy levels can contribute to and benefit from agroecological practices, ultimately enhancing on-farm resilience.

These findings align with exploring the role of social network drivers in on-farm resilience practices. Age and education influence how farmers engage with production, market, and information exchange networks, which are critical for disseminating agroecological knowledge and practices. Social network analysis (SNA) can identify key actors and connections within these networks, highlighting how younger, more educated farmers may serve as central nodes in driving innovation and adoption. Furthermore, understanding the interplay between age, education, and network dynamics helps determine the factors influencing the adoption of agroecological techniques, providing actionable insights for promoting sustainable practices among avocado producers in Kenya.

Farm Size and Avocado Planting Techniques on Farms

The study highlights significant variations in farm sizes across three agroecological zones, with 9.8% of farms covering 0.1–0.1 hectares (ha), 25.5% ranging between 1–2 ha, 19.6% between 2.1–3 ha, and 45.6% exceeding 3.1 ha. Farm size plays a critical role in climate-smart practices, as smallholder farmers often face challenges in adapting to new technologies due to limited resources and land pressure [33]. Uncertainty about the benefits of these practices further hinders adoption, particularly among smaller farms. Farm size is frequently incorporated into models predicting technology acceptance, as it correlates strongly with the capacity to adopt innovative agricultural practices [34].

This aligns with the study's third objective, which seeks to determine the factors influencing the adoption of agroecological techniques among avocado producers. Smaller farms, for instance, may struggle to implement resource-intensive practices, while larger farms may have the capacity to experiment with and scale up climate-smart methods.

The study also found that smallholder farmers with varying experiences in avocado cultivation, particularly those with mature trees, are more likely to adopt climate-smart practices. These practices include intercropping, pure stands, boundary planting, and alternate row planting, which are tailored to the specific agroecological conditions of each zone. Climate variables, such as rainfall and temperature, define these agroecological zones and influence the success of practices like integrated nutrient management and conservation tillage, which are effective in preserving soil moisture and enhancing resilience [35]. This supports the study's first objective, which explores the role of social network drivers in promoting on-farm resilience practices. Farmers' experiences and local knowledge, shared through social networks, are critical for adapting these practices to local conditions.

A positive correlation was observed between avocado yield and farm size, particularly among small farms participating in multi-stakeholder platforms. These platforms facilitate communication, knowledge sharing, and resource access, enabling even smaller farms to adopt climate-smart practices that boost productivity and land resilience [2]. This finding aligns with the study's second objective, which uses social network analysis to identify connections and centrality measures in production, market, and information exchange networks. Multi-stakeholder platforms serve as hubs for information dissemination, with central actors playing a pivotal role in driving the adoption of agroecological practices. This reinforces previous research demonstrating that climate-smart methods can significantly increase avocado output, even on smaller farms [36].

However, the increasing variability in rainfall and temperature patterns poses significant risks to agriculture, underscoring the need for regionally appropriate knowledge and technologies. Indigenous knowledge, combined with scientific innovations, is crucial for developing sustainable practices that are resilient to climate change [35]. The choice of farming strategies, such as planting techniques and crop duration, is influenced by these climatic factors, making it essential to tailor agroecological practices to local conditions. This supports the study's third objective by highlighting the importance of context-specific factors, such as climate and indigenous knowledge, in shaping the adoption of agroecological techniques.

The study underscores the interplay between farm size, social networks, and agroecological practices in enhancing the resilience and productivity of avocado farming in Kenya. By leveraging multi-stakeholder platforms and integrating indigenous knowledge with climate- smart practices, smallholder farmers can overcome barriers to adoption and improve their livelihoods. These findings contribute to the broader discourse on sustainable agriculture, emphasizing the need for inclusive, context-specific strategies that align with the principles of agroecology.

The Avocado Farmers' Social Network Analysis

The study's analysis of avocado stakeholder networks in the value chain, as depicted in Figure 2, reveals the pathways through which growers, cooperative societies, input suppliers, and purchasing companies exchange information. Farmers with higher degrees of connectivity—those more central in the network—tend to interact more frequently with cooperative societies and other key stakeholders in the production network. This centrality is often attributed to the fact that cooperatives operate across different agroecological zones, and during interviews, farmers identified certain individuals as "opinion farmers" who play a pivotal role in disseminating knowledge and practices. These highly connected farmers often assist others with field tasks such as pruning, watering, weeding, mulching, sharing sprayers, and coordinating harvests. Due to the geographical proximity of farms, farmers are more likely to seek assistance from neighbors, which reinforces localized networks of collaboration and knowledge sharing. However, the production network is less dense compared to the information exchange network, indicating that while collaboration occurs, it is often limited to specific tasks and localized interactions [19].

Agroecological zones play a significant role in shaping the information exchange network. Farmers from mid-agroecological zones are often identified as key nodes, connecting nearby and distant farmers, and various farmer groups and cooperatives. The reputation of these farmers, built on their experience and success in avocado farming, enhances their centrality in the network. This aligns with the study's second objective, which uses social network analysis (SNA) to identify connections and centrality measures in production, market, and information exchange networks. The findings suggest that information flows on the credibility and influence of central actors, who act as bridges between different groups and zones [25].

In contrast, the market network is fragmented, with farmers often selling small quantities of low- quality avocados (due to damage or malformation) to nearby retailers in urban centers. This fragmentation is exacerbated by the lack of trust among farmers and export companies, as farmers expressed skepticism about the pricing and methods used by these entities. As a result, many farmers prefer to sell their produce through brokers or new buyer organizations that offer better prices, bypassing traditional export channels. This lack of cohesion in the market network highlights the need for tailored policies, such as contract agreements facilitated by cooperatives and regulatory interventions by government authorities, to improve the quality and marketability of avocados for export [2].

These findings resonate with the factors influencing the adoption of agroecological techniques among avocado producers. The fragmented market network and limited trust among stakeholders underscore the importance of institutional support and policy interventions in fostering sustainable practices. For instance, contract farming arrangements could incentivize farmers to adopt quality- enhancing agroecological practices, such as integrated pest management and soil conservation techniques, which are critical for meeting export standards [23].

The study also highlights the role of agroecological zones in shaping production and information exchange networks. Farmers in mid-agroecological zones, for example, are more likely to be central nodes in information networks due to their ability to adapt practices to varying climatic conditions. This adaptability is crucial for promoting climate-smart practices, such as conservation tillage and intercropping, which are more effective in preserving soil moisture and enhancing resilience [35]. These findings align with how to explore the role of social network drivers in on-farm resilience practices. By leveraging the influence of central actors and fostering collaboration across agroecological zones, stakeholders can enhance the adoption of sustainable practices and improve the overall resilience of avocado farming systems.

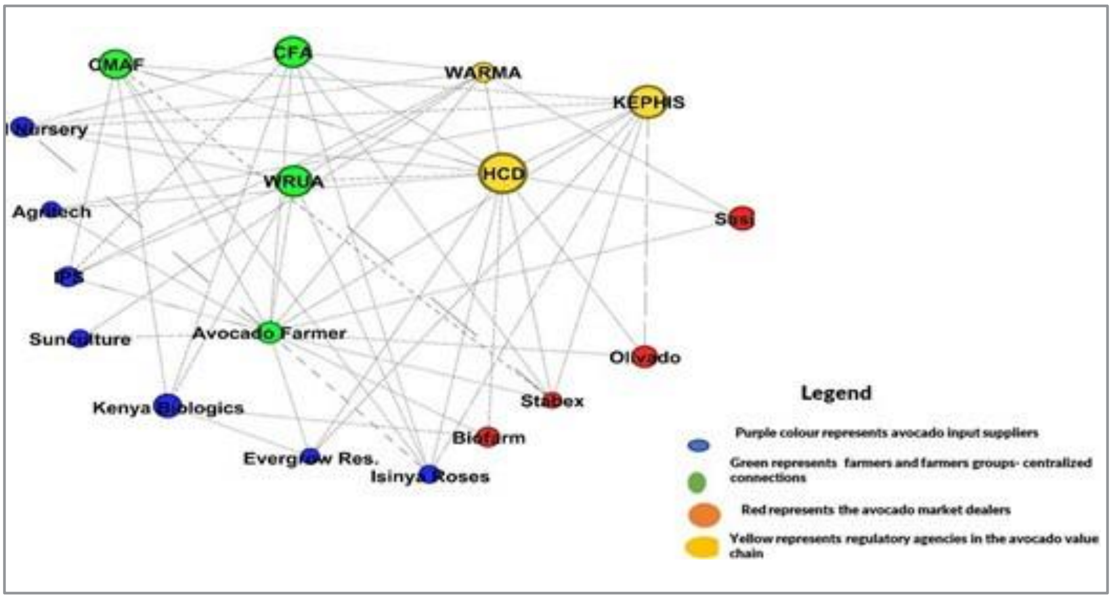

Figure 2: Avocado value chain stakeholder network with nodes indicating centrality, color-coded, representing node size and centrality.

The study's analysis of key network characteristics, as summarized in Table 1, reveals distinct patterns in the production, market, and information exchange networks among avocado producers in Kenya. The production network connects 44% of the nodes (actors), indicating moderate levels of collaboration among farmers, particularly in tasks such as pruning, watering, weeding, and harvesting. In contrast, the market network is significantly less cohesive, linking only 16% of the sample. This fragmentation reflects the challenges farmers face in accessing reliable markets, often resorting to selling small quantities of low-quality avocados to local retailers or brokers. On the other hand, the information exchange network demonstrates full connectivity, with 100% of nodes linked, highlighting the critical role of information sharing in fostering collaboration and knowledge dissemination among stakeholders [19].

Table 1: Structural characteristics and network statistics

	Network of Producers	Network of Marketers	Network for Information Dissimilators
Number of linked nodes	33 (44%)	16 (21%)	38 (100%)
Number of edges	82	27	147
Degree—av. (st.dev.)	1.32 (1.75)	0.99 (0.21)	0.99 (0.34)
Top 3 nodes (degree score)	AF (25), IR (11), WRUA (8)	CMAF (13), OV (6), BF (4)	HCD (10), WRA (10), KEPHIS (10)
Betweenness—av. (st.dev)	23.04 (44.460	7.96 (3.89)	23.49 (14.25)
Top 5 nodes (betweenness score)	AF (152), IR (78), WRUA 16)	CMAF (27), OV (2), BF (1.8)	HCD (37, WRA (33), KEPHIS (22)
Density	0.012	0.2	0.25
Massive component (% of nodes)	33 nodes (44%)	16 nodes (11%)	38 nodes (100%)
Assortativity coefficient (r)	−0.73	0%	−0.991

The density values of the production and market networks are lower than those of the information exchange network, indicating weaker cohesion and fewer connections among actors. For instance, the production network has a density score of 0.012 (1.2%), compared to 0.25 (25%) for regulatory service providers. This low density suggests that while farmers collaborate in small, localized groups—often comprising related farms or neighbors—their interactions are limited in scope and scale. The transitivity index, which measures the likelihood of interconnectedness, further supports this finding, revealing clustering within the production network. This aligns with the uses of social network analysis (SNA) to identify connections and centrality measures in production, market, and information exchange networks. The clustering observed in the production network underscores the importance of localized, trust-based relationships in facilitating collaboration and resource sharing [25].

Both the production and information exchange networks exhibit negative assortativity coefficients, indicating a tendency for nodes with differing degrees of connectivity to interact. The production network is significantly more disassortative (r = -0.73) than the information exchange network (r = -0.99), suggesting that highly connected farmers (hubs) often interact with less connected farmers (peripheral actors). This pattern is consistent with previous research by Rop et al. (2022), which argues that disassortative networks are common in agricultural systems, where central actors are bridging in the roles of disseminating knowledge and resources.

However, the strong disassortativity in the production network may also reflect power imbalances, where a few influential farmers dominate decision-making and resource allocation, potentially marginalizing smaller-scale producers.

Note: AF represents avocado farmer; WRUA is the water resource user's association, CMAF is the cis-mara avocado farmer cooperative; HCD is the horticultural crop directorate; IR is Isinya Roses seedling supplier; BF is Biofarm avocado exporter; OV is Olivado avocado exporter; KEPHIS is Kenya plant health inspectorate service.

The findings highlight the critical role of social networks in driving the adoption of agroecological practices, aligning with the study's first objective. For instance, the high connectivity of the information exchange network facilitates the dissemination of climate-smart practices, such as integrated nutrient management and conservation tillage, which are essential for enhancing soil health and resilience [35]. However, the fragmented market network poses a significant barrier to these practices, as farmers lack access to reliable markets and fair pricing. This underscores the need for institutional interventions, such as contract farming agreements and cooperative-led initiatives, to improve market access and incentivize sustainable practices [23].

The study's findings also resonate with its third objective, which seeks to determine the factors influencing the adoption of agroecological techniques. The low density and disassortativity of the production and market networks highlight the challenges of smallholder farmers in scaling up sustainable practices. By contrast, the high connectivity of the information exchange network demonstrates the potential of social networks to overcome these barriers, when central actors— such as cooperative leaders or experienced farmers—play a proactive role in disseminating knowledge and resources. These insights align with previous research emphasizing the importance of network-driven approaches in promoting agroecological transitions [19].

The study's analysis of network structures reveals essential insights into the role of social networks in driving the adoption of agroecological practices among avocado producers in Kenya. While less dense than the information exchange network, which effectively connects core nodes (central actors) to peripheral nodes (less-connected actors), facilitating collaboration and resource sharing. With a density score of 1.2%, the production network clusters 44% of the nodes, indicating moderate levels of connectivity. Centrality measures, such as betweenness and degree centrality, further highlight the limited capacity of peripheral nodes to link with sub- groups, a pattern observed in both the production and information exchange networks. This suggests that while central actors play a critical role in bridging gaps, peripheral actors often remain marginalized, limiting the overall cohesion of the network [19].

Despite its lower density, the production network exhibits a higher average betweenness centrality than the information exchange network, indicating a greater capacity to connect disparate subgroups. This is further supported by the higher average degree of centrality in the production network, which reflects the presence of highly connected nodes that facilitate the flow of information and resources. However, the standard deviation of centrality measures suggests a more uniform distribution of connections in the information exchange network, highlighting its role as a more egalitarian platform for knowledge dissemination [25].

The study's findings align with social network analysis (SNA) to identify connections and centrality measures in production, market, and information exchange networks. Centrality factors in the production network, such as support and advisory services, significantly influence climate-smart practices, underscoring the importance of well-connected actors in driving innovation and resilience. In contrast, the information exchange network does not impact adoption rates, suggesting that the quality and nature of relationships—rather than mere connectivity—are critical for fostering behavioral change [2].

Multi-stakeholder platforms, for instance, play a pivotal role in accelerating the dissemination of information and best practices, particularly when influential stakeholders with high centrality are involved. These findings are consistent with previous research, which has shown that strong, trust-based relationships within networks enhance the adoption of sustainable practices [23].

A key insight from the study is the importance of network structure in facilitating knowledge dissemination. While the research did not regress network indicators such as density, transitivity, and assortativity against adoption rates, the analysis reveals that the production network is more effective than the information exchange network in disseminating agricultural knowledge. This is attributed to stronger connections and reduced information redundancy, enabling more efficient communication and collaboration [27].

For example, farmers in the production network are more likely to adopt climate-smart practices when they receive targeted support and advice from central actors, such as cooperative leaders or extension officers.

These findings resonate with the social network drivers in on-farm resilience practices. The production network's ability to connect core and peripheral actors, coupled with the influence of central stakeholders, highlights the potential of network-driven approaches to enhance the adoption of agroecological practices. This is particularly relevant in climate-smart agriculture, where conservation tillage, integrated pest management, and agroforestry require collective action and knowledge sharing [35].

Empirical Test Evaluating Factors for Adoption of Avocado Agroecological Techniques Among Avocado Producers. The study employs social network analysis (SNA) to investigate the involvement of stakeholders in avocado value chain networks and their influence on network structures, aligning with the study's second objective of identifying connections and centrality measures in production, market, and information exchange networks. Climate-smart practices are used as the dependent variable in a multiple linear regression model to assess their adoption, determining the factors influencing the adoption of agroecological techniques among avocado producers. The model incorporates centrality metrics from stakeholder networks as independent variables, including degree centrality and betweenness centrality, to explain the adoption of climate-smart practices. Specifically, production degree centrality measures the centrality of farmers in the production network, market degree centrality assesses centrality in the market network, and information exchange degree centrality evaluates the centrality of regulatory service providers in the information exchange network [12].

Additionally, betweenness centrality metrics for production, market, and information exchange networks are included to capture the role of actors who bridge gaps between sub-groups, facilitating the flow of information and resources. Control variables such as farm characteristics and farmer-specific traits are also incorporated into the model. Capacity, measured by the number of avocado trees planted, is a proxy for production potential. Sociodemographic factors, including age, education, and gender, are included to account for their influence on farmers' attitudes toward climate-smart practices. Age and education are continuous variables, gender is a binary variable, and education levels (primary, middle, high school, and university are categorical. These variables help explain variations in climate-smart practices, providing insights into social and economic drivers of agroecological transitions [37].

Descriptive statistics and correlation matrices reveal strong relationships between degree and betweenness centrality variables within the avocado value chain networks, particularly in the production network. Polychoric correlation is used to quantify dependencies between ordinal variables, such as Likert-scale items, under the assumption of bivariate normality for latent continuous variables. This approach is the linear relationships between discrete observable variables, such as age and education, and centrality measures [38].

The findings highlight the critical role of network centrality in driving the adoption of climate- smart practices, aligning with the study's first objective of exploring the role of social network drivers in on-farm resilience practices. Central actors in the production network, for instance, play a pivotal role in disseminating knowledge and resources, thereby enhancing the adoption of agroecological techniques such as integrated pest management, conservation tillage, and agroforestry [19].

These practices are essential for building resilience to climate change and improving the sustainability of avocado farming systems. The study's emphasis on the interplay between network structure and sociodemographic factors contributes to the broader discourse on agroecology, highlighting the need for context-specific strategies that address both social and ecological dimensions. For example, gender as a control variable underscores the importance of addressing gender disparities in access to resources and decision-making, which are critical for promoting equitable and sustainable agricultural practices [23].

Similarly, the focus on education and age highlights the role of capacity-building initiatives in enhancing farmers' ability to adopt and adapt climate-smart practices.

The study reveals a strong positive correlation between degree centrality and betweenness centrality in the producers' network, as a climate-smart practice across all three networks (production, market, and information exchange) (see Table 2). This finding aligns with earlier research by Marescotti et al. (2021), which emphasized the role of central actors in disseminating agricultural technologies. Central nodes in the producers' network, characterized by high degree and betweenness centrality, play a pivotal role in spreading knowledge and practices related to climate-smart agriculture. However, this effect is less pronounced in the marketing and information dissemination networks, where core nodes do not significantly expand the adoption of avocado as a climate-smart practice. This suggests that the producers' network is uniquely positioned to drive the adoption of agroecological techniques, as it facilitates direct collaboration and resource sharing among farmers [19].

The capacity of the farmers' network, particularly the degree centrality of producers, emerges as the most critical factor influencing climate-smart practices. This underscores the importance of well-connected actors in the production network, who act as hubs for knowledge dissemination and innovation. In contrast, the marketing and information dissemination networks, have a more limited impact on adoption rates. This finding aligns with the study's second objective, which uses social network analysis (SNA) to identify connections and centrality measures in production, market, and information exchange networks. It also highlights the need for targeted interventions that strengthen the producers' network, enabling central actors to promote sustainable practices [23].

Table 2: Correlation matrix of stakeholders

Attributes 1	2	3	4	5	6	7	8	9	10
1 Age	−0.16**	1	0.21**	−0.03	−0.29**	0.14**	0.11**	−0.24	0.32
2 Education		−0.09	−0.27	0.11	1	-0.02	0.14	73	0.06
3 Gender			-16	−0.27	−0.19**	−-0.86	-−0.05	0.11	−0.07
4 Avocado amount				55.00%	0.7	25.00%	0.615	36.00%	0.62
5 Producer Degree of Centrality					0.69**	51.00%	0.59**	45.00%	0.47

6 Marketing Degree of Centrality						0.73	0.51	0.51	0.61
7 Information Dissemination							0.5	54.00%	0.69**
Degree Centrality									
8 Producer Betweenness Centrality								0.63**	0.43
9 Marketing Betweenness Centrality									0.59**
10 Information Dissemination Betweenness Centrality									

Note: For variables 1, 4, 5, 6, and 7, Pearson correlation is used, whereas for variables 1 and 2, polychoric correlation is relied on. ** represents 5% significance.

The study reveals a strong positive correlation between degree centrality and betweenness centrality in the producers' network, as a climate-smart practice across all three networks (production, market, and information exchange) (see Table 2). This finding aligns with earlier research by Marescotti et al. (2021), which emphasized the role of central actors in disseminating agricultural technologies. Central nodes in the producers' network, characterized by high degree and betweenness centrality, play a pivotal role in spreading knowledge and practices related to climate-smart agriculture. However, this effect is less pronounced in the marketing and information dissemination networks, where core nodes do not significantly expand the adoption of avocado as a climate-smart practice. This suggests that the producers' network is uniquely positioned to drive the adoption of agroecological techniques, as it facilitates direct collaboration and resource sharing among farmers [19].

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A multivariate linear regression model was developed, with climate-smart practices (yi) as the dependent variable. The model includes three independent variables—degree centrality measures for the producers' network (Network 1), marketing network (Network 2), and information dissemination network (Network 3)—along with control variables such as age (z1i), education (z2i), gender (z3i), and the number of avocado trees on the farm (z4i). The equation of the model is represented by:

$$yi = \beta i + xi + z1i + z2i + z3i + z4i \quad (1)$$

The results of the regression analysis, presented in Table 3, reveal that degree centrality in the producers' network 1 has the most powerful positive impact on climate-smart practices. This finding supports the study's third objective, which seeks to determine the factors influencing the adoption of agroecological techniques among avocado producers. The control variables also provide valuable insights: education and the number of avocado trees positively influence adoption, while age and gender show mixed effects. These findings are consistent with previous research, on the role of education and farm size in facilitating the adoption of sustainable practices [37].

The study's emphasis on the producers' network aligns with the principles of agroecology, which emphasize the importance of localized, participatory approaches to sustainable agriculture. By strengthening the connections between farmers and enhancing the role of central actors, stakeholders can promote climate-smart practices such as conservation tillage, integrated pest management, and agroforestry. These practices improve farm resilience and also contribute to broader goals of food security and climate adaptation [35].

Table 3. Multiple linear regression on sociodemographic attributes of the avocado growers.

Attributes	Network 1			Network 2			Network 3		
Attributes	**Coefficient**	**St.Dev.**	**p Value**	**Coefficient**	**St.Dev.**	**p Value**	**Coefficient**	**St.Dev.**	**p Value**
Intercept	0.4	0.28	0.163**	0.45	0.21	0.04**	0.86	0.15	0.000**
Age	−0.09	0.019	0.354	−0.02	0.07	0.8**	0.04	0.05	0.42
Education 2	-0.2	0.003	0.534	0.001	0.003	n.s.	0	0.021	0.9
Education 5	−0.29	0.38	0.534	0.03	0.03	n.s.	-0.02	0.19	0.4
Avocado yields	0.11	0	0.777.	0	0	n.s.	0.01	0	0.01**
Gender	0.001	0.32	0.063	0.09	0.001	n.s.	0.06	0.05	n.s.
Producer degree centrality Marketing degree centrality Information dissemination centrality	0.11	0.001	0.00**	-0.027	0.08	n.s.	0.04	0.03	n.s.

R2		0.58			0.084			0.18	
Intercept	0.4	0.28	0.163**	0.45	0.21	0.04**	0.86	0.15	0.000**
Age	−0.09	0.019	0.354	−0.02	0.07	0.8**	0.04	0.05	0.42
Education 2	-0.2	0.003	0.534	0.001	0.003	n.s.	0	0.021	0.9
Education 5	−0.29	0.38	0.534	0.03	0.03	n.s.	-0.02	0.19	0.4
Avocado yields	0.11	0	0.777.	0	0	n.s.	0.01	0	0.01**.
Gender	0.001	0.32	0.063	0.09	0.001	n.s.	0.06	0.05	n.s.
Producer degree centrality Marketing degree centrality Information dissemination centrality Information dissemination degree centrality	0.11	0.001	0.00**	-0.027	0.08	n.s.	0.04	0.03	n.s.
R2		0.58			0.084			0.18	
p-value		**			**			**	

Note: The dependent variable is the centrality of the producers, and the number of plants on the farm determines avocado production. Education 2 refers to elementary school, and Education 5 to secondary school or diploma level. ** indicates significant at 5%.

The study highlights several key factors influencing the adoption of avocado as a climate-smart practice among farmers in Kenya, aligning with its objectives to explore social network drivers, analyze network structures, and identify adoption factors. Age significantly impacts adoption rates, with older farmers less likely to adopt climate-smart practices than younger farmers (see Table 3). This finding is consistent with previous research that younger farmers are generally more open to innovation and new technologies [23].

In contrast, farm size does not significantly influence adoption, as climate-smart practices are adopted across farms of all sizes. Similarly, gender and education level do not show a substantial impact on adoption rates, suggesting that these factors are less critical in this context.

The socio-demographic attributes of avocado producers—such as age, gender, education level, and farm size—do not significantly alter the outcomes of the three network models analyzed (Table 3). However, the relationships within these networks play a crucial role in shaping adoption behaviors. Benefits derived from avocado yields, market relationships, and advisory services and information among stakeholders significantly influence the adoption of climate- smart practices. The information dissemination network, in particular, appears more cohesive than the producers' network, indicating that yield benefits and knowledge sharing are key drivers of adoption [37].

The information dissemination network facilitates the exchange of general farming advice and tips among farmers, with input and regulatory service providers acting as central nodes. These interactions often occur in informal settings, such as multi-stakeholder platforms, cooperative meetings, and on-farm visits, highlighting the importance of trust and reputation in knowledge dissemination [39]. Central farmers, often viewed as opinion leaders due to their expertise and community involvement, play a critical role in spreading knowledge about climate-smart practices. This is particularly important for older farmers, who are less likely to adopt new technologies independently. By leveraging these networks, stakeholders can enhance farm resilience and promote sustainable practices [30].

The producers' network, while fragmented, connects farmers who seek assistance with those who provide support, often in exchange for mutual benefits. This network is characterized by localized connections between farmers and nearby stakeholders, with clear distinctions between cooperatives and other farmer groups [40-45]. Farmers with more connections within this network in information exchange and consultation with influential stakeholders, such as regulatory service providers and input suppliers. This facilitates the dissemination of knowledge about avocado planting techniques, marketing strategies, and phytosanitary standards, ultimately enhancing the adoption of climate-smart practices [17, 46-53].

Conclusion

In conclusion, this study highlights the critical role of social networks in driving the adoption of agroecological practices among avocado producers in Kenya, aligning with its three key objectives [53-59]. First, it explores how social network drivers enhance on-farm resilience practices, revealing that networks facilitate knowledge sharing, resource access, and collaborative support, which are essential for adopting climate-smart techniques. Second, using social network analysis, the study identifies key connections and centrality measures within production, market, and information exchange networks, emphasizing the importance of central actors and cohesive networks in disseminating sustainable practices [60-64]. Third, it determines that factors such as trust, information exchange, shared values, and the involvement of influential stakeholders significantly influence the adoption of agroecological techniques.

The findings underscore the need for context-specific, network-driven strategies to strengthen communication channels, build trust, and engage key influencers within these networks. By leveraging the strengths of production and information exchange networks, stakeholders can enhance the resilience and sustainability of avocado farming systems. These insights contribute to the broader discourse on agroecology, offering actionable recommendations for policymakers and practitioners to promote sustainable agricultural practices, improve food security, and address climate change challenges in smallholder farming systems.

Recommendations

This study highlights the critical role of social networks in promoting agroecological practices among avocado producers in Kenya. To align with the study's objectives and enhance the adoption of sustainable practices, the following recommendations are proposed:

First, strengthen communication channels within production, market, and information exchange networks by leveraging digital platforms, cooperative meetings, and multi-stakeholder forums. This will improve knowledge sharing and collaboration among farmers and stakeholders. Second, build trust and cooperation by fostering transparent, inclusive, and supportive relationships within networks. Cooperative models should be encouraged to enhance collective decision-making and resource sharing. Third, engage influential stakeholders, such as cooperative leaders and extension officers, to drive the adoption of agroecological practices. These central actors can bridge gaps between farmers and other stakeholders, facilitating knowledge dissemination.

Additionally, there is a need to promote supportive policies for sustainable avocado farming, such as subsidies for climate-smart technologies, access to credit, and fair market access. Regulatory frameworks should also address quality standards and export requirements. Invest in capacity-building initiatives, including training and educational programs, to equip farmers with the skills and knowledge to adopt and implement agroecological techniques. Finally, there is a need to conduct ongoing research and monitoring to evaluate the effectiveness of network-driven strategies and identify emerging challenges. Continuous assessment of adoption rates and resilience outcomes will ensure adaptive and context-specific interventions.

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- Disclaimer (Artificial Intelligence)
- The author hereby declares that NO generative AI technologies including Large Language Models (such as ChatGPT, COPILOT, etc.) and text-to-image generators were used during the writing or editing of this manuscript.

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