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Longitudinal Network Analysis on a Farmers' Community of Practice and Their Changes in Agricultural Systems Management

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ABSTRACT

Farmer peer networks have been identified as a key way to increase adoption of beneficial management practices to minimize negative environmental impacts of intensive agriculture. We studied the social processes that contribute to beneficial management practice adoption. We administered two questionnaires to participants of a farmer community of practice, the Ontario Soil Network in Ontario, Canada, prior to participation (Period 1) and at the conclusion of the program, 1 year later (Period 2). All three measured networks, based on communication frequency, sharing and seeking advice, and production system changes, expanded from Period 1 to Period 2 and around 80% of participants adopted or expanded their use of beneficial management practices. Our findings indicate that communication in multiple forms was related to beneficial management practice adoption and expansion. These findings support the focus on farmer peer networks as a valuable policy tool to enhance agricultural environmental sustainability.

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Agriculture; beneficial management practice; community of practice; longitudinal analysis; social network analysis; sustainability

Introduction

Agriculture accounts for 40% of the global ice-free land base, and industrial, or large-scale, intensive agriculture is prevalent in many places around the world (Foley et al. 2011). The practices used by agricultural producers (farmers) in these systems are thus critical to the discussions about sustainability from local to global levels (Campbell et al. 2017; Foley et al. 2011). Intense and industrial agricultural practices can have detrimental impacts on biodiversity, soil, water, and air quality and is contributing to the transgression of several planetary boundaries (Campbell et al. 2017).

To address the negative ecological impacts of agriculture, much research has been, and continues to be, devoted to developing "beneficial (or best) management practices" (BMPs), also known as conservation practices (Wagena and Easton 2018). BMPs range

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widely in terms of their focus, from habitat conservation to soil quality to water quality to pest management. While some farmers have taken up these practices, adoption levels are still not sufficient to mitigate the ecological impacts of agriculture. In Canada, BMP adoption was estimated to be between 25% and 41% of the maximum number of BMPs applicable to each farm in 2006 (MacKay, Bennett, and Lefebvre 2010). BMP adoption is highly variable in terms of how many and which practices are used across agricultural landscapes (Filson et al. 2009; MacKay, Bennett, and Lefebvre 2010). Attention has thus been building on how to accelerate the adoption of BMPs by farmers in Canada and elsewhere (see reviews by, e.g., Bartkowski and Bartke 2018; Baumgart-Getz, Prokopy, and Floress 2012; Liu, Bruins, and Heberling 2018; Prokopy et al. 2008). There are several factors that contribute to the adoption of BMPs, including the external factors such as financial incentives, geographic location and existing policies and programs; and internal factors such as farmer demographics, risk preferences and environmental awareness (Liu, Bruins, and Heberling 2018). One factor that is widely considered to be important across studies is the positive role that social networks can play in encouraging BMP adoption (Matous and Todo 2015; Pape and Prokopy 2017; Prokopy et al. 2008; Skaalsveen, Ingram, and Urquhart 2020; Vetter 2020). An important caveat to the focus on BMP adoption as an indicator of the environmental impacts of agriculture is that of disproportionality, i.e., that the same practices implemented in one place may have very different impacts than in another place and that this is dependent on contextual factors (Nowak, Bowen, and Cabot 2006).

Farmer peer networks (i.e., farmers who interact with each other about agricultural issues and practices) can take many forms, from informal networks (e.g., discussions at a local association meeting or coffee shop) to more formalized networks (e.g., participatory workshops) (Curry et al. 2012; Lucas, Gasselin, and Van Der Ploeg 2019; Slimi et al. 2021). Farmers' networks can take the form of "communities of practice" (COP), which are defined as "groups of people who share a concern, a set of problems, or a passion for a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis" (Wenger, McDermott, and Snyder 2002, 4). For farmers, COPs provide a unique environment in which knowledge and experiences may be shared in a caring and supportive environment, seen by members as a peer-to-peer interaction rather than a top-down approach (Vetter 2020). Fundamental to COPs is the aim of participants to learn from each other (Hildreth and Kimble 2004; Wenger, McDermott, and Snyder 2002). According to Vetter (2020), the three key aspects of communities of practice are: (1) members hold a shared enterprise, such as a common problem or issue, (2) it provides a space for engagement where members can interact on a regular basis and form meaningful relationships, and (3) it fosters the development of a shared repertoire.

Even though farmers peer networks are acknowledged in the literature as playing an important role in the diffusion and adoption of BMPs, little is known about the social processes within these networks that contribute to the adoption and expansion of BMP usage. Farmer COPs have been studied in terms of their inner workings and how relationships among members facilitate learning and innovation processes (Cross and Ampt 2017). The premise is that interactions between COP members enable opportunities for learning, which in turn may have a positive effect on agricultural management practices (Nykvist 2014; Skaalsveen, Ingram, and Urquhart 2020). Moreover, previous research has identified the role of "change agents" or "influencers" as important actors that affect the degree and speed of the social learning processes (Cross and Ampt 2017; Oreszczyn, Lane, and Carr 2010; Skaalsveen, Ingram, and Urquhart 2020). Despite recent scientific advances, it remains difficult to define how and to what extent networked peers influence or facilitate the diffusion of BMPs among farmers within a COP (Cross and Ampt 2017). We draw from the field of social network analysis (SNA) (Bodin and Prell 2011; Borgatti et al. 2009) to map and quantify the social and relational dynamics of actors involved in the management of agricultural systems in order to disentangle and understand the multiple relational networks that contribute to the adoption or expansion of BMPs.

Social network theory focuses on the interdependent nature of social relations, where social ties link individuals together at different levels of closeness (e.g., professional, advice, collaboration, friendship, family) (Borgatti et al. 2009; Prell 2012). Given such interconnection and interdependence among individuals, observations are not assumed to be independent of each other. SNA focuses on observing the interdependencies among individuals and analyzing the patterns that emerge from social networks (Bodin and Crona 2009). Social relations are complex given that individuals may share more than one type of social linkages. For example, two farmers may exchange advice on farming practices while at the same time they belong to the same social or sports club resulting in two types of social ties. We acknowledge that social relationships are layered in different levels of connectivity which enhance or inhibit the influence exerted between individuals.

In this study, we study the effects that social ties, based on communication and advice, have on BMP adoption within a farmers' community of practice. This study is guided by the following questions: (1) In what ways does a farmers' COP enable the emergence of social networks among participating farmers? (2) To what extent are changes in the social networks, based on communication and advice, associated with the adoption or expansion of BMPs among participating farmers? In general, this study provides new insights about the role of peer networks in COPs as potential spaces where knowledge and experiences can be exchanged and in turn enable the spread of sustainable agricultural practices.

Case Study and Research Design

Case Study Background

The study focused on exploring the potential of farmer networks in contributing to a more sustainable agricultural system through diffusion and adoption of soil BMPs. To achieve this, we employed a case study approach with the focus on understanding the structure of a local farmers' network and investigating the social mechanisms that may influence the adoption of BMPs. We chose the Ontario Soil Network (OSN), an (extension) farmer-led network of farmers who aim to promote the use of BMPs in Ontario. The OSN hosts a 1-year leadership program and was initiated by the Rural Ontario Institute in 2017. The leadership program within the OSN is designed to provide a

Table 1. Social networks considered in this study.

Type of network	Network question in the survey
Communication	"(Since joining the OSN), how often do you communicate with this person?"
Advice[a]	"What is the nature of your communication with this person?"
System change	"(Since joining the OSN), have you made a production system change as a result of your communication with this person?"

[a]Advice network was denominated as such given the scope of the answers received, which were all related to advice-seeking, advice-giving, or mutual advice-sharing.

participatory social and educational space where farmers share experiences with BMPs and build communication and leadership skills. It is nominally led by a team of staff, all of whom are farmers themselves, and sponsored by governments, farmer associations, universities, industry and other organizations. During the program, farmers promote sustainable management practices through the use of social media, participation in road shows, written publications in magazines or newspapers, and field demonstrations. The leadership program is open to all interested farmers in Ontario, and farmers can nominate themselves to participate in the program. Between 20 and 40 farmers typically participate in the program each year.

Data Collection

A questionnaire was administered online to 31 members of the Ontario Soil Network twice: first, at the beginning of their program (March 2019), and a second 1 year later (April 2020). The survey was designed to collect two types of data from participating farmers: First, individual characteristics such as demographic data, aspects of their farm and farming practices, as well as the reasons why they opted to use certain BMPs (See Supplementary Material for complete questionnaire). Second, the questionnaire included a social network data collection section which provided each respondent with a roster of all other community of practice members, thus employing a bounded nominalist network approach (Borgatti, Everett, and Johnson 2013; Prell et al. 2021). This approach to social network data collection is bounded in the sense that participants were asked to identify social ties with only other participants within the OSN and is nominalist, as opposed to realist (Prell et al. 2021), in the sense that the roster was limited to those farmers that participated in the events and not all other possible farmers. For the networks sections, respondents were asked to rate the relational ties they had with each other; three types of networks were collected (Table 1).

The selection of social networks was consistent with previous research that emphasize the relation that communication ties have with the diffusion and adoption of farming practices and perceptions (Matous and Todo 2015; de Nooy 2013; Teodoro, Prell, and Sun 2021). Another relevant social tie in the context of BMP adoption among peer farmers is the flow of knowledge and advice (Ingram and Morris 2007). We constructed an advice directional network based on the nature of communication among farmers; the choices available for respondents were centered on advice (i.e., seeking advice, giving advice, or seeking and giving advice). Finally, we refer to the third network as the system change network and mapped the relational ties that had directly influenced their management behavior (i.e., adoption or expansion of BMPs) as a result of their interaction with other farmers. In other words, if a farmer A stated that she had expanded or adopted a BMP as a direct result of her communication with farmer B, we considered farmer B to be influential for farmer A. Using these three social networks we studied their individual changes from the beginning of the program (Period 1) to the end (Period 2), with the goal to deepen the understanding of social relational networks and the expansion of BMPs (Baumgart-Getz, Prokopy, and Floress 2012).

Even though it remains challenging to control for all possible sources of influence, we believe our study combines these three networks in a novel way. It has been shown that peers can influence each other through multiple social mechanisms, and as such it is appropriate to study their effect in a combined network analysis (Muter, Gore, and Riley 2013; Teodoro, Prell, and Sun 2021).

Analytical Approach

Survey data were managed and analyzed in different steps. First, data were separated into non-network responses and network responses. Non-network, individual attribute, data were analyzed in a descriptive way to compare and contrast the uses of BMPs across OSN participants. Moreover, responses were plotted regarding the different reasons farmers opted to expand or adopt new BMPs.

Network responses were converted into three squared network matrices M, where rows $(I = i_1, \ldots, i_n)$ and columns $(J = j_1, \ldots, j_n)$ represent the complete list of farmers and M_{ij} represent the existence of a tie (assigned a value of 1) or nonexistence of a tie (assigned a value of 0) between actors i and j. In the communications network, the non-zero value of M_{ij} also captured the strength of a tie ranging from 1 (yearly) to 6 (daily), capturing consistent intervals in between.

We employed a multiple regression quadratic assignment procedure (MR-QAP) to test the statistical association between our networks. An MR-QAP is a matrix permutation regression (Dekker, Krackhardt, and Snijders 2007; Prell et al. 2008). Given that network data are in matrix form, this method involves first calculating the Pearson's correlation coefficient between corresponding cells of two matrices (networks) and then recalculating the correlation between permutated (rows and columns) data over thousands of times and storing the distribution coefficients. This process results in the proportion of times that a random coefficient is larger or equal to the observed coefficient, this probability represents the degree to which two networks are associated (e.g., a low probability of $p < .05$ suggests these networks are significantly associated). It is important to mention that in MR-QAP analysis, the reported p-values are the statistic of primary interest because betas may be unreliable predictors of relationship strength, given the assumptions of network data (i.e., interdependency of observations) (Krackhardt 1988).

Results

In this section, we present the analytical results in the following way: We first identify the degree to which farmers adopted BMPs and the reasons they offered for this adoption. Second, we transition to the characteristics of farmers' social networks, starting with the changes in individual networks of those farmers who expanded or adopted

BMPs. Third, we present descriptive statistics of all social networks with the aim to provide a detailed interpretation of network-level measures and their interpretation of their role in supporting BMP adoption or expansion. Finally, we present and describe the results of the MRQAP model.

Of the surveyed participants, 23 farmers responded to the first survey (Period 1) and 22 to the second (Period 2). A total of 19 participants responded to both surveys. Given the focus of this study on longitudinal changes in farmers practices and network changes, only responses from those 19 farmers were extracted for the analysis.

Adoption of BMPs

The age range of participating farmers was between 36 and 65, and most respondents were male (84%). The average farm size of respondents was approximately 1,300 acres, with a range from 150 to 3,700 acres. All farmers reported growing grains and oilseeds, but also produced forage (6), pasture (2), fruit and vegetables (5), and sugar beets (1). Eight farmers reported raising livestock as well, with a mix of pork (4), poultry (2), dairy cattle (1) and beef cattle (1).

From the questionnaire responses, we learned that most farmers already used BMPs before joining OSN and most of them expanded their use of existing BMPs (i.e., implemented a BMP that was previously reported) or adopted new ones. All of the farmers that responded to the questionnaire said they were already using crop rotation to some degree in their farms, while 89% ($n = 17$) and 84% ($n = 16$) of farmers reported already using some degree of cover crops and strip-till/no-till practices, respectively, before joining OSN. After 1 year of participating in OSN activities, 15 farmers (79%) reported to have expanded or adopted new BMPs. After 1 year of participating in OSN activities, 63% of farmers ($n = 12$) reported having adopted or expanded the use of cover crops, followed by 32% ($n = 6$) of farmers adopted or expanded their use of crop rotation and manure/compost. The total number of responses about the use and adoption of BMP for Period 1 and 2 is shown in Figure 1.

We analyzed the reasons why farmers expanded or adopted the use of BMPs for Period 1 and Period 2 (Figure 2). The most common primary reason for adopting or expanding BMPs was "*It was better for my farm*" before and after the OSN period, albeit with a small decrease in Period 2. Differently, the proportion of respondents that answered "*I thought it was the right thing to do*" almost doubled in Period 2. There was also a slight increase in the concern for erosion and a slight decrease in the focus on saving money as a primary reason in Period 2. Also worth noting in these data is the lack of emphasis on subsidies and other sources of external funding as primary reasons for adopting or expanding BMPs. These data points to important questions as to the causal mechanisms that lead to changes in values or reasonings, as well as changes in behaviors.

The extent to which motivations were the same versus different for expanded BMPs from Period 1 to Period 2 was also explored. The subset of responses where reasons were given for Period 1 adoption and Period 2 expansion for the same BMP (37 instances across 14 respondents) were tested for alignment. Seventy percent of the motivations were different in Period 2 than in Period 1. Motivations were different for all BMPs, but most commonly for cover crops (8 of 11) and manure and other amendments (6 of 7).

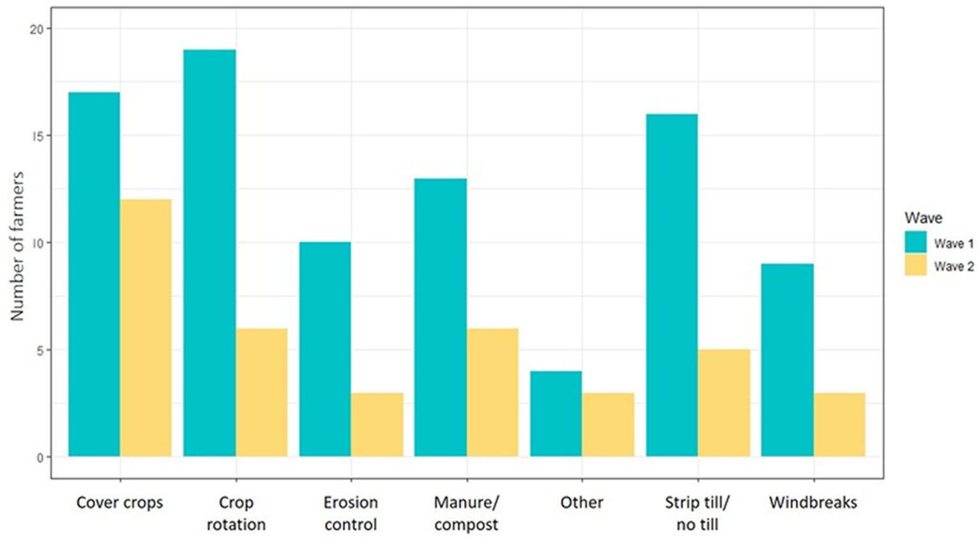

Figure 1. Number of responses of BMP use (Period 1) and use of new BMPs or expansion of existing BMPs (Period 2).

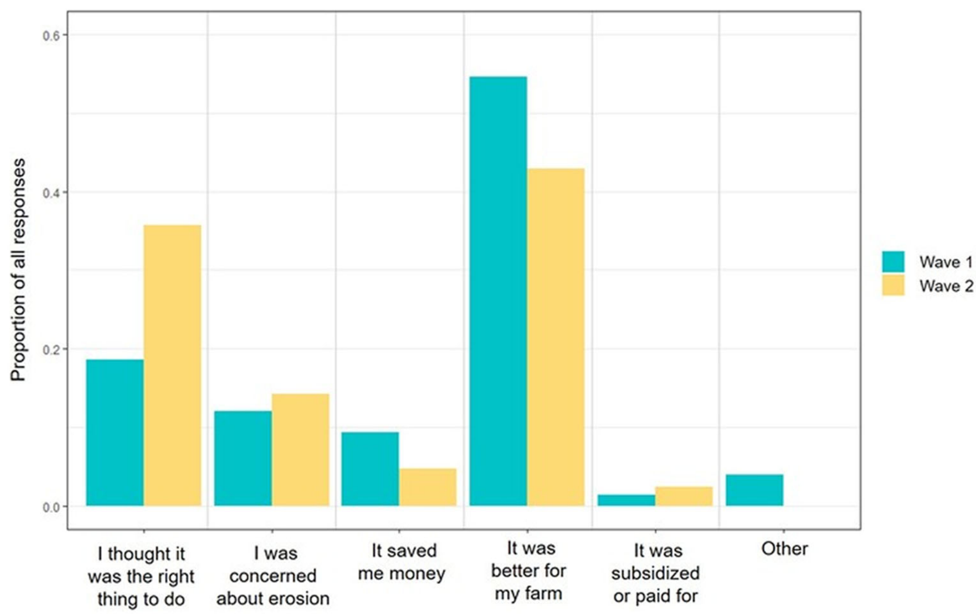

Figure 2. Primary reason for BMP or expansion. Responses were calculated per BMP, so multiple responses per respondent were common. Data are presented as a proportion of all responses.

Individual Network Changes of Expanders/Adopters

Drawing from a social networks perspective, we conceptualized the relationships that were formed and maintained during the course of the OSN. We quantified this by counting the number of people they (1) communicated with, (2) gave advice to or received advice from, and (3) were influenced by. For the majority of BMP adopters,

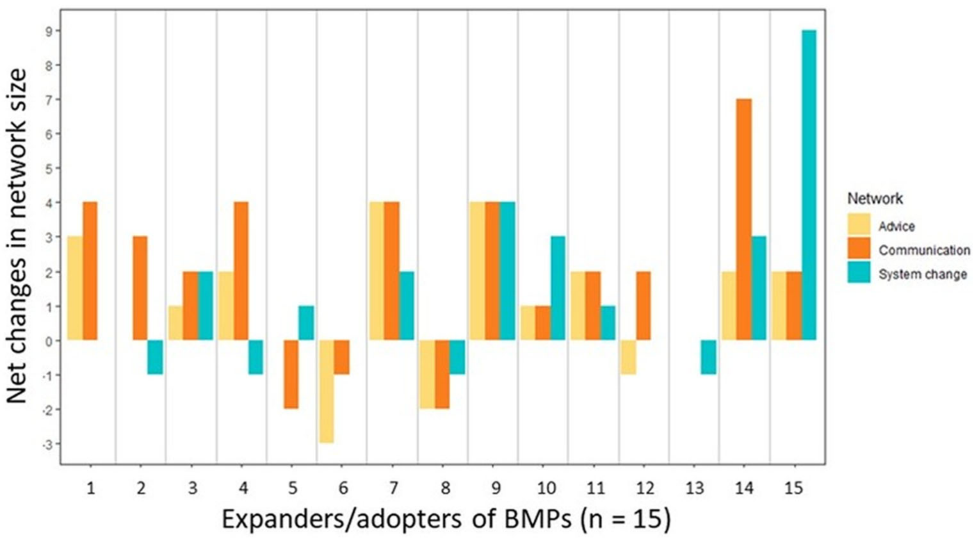

Figure 3. Network size changes from Period 1 to Period 2 of 15 expanders and adopters.

their personal networks (i.e., the number of social ties) expanded between Period 1 and Period 2 (Figure 3). The average of the net positive changes were 2.0, 1.0, and 1.4 for the communications, advice, and system change networks, respectively.

Descriptive Network Measures

Descriptive measures were computed to characterize the structure of the three social networks (Table 2). Following Freeman (1978), summary statistics of each network include (1) the density, which refers to the size and level of connectivity in a network (i.e., the ratio of existing ties and the number of all possible ties); (2) its centralization, which indicates the level of hierarchy present in the network ranging from 0 to 1; (3) the total number of ties in each network; and (4) the average degree centrality, which is the average number of incoming or outgoing ties for all stakeholders at any given time. In addition, we include the number of ties that were added or dropped in Period 2 compared to Period 1. These measures are descriptive indicators of social connectivity and provide information on the network dataset used in this analysis.

When looking at the measures that relate to the size of the networks, specifically density, number of ties, and new/dropped ties, it is evident that all three networks grew between the time of joining OSN (Period 1) and a year's worth of OSN activities (Period 2). Figure 4 shows the visual representation of the OSN communications network. The slight increase in the measure of average centrality (i.e., average number of ties) in the communication and advice networks suggest that on average farmers communicated with, and sought more advice from, a larger number of farmers at Period 2. Average centrality also increased for the system change network, indicating that sources of influence also increased on average for all farmers at Period 2. The color-coded network displays how social ties changed (Figure 4).

Table 2. Descriptive statistics of OSN social networks.

	Period	Density	No. ties	Centralization (in-)/out-degree	Avg. centrality	New ties	Dropped ties
Communication	1	0.157	54	(0.602) 0.602	0.64	–	–
	2	0.263	103	(0.784) 0.784	0.83	63	14
Advice	1	0.111	38	(0.234) 0.234	2.00	–	–
	2	0.160	66	(0.299) 0.299	2.89	44	16
System change	1	0.073	25	(0.333) 0.216	1.32	–	–
	2	0.108	45	(0.120) 0.883	1.95	39	19
	2*	0.059	–	(0.124) 0.249	–	–	–

Note: 2* involves the calculation without one farmer with disproportionately high out-degree centrality.

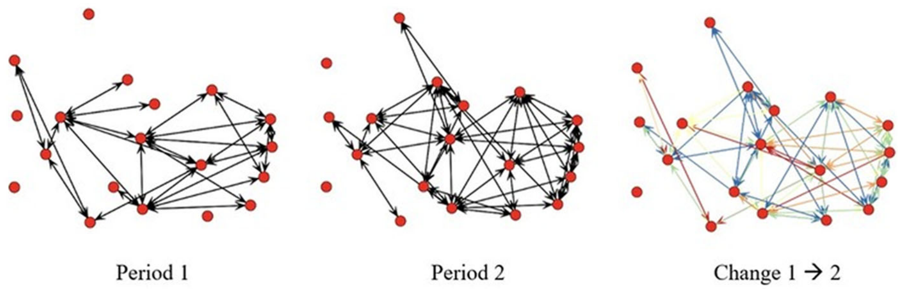

Figure 4. Network changes from Period 1 to 2; representing lost ties (red), ties that decreased frequency (orange), maintained ties (yellow), ties that increased in frequency (green), and newly established ties (blue).

Centralization scores also increased for all networks, with the exception of in-degree centralization in the system change network; an exception that we will come back to in a moment. Centralization is not only relevant for its possible changes, but also for their starting and end values. A higher centralization score (i.e., close to 1) indicates that most of the ties in the network are held by, or directed to, a small number of farmers. This is the case in the communication network, which increased from 0.602 to 0.784, which shows that there is a higher than moderate level of core-periphery structure (i.e., a highly connected core with other actors in the periphery, loosely connected to the core and each other). In other words, it suggests that some farmers were very popular (i.e., the amount of people they communicated with) even before joining OSN, and a subset of farmers became more popular than others during the year the community of practice was in operation. In contrast, ties in the advice network are dispersed across farmers, shown by the low centralization values of 0.234 and 0.299 for Periods 1 and 2, respectively. Taking centralization for both communication and advice networks together, it suggests that even though a few farmers are very popular (i.e., high centralization in the communication network), farmers tended to seek advice more evenly among their peers.

When it comes to the system change network (i.e., respondents nominating others who had influenced them into expanding or adopting a new BMP), two types of centralization scores are important: in-degree and out-degree centralization. In-degree centralization captures the proportion of incoming (receiving) ties that are accumulated by a small number of participants, in this case it captured how concentrated or dispersed are the influential farmers in the group. In-degree centralization decreased from 0.333 in Period 1 to 0.120 in Period 2 (Table 2). This decrease suggests that the number of

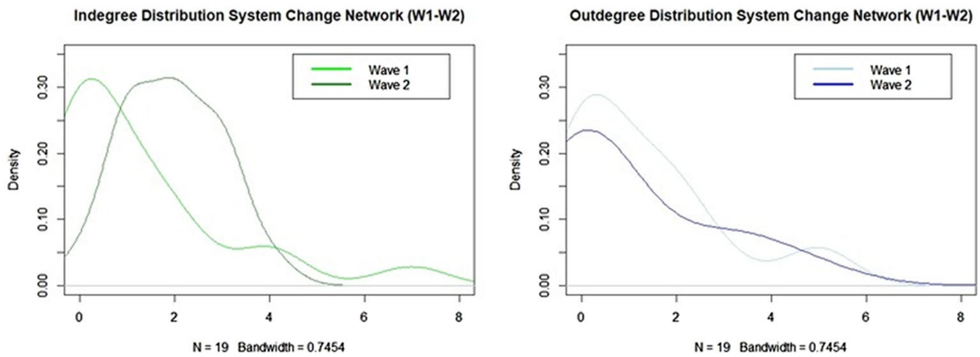

Figure 5. In-degree and out-degree distribution of ties for the systems change network. In combination with in-degree centralization, farmers displayed an increase in receiving ties (in-degree) in Period 2 than in Period 1, suggesting an expansion of the number of farmers that were considered influential.

receiving ties became more distributed across participants after joining OSN than it was before joining. In other words, the number of influential farmers increased after 1 year of OSN activities (Figure 5).

On the other hand, out-degree centralization captures the proportion of outgoing (sending) ties that are accumulated by a small number of participants, in this case it captured how concentrated or dispersed are the farmers who were influenced. Here, we include two types of results, Period 2, the full dataset (2) and a dataset excluding one outlier farmer who had a disproportionately high number of ties (2*). The decision to include 2* was done for purposes of discussion, elaborating on the extreme difference in results when removing one actor. After careful evaluation of the outlier's responses, it was determined that the farmer had misinterpreted the survey question ("*Since joining the OSN, have you made a production system change as a result of your communication with this person?*") and reported to have been influenced by all other participants in the network. We can assume the outlier believed all participants had made an overall impression on them. However, this interpretation of the question was not intended by the authors, and all other respondents provided more conservative responses. For this reason, we believe 2* represents more accurately the overall trend of the *system change* network.

Out-degree centralization in the *system change* network (2*) increased from 0.216 to 0.249. The lower values mean that a core-periphery structure is not prominent in this network (i.e., out-degree ties are well distributed across all farmers). The small increase reflects that some farmers reported to have been influenced by multiple people. Taken together, in- and out-degree centralization of the system change network shows the effect of OSN on the potential for farmers in the network to influence, and be influenced by, each other.

MRQAP Model Results

The results from the MRQAP model show the relationship of the communication and advice network in relation to the systems change network. By testing the correlations

Table 3. MR-QAP results estimating the correlation for the system change network.

	Period 1		Period 2	
	Estimate	*Pr(>=|b|)*	*Estimate*	*Pr(>=|b|)*
Intercept	−3.671	0.877	−3.216	0.190
Communication	0.399	0.112	0.536***	0.000
Advice	2.402***	0.009	1.308***	0.009
AIC	129.62		186.04	
BIC	141.12		197.55	

between networks (i.e., matrices) and comparing their probability values we find the relationships at Period 1 and 2 separately. Specifically, we sought to determine the extent to which *communication* and *advice* networks were associated with the *system change* network (Table 3). At the time when they joined the OSN (Period 1), farmers' network of communication was not significantly associated with their network of systems change. That is, if farmers were being influenced by some farmers, they were not the ones participating in the OSN. In Period 2 (1 year after joining OSN), the communication ties among participating farmers became significantly correlated with influence-based ties of *system change* network. On the other hand, the advice network was significantly associated with the systems change network ties for Period 1 and Period 2. This may be interpreted as follows: Regardless of how many other farmers they knew before joining OSN, those who sought advice from other farmers tended to also act on that advice and implement a system change. This may be true for both periods before joining and after 1 year of joining OSN with the possible difference that their advice network may have grown (and so too their system change network).

Discussion

In this study, we explored the role of social networks in the adoption of best management practices among farmers engaged in a community of practice. This community, the Ontario Soil Network, was intended to facilitate knowledge-sharing and collaboration among farmers who were already using BMPs to some extent or had expressed interest in learning more about them. In addition to the main aims of building leadership and communication skills, the OSN further contributed to building networks and the adoption and expansion of BMPs for most (∼80%) of its participants. The social mechanisms that enabled the emergence of social networks and changes in management practices were studied with social network analysis. In response to the first research question, we investigated the role that participatory programs like the OSN have on enabling the formation of social networks among participants. In response to the second research question, we tested the relationship between social networks, based on communication and advice, and the network reflecting the adoption and expansion of BMPs.

Participatory processes, like those of the OSN, have shown to enhance the cohesion among participants by means of establishing or strengthening relational bonds among them (Cvitanovic et al. 2019; Jasny et al. 2021; Reed 2008; Teodoro, Prell, and Sun 2021). In this study, we have shown that social networks based on communication and advice among participating farmers grew over the course of 1 year. MRQAP results showed that this change in communication and advice networks was also associated with the change in the network of system change. Advice-seeking and giving ties were consistently associated with influence-based ties of the system change network before joining and after 1 year in the OSN. On the other hand, the communication ties that resulted from farmer's participation of the OSN became highly associated ($p < .001$) with influence-based ties that led farmers to adopt and expand BMPs. The role of increased communication ties among farmers was facilitated by the participatory nature of OSN. These results showed how participatory COPs like the OSN may facilitate a measurable increase in member's communication networks, which in turn may be linked to changes in farmers' management behaviors.

These results echo network studies that showed how communication networks support diffusion of ideas and behaviors (Prell et al. 2010; Skaalsveen, Ingram, and Urquhart 2020; Teodoro, Prell, and Sun 2021; Weenig and Midden 1991) as well as studies that show the effect of how values are transmitted through advice-giving advice-seeking relations (e.g., Gibbons 2004). By combining both types of social ties (i.e, communication and advice), we have expanded the current understanding of the role of social networks in facilitating the adoption of sustainable agricultural management practices. In a different setting, Gibbons (2004) showed how an advice network was associated with reinforcement of existing institutional values among teachers in a school (i.e., top-down) in contrast to friendship[1] ties that were catalysts for new and different values (i.e., emergence). In this study, we saw farmers maintain a significant association between *advice* and *system change* ties before and after joining OSN. While we recognize that advice-seeking and giving ties can operate in hierarchical settings, where an advice reinforces existing ways of thinking and promotes "group think," it is possible that in a nonhierarchical setting, advice can promote the adoption of new practices. Our results from the *advice* network analysis is not inconsistent with Gibbons' (2004) results, given that most OSN farmers expanded practices that were already in use and only a few adopted new BMPs. Therefore, it is possible that OSN activities enabled advice-seeking and giving behavior among participants that reinforced an existing desire to innovate and learn about soil health, which led to the expansion and adoption of new practices. Hence, it can be said that the *advice* network may help accelerate the spread of new knowledge when the values of innovation and learning are shared among advice-givers and receivers. In contrast to Gibbons (2004), the OSN community of practice is not a formal institution and farmers are able to interact with and seek advice from other farmers who have had different experiences. The OSN enabled a higher level of interaction among participating farmers, which in turn facilitated the establishment of stronger communication bonds among them. OSN provided a space for farmers to interact, communicate, and as a result share advice and change their management practices.

When looking more closely at the levels of influence different farmers possessed and how influence was distributed across participating farmers in the *system change* network; it was not surprising to see how individuals that were considered influential at the beginning of the study increased their reach of influence to more farmers. An interesting result, however, is that farmers that were initially considered less influential later became more influential. This is seen in the decrease of in-degree centralization in the *system change* network, which suggests that instead of the usual influencers becoming even more influential, a larger number of influencers were found in Period 2, thus decreasing in-degree centralization scores. Such decrease is evidence that participatory processes may provide an open space for interaction which gives voice to often marginalized individuals and reduce hierarchies (Gaillard and Mercer 2013).

Social networks are complex and difficult to accurately represent and study with model-based approaches. Notwithstanding, even with small longitudinal networks like the OSN, much can be drawn from network-level measures and their changes from one period to another. The OSN enabled more farmers to be heard and share their experiences with other farmers, which in turn made more farmers influential in promoting BMP adoption or expansion.

In addition to the insights drawn from the social network analyses, we also looked at the reasons provided by farmers for adopting and expanding their use of BMPs. Reasons for adopting or expanding BMPs showed a proportional increase in the focus on a societal/moral obligation ("I thought it was the right thing to do") in contrast to personal benefits ("it was better for my farm") after participating in the OSN. Such changes in attitude largely resonate with Noguera-Méndez, Molera, and Semitiel-García (2016) multi-layer social learning framework, which suggests that members of a community of practice shape their behaviors and their intentions based on the approval or disapproval of others in the group. The BMP adoption literature supports this finding: Reimer, Weinkauf, and Prokopy (2012) identify perceived environmental benefits as one influential factor in the use of conservation practices, and a meta-analysis by Baumgart-Getz, Prokopy, and Floress (2012) reinforces that environmental awareness, and specifically understanding how farm-level actions influence environmental quality, has a positive relationship with BMP adoption. Our finding provides indications that social learning—or learning as a result of interactions with others—may be normative (guided by values) as well as cognitive (learning from others) (cf. Baird et al. 2014; Huitema, Cornelisse, and Ottow 2010), and be a precursor to attitude shifts and subsequently greater BMP adoption. However, more research is required to make direct linkages between social networks/social learning, shifting reasons or motivations for production system changes and the community of practice networks.

The OSN was convened as a leadership training program for farmers, thus, it attracted those who were predisposed to take on such a position within their respective communities. This represents a minority of farmers when considering the population and questions around transferability may arise. However, the focus of this study is not only to understand how farmers adopt BMPs as a result of their social ties, but to understand how those social ties are facilitated through a COP. As such, our results and conclusions can contribute to the broader knowledge of famers' COP and BMP adoption. It is also useful to study a closed network of farmers when using SNA methodology, as longitudinal data of participatory projects are difficult to collect (Prell et al. 2021). This study provides some initial evidence that convening farmers around a shared interest may result in additional benefits in terms of network building, normative shifts, and practice change although further research in additional case studies would be required to extend these findings beyond the case.

Among the constraints and limitations of this study is the small proportion of OSN participants that provided responses in both data collection periods. In our analysis, the network size does not raise validity questions, but presents a constraint to additional network dynamic modeling which demand larger network datasets (Stadtfeld et al. 2020). Research considerations for future studies include several methodological opportunities: (i) a longer study period would have granted an opportunity to collect additional longitudinal data, thus enhancing the longitudinal aspect of the study; (ii) including additional cognitive networks like mutual-understanding and mutual-respect, which have been associated with enhancing social learning in participatory processes (Teodoro, Prell, and Sun 2021); (iii) it would be useful to capture information regarding possible sources of influence that may originate outside of the community of practice and analyze the effect of those sources relative to within community influence (Halberstam and Knight 2016; Jasny, Waggle, and Fisher 2015; Malinick, Tindall, and Diani 2013); and, (iv) we recognize that a qualitative inquiry might yield further insights into relationships between the variables measured here (or unmeasured variables) and BMP adoption. While beyond the scope of this study, it is an important consideration for future work. Finally, we recognize that the focus of this study is on an engaged group of farmers and does not extend to broader agricultural communities. The farmer participants may represent positions of privilege (e.g., the ability to devote time to engaging in a leadership program; landownership) and thus only a subset of agricultural producers. However, these farmers are encouraged, through the program, to return to their home communities and engage with other farmers. The changes they experience within the program may have an impact on their attitudes toward, and behaviors with, others beyond the program, however, this question is beyond the scope of our research.

Overall, communities of practice such as the Ontario Soil Network are participatory processes that enable enhanced interaction, more and stronger social relationships, and the sharing of knowledge and experiences among its members. The results of this study show the capacity of communities of practice to achieve policy goals related to increased environmental sustainability, as well as being a ground for new collaborative policies adapted to the local ecological and social landscapes.

Conclusion

This study addressed a need to better understand how a farmer community of practice can result in network and practice changes over time. We captured changes in communication, advice, and production system change networks as a result of farmer participation in a year-long leadership program focused on soil health beneficial management practice (BMP) adoption (the Ontario Soil Network [OSN]). The OSN strengthened and built a network of early-adopting farmers that served to support production system changes over a single year. Farmers' participation in the program led to production system changes by the participants themselves (80% adopted and/or expanded at least one BMP), and these production system changes were related to an increase in communication and advice-sharing. Evidence also showed substantive changes in their reasons for adopting BMPs after participation in the program. This is one of a few studies that address a farmer-led community of practice in an intensive agriculture paradigm, and contributes to ongoing discussion about the value of, and mechanisms by which, farmer peer networks support more sustainable agricultural practices in this context (Baird et al. 2016; Curry et al. 2012; Hoffman, Lubell, and Hillis 2015; Lucas, Gasselin, and Van Der Ploeg 2019; Skaalsveen, Ingram, and Urquhart 2020; Slimi et al. 2021; Šūmane et al. 2018). Furthermore, it lends empirical evidence that farmer peer networks and communities of practice are able to support greater BMP adoption (Matous and Todo 2015; Prokopy et al. 2008; Skaalsveen, Ingram, and Urquhart 2020; Vetter 2020). Finally, more longer-term longitudinal research is needed to establish a chain of causality between social network changes, social learning, attitudes shifts, and BMP adoption.

Note

1. Gibbons (2004) operationalization of friendship ties is synonymous to our implementation of communication ties.

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