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The role of farmers' social networks in the implementation of no-till farming practices

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Abstract

This paper draws on network science and uses a Social Network Analysis to improve our understanding of how the implementation of no-till in England is influenced by farmers' social networks. No-till is a low disturbance farming practice with potential to benefit soil health, the aquatic environment and farm economy, but is currently only implemented at a small scale in Europe. Interpersonal networks are important for farmers and influence farmer learning and decision-making and farmers often view each other as their main source of information. In this study, the social networks of 16 no-till farmers in England were mapped and semi-structured interviews carried out to assess the link between farmer network characteristics and the implementation of no-till in England. We also aimed to improve our understanding of the nature and extent of knowledge exchanged within farmer networks and their spatial and temporal dynamics. Our findings suggest that intermediary farmers had an important role in increasing the information flow and knowledge exchange between the different clusters of the no-till farmer network. These intermediaries were also the biggest influencers as they were often no-till farmers with a high level of experiential knowledge and viewed as important sources of information by other farmers. No-till farmer networks were geographically distributed as the farmers preferred to discuss farming practices with similar minded no-till farmers rather than local conventional farmers who did not understand what they were trying to achieve. Therefore, online communication platforms like social media were important for communication. We question the role of formal extension services in supporting farmers with innovative practices like no-till and suggest that advisors should strive to improve their understanding of these well-developed information networks to enable a more streamlined and efficient information diffusion.

Keywords: No-till, farmer networks, SNA, knowledge exchange, learning

1. Introduction

The Agricultural Innovation Systems (AIS) approach regards innovation as the result of a process of networking and interactive learning among a heterogeneous set of actors (Hall et al., 2003, Hall et al., 2004). This framework captures the diverse networks of widely distributed actors and learning pathways that have emerged with a shift towards more demand-driven and market-oriented extension. These networks have been studied from multiple perspectives examining, for example: their interaction with innovation support services in the AIS (Brunori et al., 2013); their role in diffusion (Wu and Zhang, 2013), or translation of innovations through actor networks (Gray and Gibson, 2013, Schneider et al., 2010) the influence of intermediaries and brokers (Cerf et al., 2017, Cvitanovic et al., 2016) and farmers' use of diverse networks seeking information and support (Klerkx and Proctor, 2013). However, less attention has been paid to the network of social relations that surround farmers. Wood et al. (2014) notes "the business of farming embeds farmers in influential relationships with an occupationally diverse array of people". The structure of these social relations is referred to as social networks and the characteristics of these social networks potentially play a crucial role in the circulation of knowledge within the AIS (Wood et al., 2014, Ramirez, 2013, Cvitanovic et al., 2016).

Social networks have always been an important influence on farmer learning and decision-making (Rogers and Kincaid, 1981). The role of interpersonal networks, forged through discussion groups, farmer to farmer ties, and peer-peer advice networks in facilitating learning has been demonstrated in a number of studies (Isaac et al., 2007, Baumgart-Getz et al., 2012, Schneider et al., 2010, Dolinska and d'Aquino, 2016). Furthermore, meta-analysis has shown that farmer networks (both peer to peer and with other actors) are more influential in sharing information than other more established factors, such as farmers' age and farm size (Ramirez, 2013, Baumgart-Getz et al., 2012, Prokopy et al., 2008)

Learning is a social process and as such is bound up in network relations (Lankester, 2013). The nature and extent of learning in networks is multi-faceted, however peer to peer learning is particularly significant, as farmers often view other farmers as their main source of advice:

"valuing knowledge delivered by persons instead of roles" (Wood et al., 2014, p. 1). Adoption and diffusion studies in agriculture have consistently shown that one of farmers' most commonly cited sources of information and ideas is other farmers (Oreszczyn et al., 2010, Rogers, 2003). The ability of farmers to innovate and share their own experiential learning, either with peers or more widely, is well documented (Dolinska and d'Aquino, 2016, Munshi, 2004, Morgan, 2011, Ingram, 2015). When individuals develop shared understandings of a problem in this way, this is known as social learning (de Kraker, 2017, Reed et al., 2010). Social learning is influenced by characteristics of the network such as the degree to which actors are connected to others via networks in the knowledge system (Bandura, 1977), while the strength of social ties between network actors influences attitudes and awareness (De Lange et al., 2004), and the uptake of new technologies (Wood et al., 2014, Ramirez, 2013).

Theoretical understanding, together with empirical evidence, shows that social networks can accelerate innovation and cooperation (Lubell et al., 2014, Wu and Zhang, 2013). Multiple studies demonstrate, for example, the role of social ties in agricultural knowledge exchange in promoting or seeding sustainable farming practices (Oerlemans and Assouline, 2004, Cadger et al., 2016, Isaac, 2012). This learning and innovation in social networks is particularly important in the transition toward new agricultural systems such as organic, agro-ecological, and conservation agriculture. These systems are characterized both by the need to develop situated and experiential knowledge (Leeuwis and Van den Ban, 2004), and to share this knowledge in the absence of support from conventional advice systems. According to Klerkx et al. (2010) the influence of individuals in innovation networks are important contributors to socio-technical change. The ability of each actor in a network to take action and make a difference, the actors' 'innovation agency' (Giddens, 1984), relates to the resources and competence that an individual has that can contribute to innovation, with knowledge and skills highlighted as particularly important in the context of successfully implementing new farming practices.

No-till (NT) is one such knowledge intensive system which is emerging as a relatively new practice, adopted on about 157 million hectares globally[1] (Kassam et al., 2015). Scholars, in trying to understand what determines the implementation of new tillage systems (zero, reduced, conservation), tend to take an adoption perspective seeking explanatory factors for farmer uptake. Systematic reviews, however, have revealed that there are no universally applicable factors that determine adoption of new tillage practices (Knowler and Bradshaw, 2007) or soil conservation more widely (Wauters and Mathijs, 2014). Instead, the significance of social capital (described as the interconnectedness among individuals) and of farmers acting as innovators and sharing knowledge on new tillage systems in social networks was identified as important for farmer decision-making (Knowler and Bradshaw, 2007, Ingram, 2010, Schneider et al., 2012, Bellotti and Rochecouste, 2014). This suggests, in accordance with AIS perspectives, that understanding the dynamics and relations of social networks is a more useful way of revealing the active and creative role of farmers and other actors in generating innovation in the context of tillage systems.

While the role of social networks in NT implementation is known anecdotally to be important, there is a lack of research that seeks to identify the nature and role of these social networks. Using what Lubell (2014) calls ‘‘network science’’ offers systematic methods that can help

[1] Data from 2013 published by FAO

elucidate social networks more explicitly. Using these methods to understand the structure and function of social networks will not only help to reveal the role of farmers and other actors in NT innovation but also identify leverage points in agricultural advisory systems (Bourne et al., 2017). This is important as NT is a low disturbance farming practice that has potential to improve soil health (Bertrand et al., 2015, Crotty et al., 2016), reduce soil degradation by erosion (Skaalsveen et al., 2019, Lundekvam, 2007), improve water quality (Schoumans et al., 2014, Mhazo et al., 2016), as well as offer economic benefits to farmers (Lahmar, 2010, Kassam et al., 2012). It is, however, currently only implemented at a small scale in Europe (Schneider et al., 2012, Kassam et al., 2015).

This paper, therefore, aims to better understand how the implementation of NT in England is influenced by farmers' social networks. It uses a Social Network Analysis (SNA) approach to map the connections of the social network of a sample of NT farmers in England and "opens a window into the mechanisms behind the dynamics of social interactions" (Reychav et al., 2016, p. 444). Alongside the SNA, semi-structured interviews provide an in-depth analysis of the interconnectedness of targeted NT farmers. Specifically, the paper addresses the following research questions:

- Is there a link between farmer network characteristics and implementation of NT? What are the structural and functional attributes (according to SNA methodology) of networks of farmers who have adopted NT farming? Who are central to these networks and who are the influencers?
- What are the temporal and spatial dynamics of farmer networks in relation to NT?

- What is the nature and extent of knowledge exchanged in social networks?

2. Characterising social networks

2.1 Social networks and learning for NT

Social networks are particularly important for new practices where conventional advice systems are inadequate. Farmers look for alternative support and substitute formal knowledge with their own informal sources from within the farming community (Isaac et al., 2007, Ingram, 2010, Šūmane et al., 2018). In this case, information diffusion then becomes highly dependent on the relationships and interactions between farmers (Wu and Zhang, 2013).

A transition to a complex system like NT demands a higher standard of overall management compared to ploughing, often gained through experimentation (Milestad et al., 2010a, Ingram, 2010), learning from others (Brunori et al., 2013, Maddison, 2007), problem solving and building up of experiential knowledge (Ingram, 2010, Samiee and Rezaei-Moghaddam, 2017, Baars, 2010). In similar system changes which require attention to detail, for example organic farming, the importance of knowledge building and social learning in networks in the absence of formal information sources has been demonstrated (Padel, 2001, Morgan, 2011). Similarly for agroecology in Canada, where farmers were marginalized with little direct access to institutional or governmental support, emerging networks were described by Laforge and McLachlan (2018, p. 266) as a "mycorrhizal network of hidden underground ways that connected farmers together through virtual or online communities" that enabled new farmers to gain knowledge.

In such transitions farmers rely particularly on experience-based knowledge as it has practical, personal and local relevance and is accumulated over long periods of time by doing, experimenting and observing (Šūmane et al., 2018). Through these processes farmers learn to recognise what works on their farm and come to understand their soil, plant and farming system (Ingram, 2010). They change their behaviour over time as a result of observable outcomes on the farm and are encouraged to experiment further by the experience of success (Lubell et al., 2014, Milestad et al., 2010b). Experiential learning is a constant process that happens not only at the individual level but also at the interpersonal level as practical experiences are shared and joint problem solving undertaken, in accordance with social learning concepts (Laforge and McLachlan, 2018, Oreszczyn et al., 2010, Milestad et al., 2010b, Lubell et al., 2014). Ingram (2010) showed how individual farmers learn at the farm level through experimentation and adaptation, used a variety of networking devices to take this learning and validate and reflect on it by interacting with others with the same experiences. In doing this the individual activity of on-farm learning is accompanied and enhanced by a process of social learning. Networks extend other actors and information from several sources is also drawn in to support management decisions (Bellotti and Rochecouste, 2014).

3. Methodology and methods

3.1. SNA components

In this study the social networks were measured using a SNA, which is a body of research methods to represent the structure of social networks including network matrices, diagrams and mathematical measures (Bourne et al., 2017, Otte and Rousseau, 2016, Haythornthwaite, 1996), with a set of procedures built on principles from graph theory for analysing the presence, direction and strength of connections between actors (Scott, 1988). The methodology entailed SNA to assess the characteristics of the ego-networks (e.g. identify frequency of interaction, homophily, formality and influence of different members) of each farmer in the study, and the links between them.

A social network is a set of connections among people with various social relationships where information and other social processes flow. Actors within networks are referred to as “nodes” and their relationships seen as “links” or connections (Borgatti and Halgin, 2011, Wasserman and Faust, 1994). The connections, distribution and segmentation of nodes are important aspects of social networks, characterising aspects such as the reciprocity, centrality and cohesion respectively (Ramirez, 2013). Centrality is an important factor in social networks with central actors being strongly influential (Scott, 1988) and hold critical resources in the network (Reychav et al., 2016). The information that is flowing within networks often depends on key actors that can be both negative and positive to adaption and act as “communication bottlenecks” or “community bridges”. Bridges, also known as knowledge brokers, are important for new information and innovation as they contribute to increased information flow by transforming explicit knowledge from actors outside the group to tacit knowledge within the group (Bourne et al., 2017). The type of actors within a social network is also important for the information flow as networks with a high degree of homophily, assessed by comparing the number of links between similar actors to the number of links between different actors, can limit knowledge diffusion as there are limited ties to actors outside the network and therefore little access to information that does not exist in a closed circle of friends, family or neighbourhood. Actors of networks with high homophily mostly have ties to people who are similar to themselves (e.g. mostly farmer-to-farmer interaction).

Social networks enhance adoption of new technology by increasing the information[2] flow and knowledge[3] exchange due to the interaction between actors (Ramirez, 2013). A high density of ties (connections) in a network means a high level of interaction between actors which increases the potential for information distribution, resilience and social memory of the group. Ramirez (2013) suggests three forms of social collaboration amongst farmers in social networks: kinship relations (family), land owner-tenant relations (work) and affiliations (social associations). In-family networks are in this paper understood as the interactions between family members cooperating within the farming business.

Boundaries are an important part of the SNA as some structural features of networks can only be interpreted correctly when the information is gathered from all the actors in the network (Marsden, 1990). Farmer network boundaries can be difficult to determine in an agricultural context and involve a large number of actors (Bourne et al., 2017), making it necessary to focus on personal networks where all relationships of one actor are registered, often referred to as ego-networks (Bourne et al., 2017, Baird et al., 2016, Marsden, 1990).

3.2. Recruitment and data collection

[2] Information comprises facts, interpretations and projections, while advice implies the recommendation of a particular course of action or the presentation of different alternatives (Garforth et al., 2002).
[3] Peoples understanding of the information turns it into knowledge (Stenmark, 2002).

Farmers were identified through Twitter, by searching for NT farmers on the internet and from snowballing from already established contacts. All identified NT farmers were approached by email or Twitter with a request to participate in an interview and a SNA. As there is still a relatively low number of NT farmers in England, only covering around 4% of the total cultivated area at the last estimate (Defra, 2010), finding and approaching as many as possible was the only way to get a satisfactory number of individuals. Eighteen farmers were recruited for the interview and 16 of them participated in the SNA. Most of the farmers in this study were five years or less into the practice, but several had a transition period of reduced or minimal tillage before implementing NT. The interviews were conducted between August and November 2018, and lasted between 45 to 60 minutes. The farmer interviews were digitally recorded and transcribed verbatim to a Word file.

3.3. Social network analysis method

The network data was gathered by asking participants about the individuals in their social network. The researcher directed the participant to indicate who they discuss their NT farming practices with, with responses recorded on a table (see appendix). This inevitably resulted in respondents mentioning the individuals in their network by name, therefore any identifying details were removed from the table prior to analysis. Additionally, respondents were asked to provide information about (i) each persons' 'occupation or their relationship to this person (e.g. son, father, wife)', (ii) whether they had a 'formal' or 'informal' relationship[4], (iii) whether the person had implemented NT (if applicable), (iv) how often they would discuss with this person (daily, weekly, monthly or less), (v) their main way of communicating (face to face, telephone, social media, farmer events, forum or other), (vi) how often they would seek each other's advice (daily, weekly, monthly or less), (vii) how influential the person was (score from one to five) and (viii) if they started communicating 'before' or 'after' they implemented NT. The SNA figures only show farmers within the UK.

The temporal dynamics of networks of farmers in this study was measured in the SNA by assessing the changes in farmers' social networks before and after they implemented NT on their farm. The farmers were asked who they were influenced by before and after NT, and what sources of information they used to learn about NT during implementation and after. Spatial dynamics of farmer networks were determined by the geographical distribution of actors in the SNA before and after NT implementation, and whether they were local, regional, national or global actors of their networks.

Alongside the SNA, a semi structured interview was conducted with each farmer to provide details of each farmer's reason for implementing NT, what sources of information they used to make the transition and where and how they would seek information today, how farmers characterise and evaluate the level of knowledge in their networks and how the networks developed after implementing NT. The nature and extent of knowledge communicated within the social networks of the farmers in this study was assessed by interviewing farmers about

[4] The terms 'formal' and 'informal' were in this context left for the farmers to interpret based on their own definition of the words and types of relationships. In relation to information networks, 'informal' connections normally refer to peers or community-based sources, while connections to organizations, extension agents etc. are seen as 'formal' (Isaac, 2012).

their perceived level of knowledge within their farmer networks and amongst the local farmers in their area. The types of actors in their networks (i.e. other farmers, researchers etc.) and the kind of knowledge that was shared (e.g. based on experiential knowledge or research) indicated whether the nature of information that was shared between the actors was tacit or explicit[5].

Although theoretically we can differentiate information and knowledge, at a farm level the two terms are used interchangeably.

3.4. Data analysis

The SNA was carried out using the online software Polinode where relational data from the NT farmers was uploaded via an Excel template provided online, where all nodes (actors in the social network) and edges (the relationships between them) were specified. The software then generated a network figure of the nodes and edges of the network based on the input from the template, and further analysis was carried out by using different functions and matrices within the software. The SNA collaboration matrix was created by calculating the extent to which actors, based on their occupation (e.g. farmer, advisor, academia), interact with each other. A NT farmers' acquaintance network was built by the same method to assess the degree of connectedness between the 16 respondents in the SNA study. Built-in metrics in the Polinode software were used to calculate the in degree (the number of incoming edges, illustrating the number of times an individual is mentioned by other actors in the SNA), out degree (the number of outgoing edges, illustrating the number of other actors the individual

[5] Tacit and explicit knowledge are two different types of knowledge. Explicit knowledge refers to knowledge that is communicated in a formal and systematic language, while tacit knowledge is embedded in action, commitment and involvement in a specific context with a more personal quality (Nonaka, 1994).

listed in the SNA), the sum of incoming and outgoing edges (total degree) and the network density.

Influencers were identified by the combination of the number of incoming edges and the influence rating (scale from one to five) in the SNA analysis. These are key actors with high importance to knowledge flow because of their central role in the network (Bourne et al., 2017). The definition of intermediaries varies; the extension services were traditionally considered the main intermediary in supporting agricultural innovation by providing knowledge and technology from research to farmers, but this approach has been questioned and the landscape of intermediaries changed as a result of the recognition that innovation requires broad systemic support and interactions between a diverse set of actors (Kilelu et al., 2011). Klerkx and Leeuwis (2008) described innovation intermediaries as organisations or bodies that provide network brokerage, demand articulation and management of innovation processes and function as catalysts of innovation by facilitating the formation and maintenance of innovation networks. While Kilelu et al. (2011) proposed that innovation intermediaries undertake a broader support and management role beyond knowledge brokering by acting as “bridging organisations” that provide access to knowledge, goods, skills and services from a wide range of organisations. In this study, intermediaries were recognised as individuals who connected several other actors and therefore largely increased the overall connectedness of the network, while knowledge brokers were understood as those who connect researchers with the farmers. Early adopters are here defined as a farmer who implemented NT before the practice was common amongst farmers in England (> 10 years ago).

Interview transcripts were analysed using the qualitative analysis software NVivo (version 11.4.3). The thematic analysis was carried out by systematic coding to address all the research questions, meaning that relevant content from the transcriptions was marked and sorted according to the categories outlined that emerged out of the analysis (see Appendix). Once the data was coded it was analysed by comparing the answers and statements from the different farmers and used to explain the results from the SNA.

4. Results

4.1 Network characteristics and implementation of NT

4.1.1 Network characteristics

Drawing on the SNA collaboration matrix, the social networks of the NT farmers in this study mainly comprised other NT farmers. Indeed, 66.7% of the respondents discussed their farming practices with other farmers, and 85.4% of these were NT farmers. The second largest group was agronomists and advisors with 11.3%, followed by researchers (8.5%), representatives of farmer organisations (6.8%), machinery manufacturers (4.0%), suppliers (e.g. seeds) (1.1%) and others (1.7%) (Figure 1). The network consisted of 177 connections (edges) between the 134 nodes and 32% of these relationships were seen as formal.

The farmers mostly had informal relationships to each other, while they often saw their relations to non-farmer contacts as formal. The key farmer nodes in Figure 1 were NT farmers who had the largest number of edges coming in (listed as a source of information or discussion by other farmers in the network) and the biggest sized nodes (how influential the other farmers rated them as).

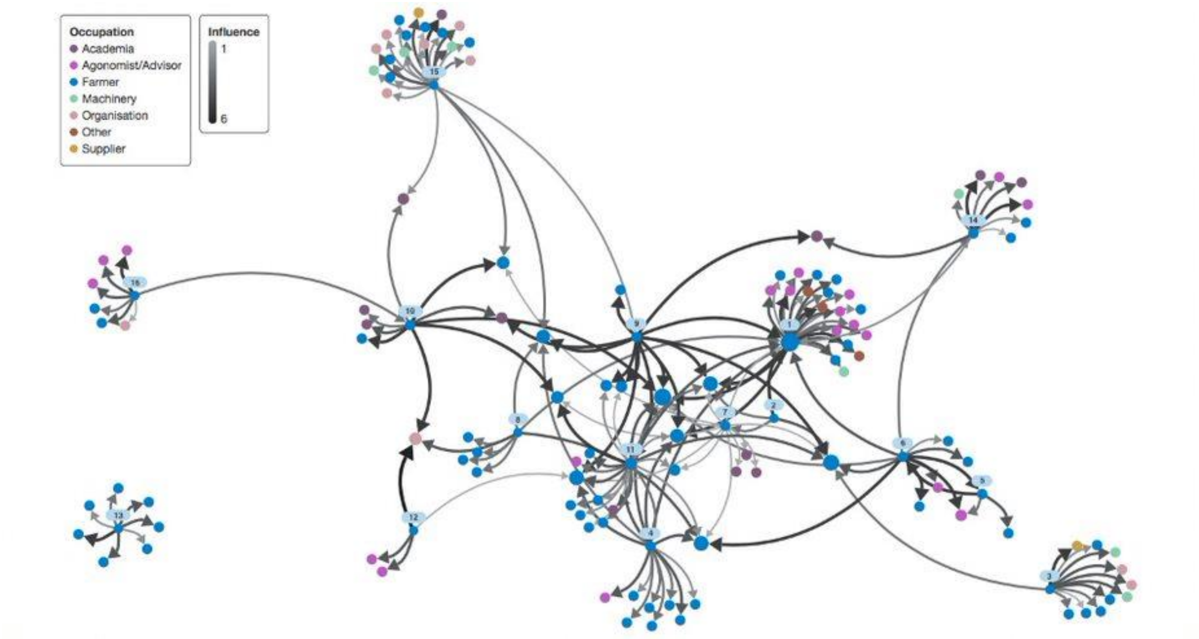


Figure 1 Social network analysis (SNA) showing the networks of NT farmers revealed in the study[6].

4.1.2. NT farmers' acquaintance network

The NT farmers' acquaintance network shows only the farmers that participated in this study without the rest of their ego-networks (Figure 3(a)). The connectedness between these NT farmers has been analysed to assess the direct connections between them. The network density of the acquaintance network is 0.071 and is calculated by dividing the actual number of ties by the total possible number of ties (Scott, 1988), meaning that only 7.1% of the possible connections were made (100% would mean that all members would be directly

[6] *The nodes of farmers who participated in the study are labelled with numbers from 1 to 16. The colour and thickness of the edges (links) between the nodes (actors) show how other farmers rated them as on a scale from one to five, with darker edges meaning higher influence on their farming decisions. The size of the nodes illustrates how many incoming*

connected with each other). This is a measure of network cohesiveness and shows that the farmers in this study are mostly connected by fellow contacts, and not by direct links to each other. The total average degree of the network is 2.13, which is the number of edges that start from or point to a node.

4.1.3 Information from interpersonal social networks

All the interviewed farmers stressed that the transition to NT was farmer-led and that the most relevant information was delivered by their interpersonal social networks, where the most influential individuals were other NT farmers, as illustrated by one participant: "The only person who can sell a new concept to a farmer is another farmer" (Farmer 14). As Figure 1 shows, the role of individual experienced NT farmers, both from within and outside England, is important for farmers considering, or wanting to start, implementing NT. In-family networks, especially the interaction between fathers and sons, was also regarded as important for successful NT implementation. This was confirmed by the SNA, which showed strong links and high influence between fathers and sons who were working together. Several of the farmers in this study said that young farmers often had larger social networks than their fathers and these were a source of ideas and inspiration to make changes to their farming systems.

It is also the collective understanding of the network that provides some assurance, as this remark referring to the farmer's NT network shows: "The new network gave me the strength and confidence to make a change" (Farmer 4). According to some respondents, farmers' personality traits are also crucial, as the ability to interact and network to find and acquire information was seen as important in becoming a NT farmer, for example: "…they will decide to become NT if they want to because they'll be that type of person who will chat to everyone and get that information. If you're not that way inclined, you are likely not to succeed. It is as simple as that" (Farmer 11)

4.1.4 Mechanisms for networking

Most farmers said they preferred to speak to other actors of the network in person, which was underpinned by the preferred methods of communicating with the different actors stated in the SNA (see SNA table in Appendix) showing that 30% of the communication was 'face to face', along with 20% at farmer events. However, as the farmers in the study were spread out geographically, internet platforms were crucial for communication and information flow, with 29% of the interaction carried out on social media (21%) or internet forums (8%) (Figure 2). Farmers favoured Twitter saying they appreciated the feedback they received, both as a way of questioning or verifying their methods and to hear other people's solutions to problems they encountered. It also allowed them to cross geographical boundaries:

> "That's the good thing about Twitter. It doesn't matter where you're from really" (Farmer 17)

Also all UK based farmers with a NT 'Crosslot' seeding drill were members of the same WhatsApp group which has become a central part of their information network (the group was created by the farmer who started importing the drills to the UK from New Zealand through the family business), enabling them to ask each other questions about NT practices, and the members often viewed each other as key actors in their farming networks.

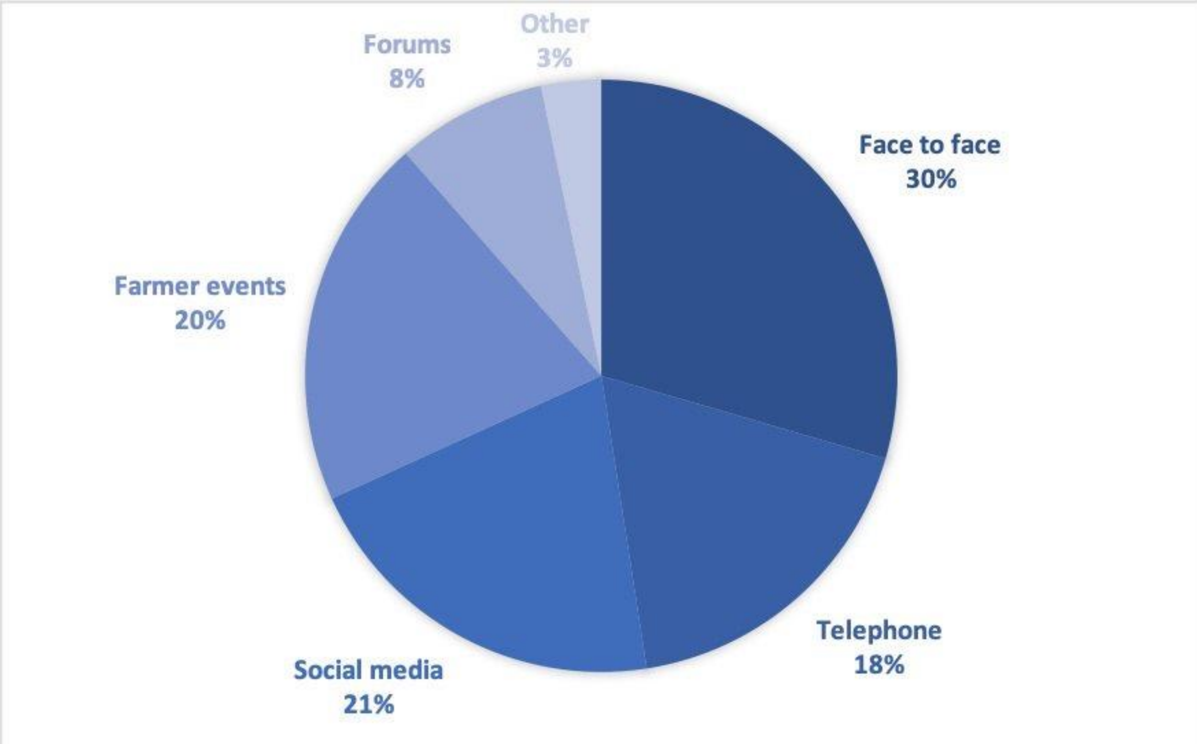


Figure 2 Forms of communication in the NT farmers' social network.

4.1.5 Influencers

As shown in the SNA, some farmers stood out as clear influencers in the network by scoring high on influence rating by other farmers and having a high number of incoming edges. They were often referred to as 'early adopters' of NT and seen to have a high level of experiential knowledge, as well as other characteristics pointed out by the farmers in this study, such as: having shared goals, passionate about what they are doing, having the ability to be innovative and think outside the box, running a good business, or as someone who prompted other farmers to change to NT practices. These influencers have an active social profile through social media. An interesting characteristic of NT networks was that members were highly influenced by international NT farmers with decades of NT experience (notably USA but also New Zealand, Australia, France and Germany), but these farmers were not listed in the SNA as someone they would normally discuss their practices with, so they were seen as sources of inspiration rather than influencers in the network. Some of these connections were made by former Nuffield scholars[7] who expanded their networks by traveling abroad.

Farmers who said that they tried to influence other farmers in their network by giving talks at farmer meetings and conferences were often seen as influential by the other farmers in the SNA:

> "I have gone from one of the people asking questions to one of the people who answers the questions. That's probably how it has changed in the last 7 or 8 years" (Farmer 17)

4.1.6 Intermediaries

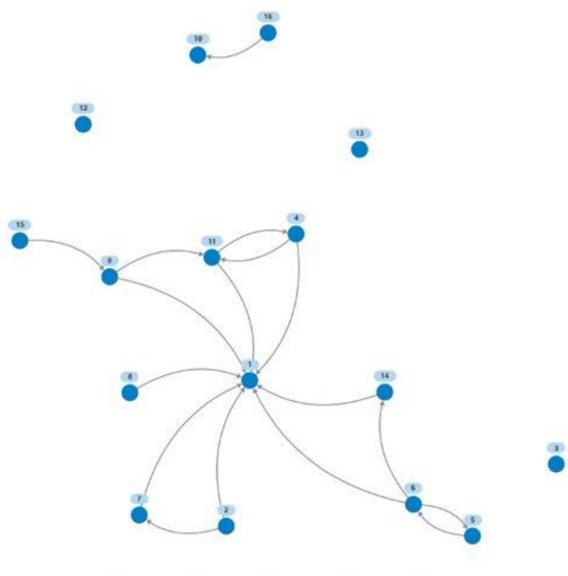
Intermediaries, whilst not always early adopters themselves, have an important role in connecting individuals and groups either to each other or to external communities. In doing this, they are also redistributing information to farmers, and are important for knowledge diffusion in the network. Figure 3 shows the importance of one intermediary (the yellow

[7] Farmers who have received scholarships from the Nuffield Farming Scholarships Trust. The funding allows 20 farmers each year to research topics of interest, often including international field visits, within farming, food, horticulture or rural industries.

node) in the network to connect different clusters of the social network. This farmer was not one of the participants in the study, but was identified by seven of the farmers (44% of the participants) as someone they would discuss their NT practices with. Figure 3(c) shows how the NT farmers' acquaintance network (see Figure 3(a)) changes when this intermediary farmer is added, tying more of the NT farmers together. This increases the network density from 7.1% to 8.8% and the average total degree from 2.13 to 2.82, which means a 25% increase in the total number of edges in the network. However, there are other individuals who also act as intermediaries in the farmer network, and Figure 4 shows the same social network, but with the addition of individuals who were identified in the SNA by five or more farmers (> 30% of the participants) (n = 5). By adding these four additional individuals to the network the density increased to 10.7% and the average total degree increased to 4.29, which is by more than 50%.

Some of these intermediaries are also knowledge brokers (Meyer, 2010) as they have links to the science community and see their role as linking formal scientific (explicit) to tacit knowledge and allowing new and different forms of knowledge (e.g. the importance of soil biodiversity and the impact of farming practices on C and N emissions) from outside the farming community to enter the network. One intermediary farmer comments:

> "I see a lot of studies going on that I wish other farmers would be seeing. It doesn't go beyond the paper. The information doesn't go through to the farmers" (Farmer 14)



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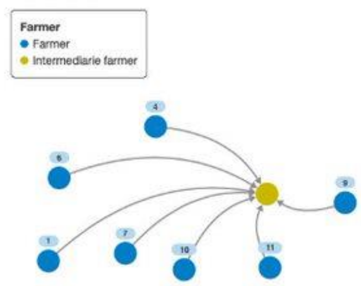
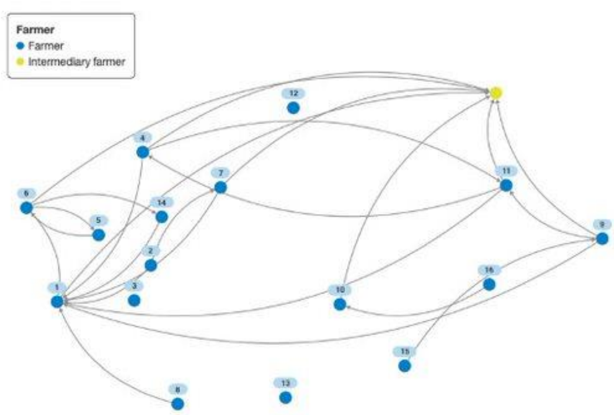


b

Figure 3a, b and c (a) The NT farmers' acquaintance network illustrating the contact between the NT farmers (n = 16), (b) an intermediary farmer from outside the interviewed farmer group who were listed by the highest number of farmers (n = 7) in the SNA (yellow node) and (c) The NT farmers acquaintance network including the intermediary farmer (yellow). The average total degree of the network is 2.82 and network density of 0.088 (8.8 %).



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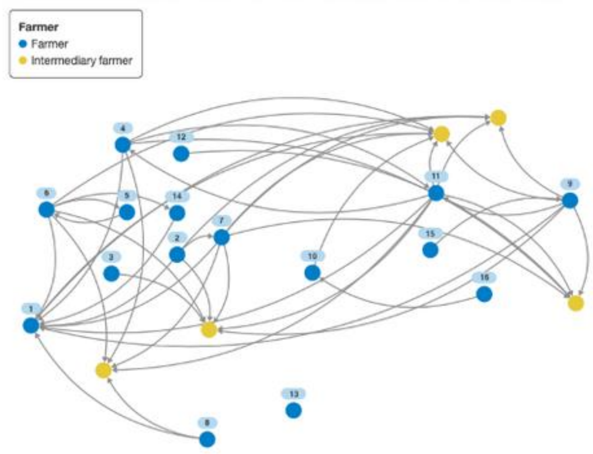

Figure 4 The contact between the NT farmers (n = 16) (see figure 3(a)) including the five farmers (not interviewed) who were mentioned by five or more farmers (> 30% of the farmers). The average total degree of the network is 4.29 and network density of 0.107 (10.7 %).

4.2 The temporal and spatial dynamics of farmer networks in relation to NT

4.2.1. Temporal dynamics

Network dynamics are characterised by changes over time, not only in NT information sources within a network, but also in the reliance placed on it. NT farmers' ego-networks normally expanded after implementing NT, mainly from meeting and talking to other NT farmers. The SNA showed that on average 35% of the connections were made after they implemented NT, although some of the farmers were only a few years into implementing the system. This was due to the necessity of actively seeking information and advice from other NT farmers when transitioning from conventional to NT, as demonstrated by this farmer:

"There is no manual, as every farm and system is different. People who are just trying to NT without knowing anyone else... I can imagine that that must be quite difficult" (Farmer 6)

The intensity of this increased network interaction largely depends on the time of the year. Some farmers explained that they would talk to other people daily or weekly during critical periods for NT such as drilling or harvest, but only a few times during the rest of the year. However, this is more nuanced, as farmers in this study were found to use networks in different ways, with some farmers already having an established network of NT farmers before implementation and others building their network afterwards. This is illustrated in Figure 5 which shows two farmers' ego-networks before and after adopting NT. Farmer 4 knew most of his current network before changing practice (four new actors) while Farmer 11 only discussed his farming practices with two people from his network before changing to NT (17 new actors).

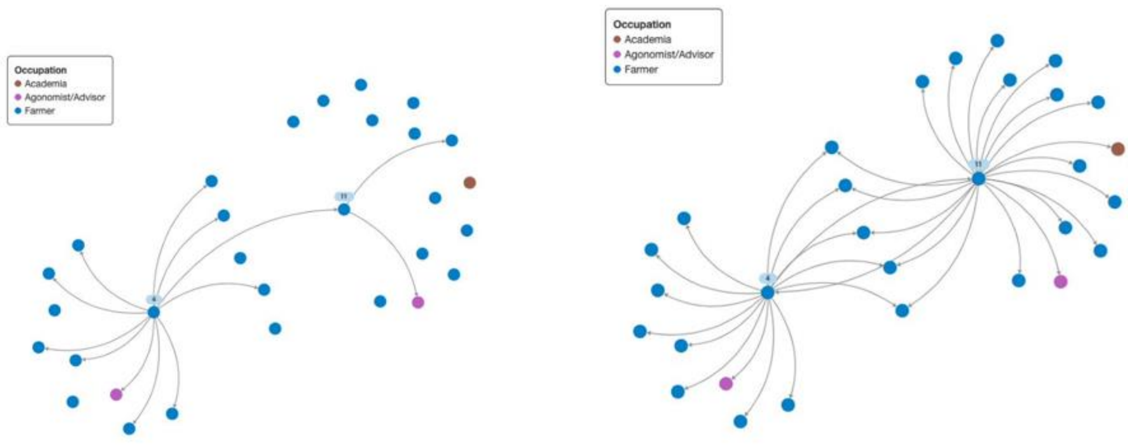

Figure 5 The ego-networks of Farmer 4 and Farmer 11 showing their networks before (left) and after (right) implementation of NT.

For some farmers the role of the agronomist had changed quite drastically as well, from being the main source of information when they were conventional farmers, to being a minor source of information after NT implementation, as the farmers became more knowledgeable about the practice. Despite this, the agronomists were usually rated as highly influential by NT farmers, scoring 4 out of 5 by most farmers in influence score, but this was with respect to fertilisers and pesticide recommendations.

There were also temporal changes to the reliance on social networks associated with the transition farmers go through when they implement NT farming. As farmers built up experiential knowledge about NT, their dependency on other farmers decreased. The common perception by farmers was that farmers were more fixed in their methods, following 'the rules of NT' in the first years after implementation, but that they gradually became more opportunistic as they gained more experience from experimenting on their own farm. Years of building up their own knowledge allowed the farmers to adapt the system more to local farm conditions and rely less on other farmers. Respondents agreed that information about NT has become easier to access in the last few years, both as a result of online availability and a larger community of experienced NT farmers. One of the early adopters explained how he relied on a drill manufacturer for information when he first implemented NT as there were very few other NT farmers. However, he also said that in hindsight, after gaining more experience, he realised that this source of information was unreliable because of limited experience with the practice in England at the time.

4.2.2. Spatial dynamics

The networks of NT farmers in this study differ from the traditional perception of farmers' networks in that, rather than being locally orientated, they extend outside the local area to include national and international members. This is enabled by the use of social media (as shown in 4.1.5) which has in many ways revolutionised the way farmers communicate. Nuffield scholarships and events such as those run by BASE UK, which invite international guest speakers, are helping to build these networks, as described by one farmer:

> "My farming network is all over the place, a lot of social media stuff, so I guess if we start globally; I met a lot of people doing my Nuffield travels and I have kept those connections going so I can find out what happens in agriculture all around the world" (Farmer 1)

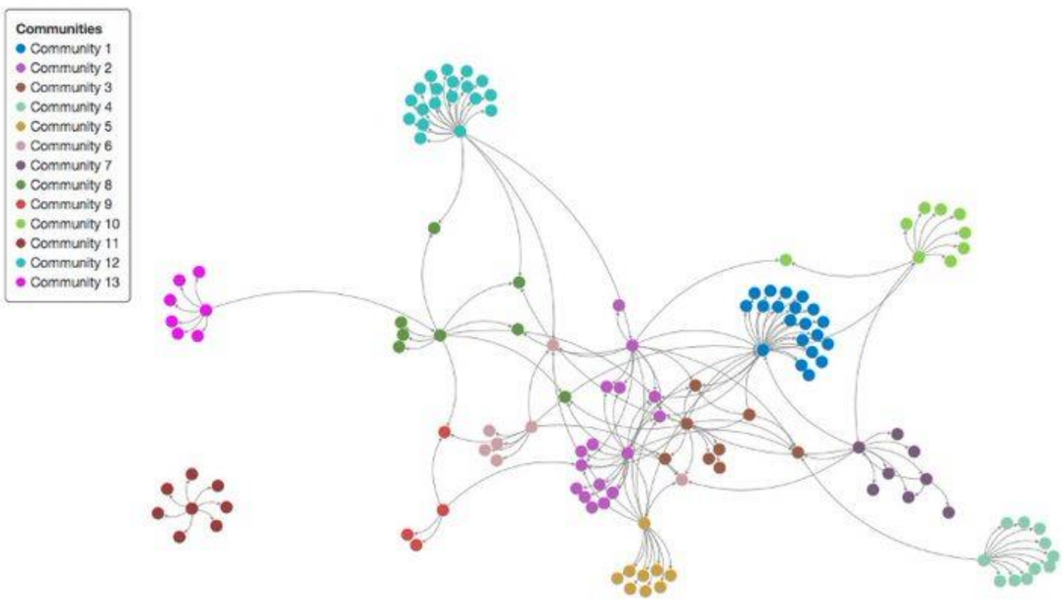

Figure 6 The 13 different communities of the network generated by the SNA.

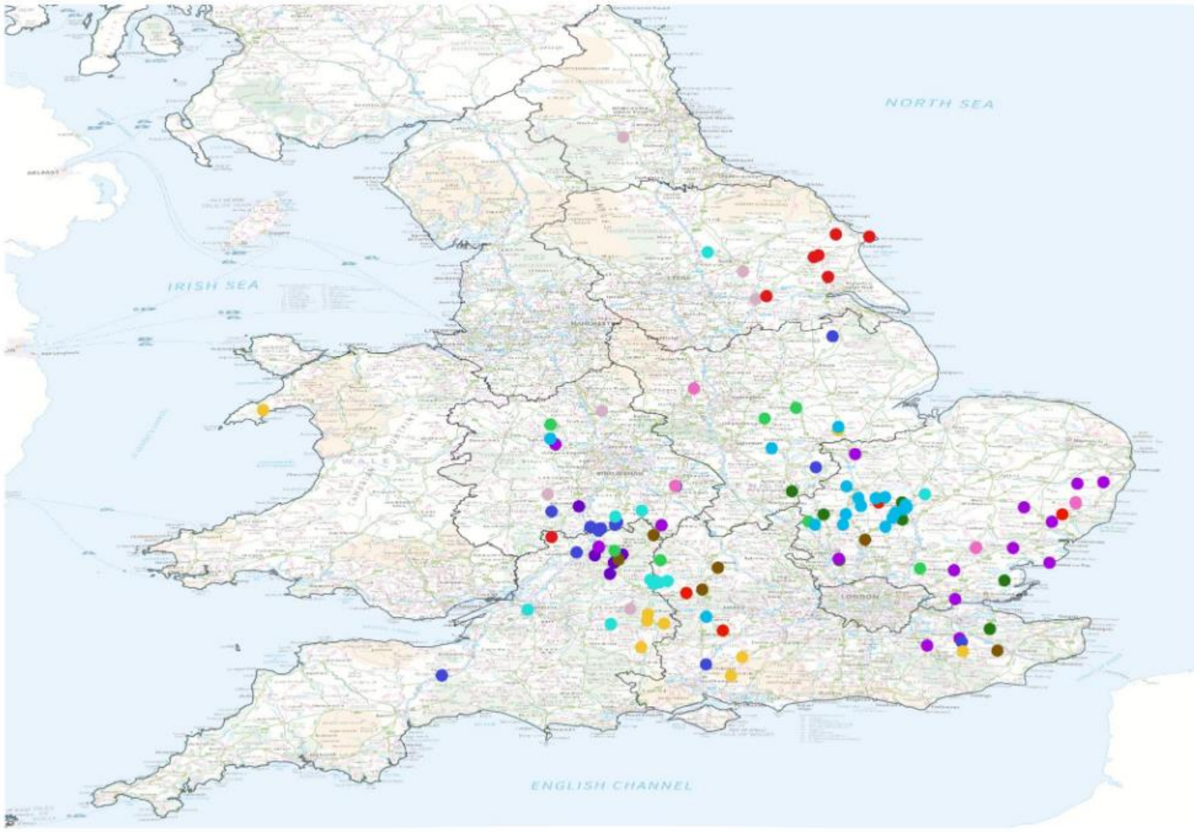

Figure 7 A map showing how the 13 communities of the SNA (see Figure 6) are distributed geographically across England.

Most NT farmers said that their networks included farmers from outside their local area. In Figure 6 the farmer network was divided into 13 different clusters of the network marked by separate colours, showing a core to the network made up of Communities 1, 2 and 6, while in Figure 7 all the nodes in Figure 6 are distributed on a map of England (with the same colour codes) to show the geographical distribution of each of the individuals within each cluster. There are differences in how spatially scattered the clusters are, but the map clearly shows that NT farmers find their networks outside their local areas. The main reason for this pattern is that there were few NT farmers nearby and overall the level of knowledge about NT amongst local farmers was minimal. The isolation of being a pioneer on NT led the farmers to identify as being different or unconventional:

> "Very few people in the area have gone down the same route as us. We are the black sheep, I'm afraid" (Farmer 18)

Farmers also lacked support from neighbouring farmers who were described as 'nosy' people who were watching over the fence and waiting for them to fail. This is a key reason why they seek assurance and support outside their local community.

4.3 The nature and extent of knowledge communicated by farmer networks

The nature of knowledge about NT exchanged in the farmer networks was tacit rather than explicit. The NT farmer network had a significant role in circulating experiential knowledge between fellow farmers. The emphasis is on sharing experiences and experiments on the farm; joint problem solving when results were poor was an important element in maintaining the NT network. NT is complex with multiple variables that affect the outcome (e.g. weather conditions, timing of field operations, different soil types, different rotations, cover crops, crop residues, weeds, pesticides and fertilisers). Acquiring knowledge about all these factors is too challenging for any one individual, and as a farmer you "only have one" go per year and "just a limited number of rotations" (Farmer 13) in a lifetime, so to harvest knowledge from other farmers about different experiences with NT practices is an effective way to enhance learning, as this farmer explained:

> "I would love to have ten goes at it per year, but you only have one. Now we will have to wait another 12 months before we can have another go at it... You spend an awful lot of time thinking about it and a lot less time doing it" (Farmer 13)

This networking and exchange of tacit knowledge between NT farmers compensated for the absence of support or relevant knowledge from more formal sources. Knowledge from the science community was often seen by many as irrelevant or inaccessible, as these remarks demonstrate:

> "I feel disengaged with the science community because they don't see the complexity in a practical day to day system" (Farmer 12)

> "Farmer to farmer learning is a quite powerful tool. There is a whole lot of science paperwork out there, but it is on a shelf somewhere" (Farmer 15)

Some farmers claimed that there was a lack of research on the topic, while others said that there was probably a great amount of research conducted, but that it was normally unavailable to farmers. The SNA showed that the majority of the farmers had no direct connection to the research community, however the picture is more blurred, as five individuals listed a total of ten researchers or research organisations as someone they would discuss their farming practices with, but only half of these were seen as highly influential.

5. Discussion

In accordance with a number of other studies on farmer networks (E.g. Wood et al., 2014, Isaac, 2012, Wick et al., 2018, Sligo, 2005, Sligo and Massey, 2007) our results show the importance of interpersonal sources of information and that farmers mostly talked with other farmers about their farming practices as they consider their successful peers to be reliable experts because of their practical experience under comparable conditions (Šūmane et al., 2018).

The ego-networks in this study were dominated by farmers with shared practice that expanded rapidly after implementing NT, a pattern aligning with the homophily principle in which contacts occur more frequently between individuals in homogenous groups than actors with more loosely tied and heterogeneous networks (McPherson et al., 2001). The SNA showed that the NT farmers had rather homogenous networks as the majority of the individuals were other farmers with shared practice. A strong connection between identity and farmers who see themselves as conservationists was also found by Sulemana and James (2014) when assessing the link between identity, ethical attitudes and environmental practices in a survey of 3000 Missouri farmers. The NT farmers in our study identified with each other as they viewed themselves as a separate community of farmers that were characterized by a fellow interest in NT practice. This concurs with other studies, such as Mann (2018), who assessed triggers for adoption of innovative conservation technologies in Switzerland and found that an important characteristic of NT farmers was that they shared a motivation to devote more attention to environmental issues than the other farmers in the study. Indeed farmers' participation in networks and a shared identity can increase their commitment to the ideologies and practices (Gray and Gibson, 2013). This homophily, expressed as sharing of a common goal, practice and identity, aligns to the conceptualisation of the networks as a Communities of Practice (CoP) which can both advance and constrain innovation (Morgan, 2011, Ingram et al., 2014).

The NT farmers in our study also preferred to communicate with each other as they believed that the level of knowledge amongst other NT farmers was high. The network was driven by each individual's ability and eagerness to communicate with and learn from other farmers and to find and acquire what they considered to be valid and trusted information. A study of young innovative farmers in Italy by Milone and Ventura (2019) found that the farmers' passion for their work and their land was a common theme amongst them. This led them to manage their farms in new ways, which was an important driver for the introduction of new farming practices that would reduce soil threats and give incentive to reach out to new markets and create partnerships with actors with similar values. NT farmers' ability to network with other NT farmers and find relevant information was seen as essential, confirming that farmer information networks are sustained by the need for a specific type of knowledge and fear of not succeeding when implementing challenging or novel farming practices (Šūmane et al., 2018). Tacit knowledge, embedded in practice, commitment and involvement in a specific context with a more personal quality, thus plays a central role in NT implementation and networking.

Intermediaries have an important role in the NT farmer networks in connecting farmers to each other and to other sources of information, or to the soil research community as knowledge brokers. Intermediaries connect different networks or clusters with far reaching information and knowledge network connections (Meyer, 2010). Farmers with core positions within their networks can act as intermediaries in disseminating innovative farming practices (Šūmane et al., 2018, Pei et al., 2014, Klerkx et al., 2012) while knowledge brokers play an important role in 'translating' science into accessible information for farmers, or transforming explicit knowledge from actors outside the group to tacit knowledge within the group (Bourne et al., 2017). Intermediaries also provide a link and information flow between the different clusters of farmers in the network. Information flow within networks often depends on a few outstanding individuals (Bourne et al., 2017), and such intermediaries or brokers mentioned by several farmers in our study appeared central and important both in connecting the network and building up a body of knowledge within it. These key individuals in the social network hold the majority of ties and the connections between these individuals draws the other actors together, as noted in other research (Wood et al., 2014). This is supported by the SNA measures of network cohesiveness which show that the farmers in the study are mostly connected by fellow contacts, and not by direct links to each other. The intermediaries in this study also had the role as influencers in inspiring farmers to convert and to provide information to farmers who were new to the practice. For NT farmers, other NT farmers with longer experience and similar goals to them who were passionate about what they were doing were often their main influencers, along with farmers who could demonstrate an increase in income despite spending less on inputs. The findings fit with the widely used concepts of early and late adopters, where the experienced NT farmers were the 'innovators' and the more recent adopters were the 'imitators' (Wozniak, 1993).

Previous empirical work on agricultural advice networks suggests that the most common source of advice is often regional actors, including agricultural advisers, and regional to national non-governmental organizations, followed by family and neighbours and other non-local businesses (Baird et al., 2016). In these cases, farmers with larger and more diverse ego-networks were more likely to implement Best Management practices. However, given the relative infancy of NT adoption, the lack of existing advisory networks and the particular knowledge needs required for implementation, NT networks tend to be more homogeneous and horizontal, with most connections within the (NT) farming community. NT farmers also perceived themselves to have higher levels of knowledge about NT than other actors such as researchers or external organisations, because of their practical experience. Our findings show that the level of knowledge and experience amongst NT farmers in this study was largely affected by farmers experimenting on their own farm and exploring new ideas and techniques, and communicating this experiential knowledge through informal learning networks, thus supporting previous work (Tran et al., 2019). Poncet et al. (2010) suggested from work in Morocco that farmers must be seen as the new local experts and that agricultural extension should focus on creating and sustaining innovation networks to facilitate knowledge exchange and interaction between individuals. In accordance with our study, they discovered that farmers use a wider range of knowledge sources and intermediaries, and that information diffusion of innovation between farmers was particularly important. Innovation was dependent on farmers' ability to interact and exchange knowledge and information, suggesting that extensionists should focus more on connecting different actors by network building, knowledge production and circulating (also to small-scale farmers), and learning from farmers how they practice, learn, exchange and innovate through their networks.

Studies show that knowledge pools are not equally accessible to all farmers (Ramirez, 2013), but we suggest that these differences were less pronounced within the NT farmer community where many of the connections were unlikely to be local, and the network often geographically distributed and virtual. Indeed, in our study, some of the greatest inspiration sources were farmers with long experience situated outside of England, particularly from

America, where NT was more widespread. One likely explanation for this is that the formal advisory systems are not able to support the increasing requirements for diversified and complex knowledge by farmers (Poncet et al., 2010, Milone and Ventura, 2019), as noted for soil management in particular (Ingram, 2010, Ingram and Mills, 2019). The weak social ties to overseas farmers were therefore an important way for the English NT farmer networks to increase the internal information flow and benefit from the experiential knowledge pools of farmers with decades of experience. Granovetter (1983) reviewed the strength and role of weak ties in affecting cohesion in complex social systems. He concluded that one of the advantages of weak social ties is the effect on the diffusion of ideas and innovations, suggesting that individuals with few weak ties will be deprived of information and restricted to the ideas of their immediate network. Granovetter's findings underpin the importance of the geographically distributed networks of NT farmers in developing their practice with some individuals able to bridge externally to other networks to access new sources of information about innovative NT practices, while the strong social ties caused by homophily within the clusters have higher influence in terms of consolidating individuals' decisions and practices providing locally relevant knowledge.

It is notable in our study that farmers are linked remotely in distributed Networks of Practice (NoPs). Members of a NOP may never meet each other yet, like CoP, they share a common culture, know-how, practice and activities and are capable of sharing knowledge and identity (Brown and Duguid, 2001). Connections to these more geographically distant networks are made possible by information and communication technology (i.e. internet, smart phones and other communication mediums) (ICT) as shown in other studies (Šūmane et al., 2018, Mills et al., 2019, Eastwood et al., 2012). ICT have facilitated the development of a networking culture amongst young farmers in particular (Milone and Ventura, 2019) and specifically for soil, Mills et al. (2019) noted how social media can enhance sharing of experiential learning about soil and tillage management. Initially, learning within NT social networks with social media was quite superficial as farmers connected with each other to learn the essentials of how to 'do NT' but as they became more experienced, they shared more detailed knowledge about the soil health dimensions and the other benefits of NT.

NT farmers had the perception that they received very little support and understanding from the local conventional farmers. They described the level of knowledge about NT amongst farmers in their areas as poor, which was also pointed out as the greatest barrier to NT adoption. This aligns with a study by Saimee and Rezaei-Moghaddam (2017), which assessed predictive models for adoption of NT in Iran, indicating that the level of knowledge about the practice was one of the most important differences between adopters and non-adopters. Our findings also concur with Oreszczyn et al. (2010) who found that the introduction of agricultural innovations has the potential to strengthen or weaken farmers' Networks of Practice (NoP) by dividing or enhancing farming communities. In the case of NT farmers, the lack of knowledge of neighbouring conventional farmers about NT farming means that new adopters must look further afield for information and, therefore, their network becomes more dispersed and distributed. In other words they become more socially aligned to individuals in their NT network, who may be geographically distant, than their local farming neighbours (Liu et al., 2018).

Schneider et al. (2010) argued that Swiss farmers based their decision to adopt or reject soil conservation measures on common explicit and tacit understandings, including values and social norms ("life world"). Similarly, in our study NT farmers' image of themselves, their social norms seemed to strengthen their NoP, and by implementing NT farmers did not only adapt to a new practice by changing farm routines, but also changed their identity by adjusting their underlying values, the image of themselves and their perception of the aesthetics of cultivated fields. The importance of social norms was also shown by Isaac et al. (2007) who found that marginal individuals, like settler farmers, were more likely to take on core roles and introduce or adopt innovations due to less pressure for social conformity from peers.

6. Conclusion

NT has the potential to provide a number of beneficial agricultural and environmental functions, however its uptake in northern Europe is still relatively low. Like other systems that demand complex changes in practice, NT is characterized both by the need to develop situated and experiential knowledge, and to share this knowledge in the absence of support from the advisory services. SNA systematic methods used in this study show that social networks play a crucial role in the circulation of experiential knowledge about NT in this context in England. This analysis of the characteristics, dynamics and relations of these social networks, is a useful way of revealing the role of farmers and other actors in generating innovation in tillage systems. It complements previous research, which is largely qualitative, about farmer tillage networks with quantitative evidence. Notably it allows us to identify two leverage points in agricultural advisory systems where interventions could help to enhance uptake of NT and similar practices.

Firstly it confirms the importance of farm to farmer networks and provides support to the argument for agricultural advisory services to foster farmer innovation networks. Facilitation of knowledge by advisors requires understanding of how knowledge is produced and circulated within farmer networks (Poncet et al., 2010). Previously calls have been made to support groups through the CAP mechanisms (Brunori et al., 2013), and policy instruments such as Operational Groups (part of the EU Rural Development Programme) now offer such means. However, given the emergence and use of social media in the farming community in facilitating such networking, support or curation of such media should arguably become part of the advisory services portfolio. This questions the role of advisers in such support. Whilst their ability to provide the tacit knowledge, embedded in practice that farmers require for NT is limited, they can adapt their practices, skills, and capabilities to facilitate and support networking (Rijswijk et al., 2018, Poncet et al., 2010). Wick et al., (2018) describes how modern approaches can build upon traditional advisory approaches, by embracing social and knowledge networks concerning soil health. In this respect, advisory services can act as a boundary organization or knowledge network manager. Advisers can play a role in providing validity and scientific evidence and so assist farmers with critical assessment and interpretation of information (Wick et al., 2018). Advisers can also access institutional resources to provide the digital infrastructure and capacity to act as a moderator, which is often absent when it is farmer-led; and provide a single portal to access fragmented or dispersed networks.

Secondly the research highlights the key role of intermediaries and knowledge brokers. Identifying and enabling these intermediaries to be active in their connecting role could help to accelerate NT uptake. Their ability to connect different groups could also be harnessed to expand more insular networks or individuals, both with NT and other beneficial practices. Their bridging role in connecting nonNT farmers and advisers to the large repository of knowledge that resides within the NT community is crucial. Equally the role of influencers is also revealed as important, particularly where the practice requires inspirational voices and its advancement is tied up with a common culture or passion. In social media contexts such 'opinion leaders' have been termed 'superspreaders' (Pei et al., 2014) and the potential of targeting them with important information for dissemination has been recognised.

The networks described here have been shown to support systems of actors that are achieving individual and collective goals (Engel, 1995) with the function of guiding, convincing, binding and mitigating uncertainties (Berkhout, 2006, Klerkx et al., 2010). However, their role in the wider AIS is not so clear. Studies looking at the interface between such networks and the AIS have revealed how innovation networks emerge in the absence of conventional AIS support, but equally that they can contribute to the overall performance of AIS and should be fostered by reforming the AIS to become more adaptive and flexible (Klerkx et al., 2012, Ingram, 2015).

This suggests that as well as supporting farmer NT networks with facilitation and network management, the AIS itself needs to provide space and legitimacy for such networks. The SNA approach is a useful tool for mapping farmers' social networks. It was, however, limited to mapping current networks of the participants and the snowball approach to recruitment may over-emphasise the connections within the network. Further, people who the farmers followed online but did not directly interact with were not included in the SNA, perhaps distorting the broader picture of farmers' influencers. The identification and recruitment of some of the farmers through Twitter can also overemphasize the role of social media platforms in facilitating communication between NT farmers. More evidence is needed to fully understand the dynamics and characteristics of NT farmer networks and future studies would benefit from repeating the SNA mapping, for example both before and after implementation of NT, to provide a more thorough analysis of the temporal changes in farmers' networks with NT adoption. Further assessments of the global farmer networks are also needed to understand the diffusion of knowledge and uptake of technology resulting from links between farmers across countries.

Author contributions

The authors have no competing interests to declare. All authors conceived the idea and contributed to the planning. KS undertook the literature searching and analysis and lead on the writing. All authors contributed critically to the drafts and gave final approval for publication.

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Supplementary material

Overview of research questions (RQ) and their links to network characteristics, how characteristics are measured and the relationship to information flows.

RQ	Network characteristic	How the characteristic is measured	Relationship to information flows
Is there a link between farmer network characteristics and implementation of NT?	The role of social networks in providing information about NT.	- Network density - The average total degree - Betweenness centrality - Closeness centrality - Average neighbour degree	- Higher density between members of the network can increase information flow. - The level of interaction between actors in a social network affect information flow.
What are the characteristics of networks of farmers who have adopted NT farming?	Actors in interpersonal networks, mechanisms for networking, formality	- The types of actors within farmer networks (farmers, academia, farmer organisations etc.) and communication intensity (SNA). - Preferred communication forms (e.g. face-to-face, telephone, social media) - Formal or informal relationships (SNA). - NT farmers' acquaintance network.	- Homophily can decrease the amount of new information coming into the network. - Bridging ties increase access to external information. - Bonding ties increase the uptake of new technology.

Who are the influencers?	Influencers and intermediaries	- The in degree (number of incoming edges) - Influence rating by respondents in the SNA. - Nodes in the SNA that connect clusters	- Central actors can increase information flow by spreading information to a larger number of people. - Key players increase information diffusion between clusters.
What are the temporal and spatial dynamics of farmer networks in relation to NT?	Changes in social networks before after NT implementation Geographical distribution of social network (local/regional/national/global)	- Changes to members of respondents' social network before and after implementation of NT (SNA). - Changes to who respondents were influenced by before and after NT. - Sources of information before and after NT. - Geographical location of members of respondents' social networks (SNA).	- An increasing number of connections in a network increase density and information flow.
What sort of NT knowledge is communicated by farmer networks?	The extent of knowledge communicated within the NT networks. The nature of information	Interview questions: - Level of knowledge? - Tacit or explicit knowledge?	- Bridging of explicit knowledge to tacit forms can make new information more accessible.

	within NT networks.

Overview of coding categories used to analyse interview data in NVivo.

Nr.	Codes	Sub-codes
i	Implementation of NT	Knowledge transfer Age of adopters Information sources under implementation
ii	Information sources	Information from farmer discussion groups Farmer to farmer learning Social media as information source Farmer influencers Who interviewed farmers influence
iii	Spatial and temporal dynamics	Spatial dynamics of NT farmer networks Temporal dynamics of NT farmer networks Contact intensity between farmers in NT network Changes in the networks before and after implementation of NT
iv	Network characteristics	Regional and national actors of NT networks Global actors of NT networks Local actors of NT networks The level of knowledge of NT amongst local farmers The level of knowledge about NT within the learning network