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Agricultural Information Networks and Adoption of Conservation Agriculture in East Africa

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Abstract

Previous studies have shown that there is not one universal set of factors that contribute to smallholder farmers' adoption of Conservation Agriculture. However, network influences at the local and regional levels play a key role in innovation and technology diffusion. A major challenge in research dedicated to measuring these influences is representing farmer network structure. Mixed methods baseline and endline surveys on adoption of Conservation Agriculture and farmer information sources were carried out in 2010 and 2014 in Molo, Uganda (n=92), Kween, Uganda (n=94), and Kitale, Kenya (n=65). Network structure is explored at multiple levels: the meso-level, where agents serve as sources of vertical knowledge; and the micro level, where farmers spread new technologies horizontally, often through involvement in farmer groups and associations, and integrate them into existing local knowledge. The survey results indicate that farmers understood the three principles of Conservation Agriculture as independent concepts and that crop rotation is widespread. Adoption of minimum tillage increased significantly ($p < 0.01$) in the Ugandan sites, and knowledge of minimum tillage increased significantly in all research sites.

Keywords: Technology adoption, Conservation Agriculture, social networks, East Africa, innovation diffusion

Introduction

Conservation Agriculture (CA) is increasingly promoted as an improved long-term approach to agricultural production for smallholder farmers, based on three principles: minimum mechanical soil disturbance, permanent organic soil cover, and crop rotation (FAO, 2015). There is a growing interest by major development agencies to further the development of locally-adapted CA production systems in many regions of the world and to promote adoption of CA practices among farmers (Hobbs, Sayre, & Gupta, 2008; Hobbs, 2007; Kassam, Friedrich, Shaxson, & Pretty, 2009; Knowler & Bradshaw, 2007; Marongwe, Kwazira, Jenrich, Thierfelder, Kassam, & Friedrich, 2011).

Knowler and Bradshaw (2007) provide a synthesis of research focused on farmers' adoption of CA all over the world to identify common variables that explain adoption. They conclude that there do not seem to be any universal explanations of adoption and suggest that future studies should focus more on the circumstances of local and regional stakeholders in the promotion of CA. Taking this into account, we share our findings from a study in which we explore farmers' agricultural information networks in three sites in Kenya and Uganda at two different points in time. We focus on the ways that information reaches farmers and the key relationships that promote innovation diffusion rather than on individual farmer attributes (such as socioeconomic status and education) that might contribute to their decision to adopt or not adopt CA.

Theoretical Framework

Previous research in the Mt. Elgon district of western Kenya and eastern Uganda indicates the importance of community support networks in facilitating a mindset change towards CA principles (Moore et al., 2012). Growing recognition of the instrumental role social networks play in effecting widespread adoption of new technologies increasingly challenges the conventional “diffusion of innovations” theory, a popular appellation coined by Rogers (2002) to describe the linear model of technology transfer from the agricultural researcher to the local extension agent to the farmer. Wolf (2006) argues that the linear model fails to consider local actors and knowledge, thus rendering it ineffective and inappropriate when applied universally.

Hermans, Stuiver, Beers, & Kok (2013) discuss the need for more studies focused on the roles actors play at the micro level and the intersection between these roles and the innovation systems in which they participate. Hermans et al. (2013) describe a multi-level perspective, in which three different levels of an agricultural system affect innovations and technology diffusion: the micro, meso-, and macro-levels. The authors break down these levels as: “(1) The relatively fast-changing micro level of niches, (2) the stabilizing mechanisms of meso-level regimes, and (3) the slow-changing macro-level of socio-technical landscapes” (Hermans et al., 2013).

This multi-level perspective considers both vertical and horizontal knowledge transmission and innovation diffusion. Vertical, or hierarchical, processes refer to formalized knowledge produced by researchers, adopted into the curriculum of extension agents or the products of agribusiness companies, and transferred to farmers. However, local adaptation of this knowledge requires farmer networks to discuss, test, and evaluate adaptations to the local context, and this creates local agricultural knowledge that is often more relevant to farmers than formal knowledge (Moore, Lamb, Sikuku, Ashilenje, Laker-Ojok & Norton, 2014; Wood et al., 2014).

Such processes at the micro-level constitute Herman et al.'s (2013) horizontal diffusion.

Micro level farmer information networks are difficult to fully capture when working across multiple networks. Instead of designing a study to measure exact contact between farmers in dense social networks at the village level, we approximate such networks through shared membership in community groups. Affiliation networks are well-established in the social network literature as a means to studying the role of co-attendance to events and co-membership in groups (Jasny, 2012). Development researchers have argued that the formation and composition of endogenous rural producer organizations and other community-based organizations in Ghana and Ethiopia have important implications for development policies and social network based interventions (Arcand & FaFchamps, 2011; Zeitlin, 2011). Identifying sub-groups or cliques and then identifying opinion leaders from within those groups has been studied and used in the context of public health promotion, such as in nutrition promotion, safe sex behaviors, and tobacco prevention (Valente & Fosados, 2006). Community groups have been associated with HIV prevention strategies in Zimbabwe (Erbaugh, Donnermeyer, Amujal, & Kidoido, 2010), and Farmer Field Schools have long been established as conduits for farmer-to-farmer information exchange in agricultural development (Erbaugh et al., 2010; Simpson & Owens, 2002).

CA is the ideal technology to study networks of stakeholders and their roles in developing and spreading innovations for three reasons: it is a controversial technology, it must be adapted to local agro-ecological zones, and its dissemination occurs over the course of years.

The most controversial aspect of CA is the tenet of minimum soil tillage. Conventional tillage and increased mechanization has traditionally been associated with weed control and progress in agriculture (Triplett & Dick, 2008), and conservation tillage has historically been met with some reluctance and skepticism by farmers (Bultena & Hoiberg, 1983). This element of resistance and perceived risk means that a farmer's decision to adopt a minimum- or no-till system is part of a more complex process than a simple diffusion of information or farm inputs. Additionally, the crops selected to act as organic soil cover in CA systems will vary widely by agro-ecological zone, requiring local actors to serve as innovators in order for CA to become established. Determining the most appropriate cover crop in a specific agro-ecological zone may take more than one season, and it may take multiple planting seasons before late adopters are convinced to implement CA on their land. Disadoption or abandonment of CA practices may occur at any point after initial adoption of the technology.

Purpose and Objectives

We discuss farmer information networks in Kenya and Uganda using horizontal, or micro level, and vertical, or meso-level, diffusion processes as an analytical framework. We show that farmers seek agricultural advice as much from local contacts, such as neighbors and endogenous community group leaders, as from contacts at the meso-level, such as private agro-input vendors and extension agents. Additionally, we discuss the interaction between these two levels within the local context.

We also measure adoption and disadoption of CA between a baseline and endline survey in Kenya and Uganda and find that adoption rates increased significantly in the Uganda sites between 2010-2014, and we discuss the different ways that farmers learned about the technology within vertical and horizontal networks.

Methods

Baseline data collection

The Sustainable Agriculture and Natural Resource Management Collaborative Research Support Program (SANREM CRSP) Long-Term Research Activity in East Africa conducted research on CA among farmers in the Mt. Elgon region of western Kenya and eastern Uganda. As part of that research, farmers and service sector/community agents were interviewed and data collected on their beliefs about CA and on the structure of their agricultural information and resource networks using a mixed methods approach combining focus group and key informant interviews with a formal survey of using standardized questionnaires (Moore et al., 2012).

The sampling methodology for the formal survey baseline data used in this study is described in detail in Moore et al. (2012). Briefly, in Uganda, farmers were selected from Kidoko and Kipangor parishes in Molo subcounty and from Kere and Kwosir parishes in Kween (formerly part of Kapchorwa) subcounty. On-farm demonstration gardens were established in each of the parishes in partnership with landowners. In Trans-Nzoia District, Kenya, the peri-urban populations of the Kibomet and Milimani sublocations were selected for the study. A list frame was created by obtaining records of household heads from each subcounty or sublocation and then by performing a stratified random selection from each list. Substitutions were made in the field when households could not be located. In each site, mixed teams of 2-3 men and women were employed as enumerators to ensure familiarity with the local language and geography, and a local community leader was hired as a guide to introduce the research team and to coordinate interviews. The survey instrument was developed in close collaboration with Ugandan NGO partners who were familiar with the local languages and with administering surveys in the area. Many questions from the baseline survey were included in the endline survey instrument to measure adoption between the two time points. Then, the survey instrument was tested on 10 individuals, who gave detailed feedback about their interpretation of each question. Once the survey instrument was finalized, the enumerators were trained for one full day at each site to ensure consistency and credibility. As part of the training, enumerators practiced administering the survey to one other in English while being monitored for any inconsistencies. The teams of enumerators conducted the first three surveys at each site as a group to ensure that the questions were being asked in a uniform way. A member of the research team sat in on the administration of every survey.

During the administration of the surveys, measures were taken to ensure the construct validity of the variables used to measure the adoption of CA practices. If participants responded affirmatively to a question about the adoption of a CA practice such as minimum tillage, they were also asked follow up questions about the percentage of land on which they implemented the practice, the year in which they began practicing it, and the reasons for which they chose to practice it. If it became clear through their qualitative explanations that they had not understood the adoption question fully, the question was revisited.

Surveyed individuals identified their contacts for agricultural information, advice, and resources from a list of occupational categories that was created from a position generator during focus group interviews with local stakeholders and farmers (Moore et al., 2012). The position generator method asks respondents about their relationships with members of specified occupations, which in this case were service sector and community agent occupations related to agricultural production and community engagement, such as extension agents, market vendors, and religious leaders (Lamb, Mills, Moore, & Alwang, 2011). Between eighteen and twenty-two of these agents were identified in each site. Those agents from the occupational categories who were identified by more than five respondents were then interviewed in a snowball sample. The service sector and community agent categories that were identified included government extension agents, vendors in agro-vet shops, leaders of farmer groups, and local political leaders. This sampling methodology allowed for a detailed representation of agricultural networks beyond the village level.

Endline data collection

For the endline survey, we resurveyed the households that were interviewed for the baseline survey and conducted another round of interviews with key informants. The survey instrument for the endline survey replicated questions about the structure of farmers' information networks and also included questions about farmers' adoption of CA practices. All households from the baseline survey in Molo, Uganda (*n*=92) and in Kween, Uganda (*n*=94) also participated in the endline survey, but there was a 20% attrition rate in Kitale, Kenya (*n*=65). During the endline survey, respondents also answered questions about their membership in community groups, such as farmers' groups, savings groups, women's groups, and youth groups. Using the names of the groups to which each respondent belonged, we created one-mode and two-mode affiliation networks for each site to estimate farmer-to-farmer contact at the micro level (Jasny, 2012).

Network Construction

Two distinct types of networks were constructed using the data: directional farmer contact networks at the meso-level with service sector and community agents; and bipartite, or two-mode affiliation networks that depict farmers and the community groups to which they belong at the micro level. The network graphs are directional. Nodes represent the respondents and the service sector/community agent categories, and edges were determined from responses to a question about respondents' information and resource contacts: “Do you exchange physical resources with [occupational category] such as seed, fertilizer, or cash, information about agriculture, or both?”

The relationships are directional because the service sector/community agents who were identified by name by more than five respondents were interviewed about their roles in promoting agricultural technologies and their attitudes towards CA practices, but since many of them served in a more formal role at the subcounty level, they could not identify all of the specific farmers with whom they exchanged information. The extension agents, for example, held trainings and field days with many groups of farmers at once across several different subcounties.

Often, local leaders served in several roles and were known more for one role over another by different respondents. For example, religious leaders also often worked as schoolteachers. Veterinary service providers sometimes had agro-vet shops of their own. Farmer groups and organizations often functioned as savings groups or women's groups as well. In some cases, respondents listed individuals in the “Other” categories who actually held formal roles, such as leaders of savings groups or village chief, but the respondent knew the person they listed in another capacity outside of that role. Additionally, respondents did not identify contact with a certain category if they themselves fell into that category. For example, a respondent from the original random sample who happened to be a farmer group leader did not answer questions about her or his contact with "Leader of farmer group", as a category. Due to this, some categories were likely underreported.

Bipartite graphs, or two-mode affiliation networks, were constructed using data on membership to community groups. Respondents were asked: "Are you an active member of any groups, organizations, or associations? Please list all and specify the **type** of group (farmers', women's, savings, youth, health, etc.)"'. The group names were standardized and affiliation edge lists were created from the data. All network graphs were built in Gephi using the Force Atlas 2 and Fruchterman-Reingold algorithms (Jacomy, Venturini, Heymann, & Bastian, 2014).

The three principles of CA (minimum mechanical soil disturbance, permanent organic soil cover, and crop rotation) are often understood and promoted separately. Even producers who are familiar with each of the principles individually may not have a good concept of Conservation Agriculture as a coherent technological package. Because of this, survey respondents answered the same set of questions about each of the principles.

In the baseline and the follow-up survey, producers were asked if they had heard of minimum tillage and if they practiced it on any portion of their land. Project participants had established demonstration gardens in each of the sites in 2010 to measure the agronomic effects of a CA system in each agro-ecological zone. The primary focus of the project was collecting agronomic measurements rather than on outreach, but some educational meetings were held early on to discuss the potential merits of adopting a CA system. The survey included questions on disadoption as well as adoption of CA practices, as farmers who have disadopted the technology can help researchers better understand the barriers to adoption that farmers face in a specific area (Giller et al., 2011).

Results and Discussion

Meso-level network structure

Table 1 lists the five service sector and community agents from each research

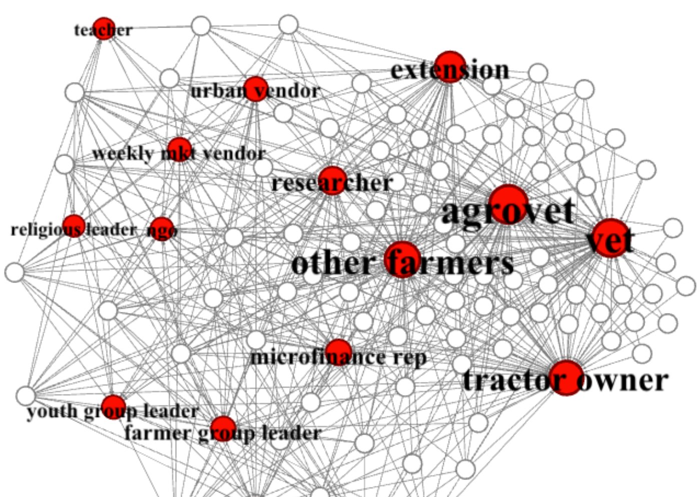

Figure 1.Top in-degree contacts in Kitale, Kenya (2010).

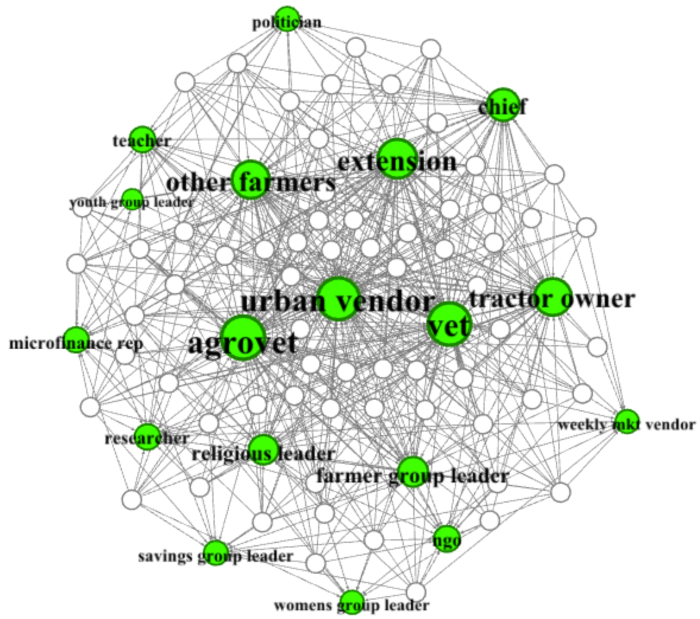

Figure 2. Top in-degree contacts in Kitale, Kenya (2014).

site that had the highest in-degree at the time of the baseline and endline surveys. Figures 1 and 2 visually depict the farmer information network structures in Kitale, Kenya in 2010 and 2014. White nodes represent farmers, and colored nodes represent service sector and community agents. Larger node size indicates larger in-degree centrality. The lines, or edges, between farmers and community agents represent a relationship between the two nodes connected by them. During the period of four years, we would not expect the structure of participants' social networks to remain static. Service sector or community agents who hold a prominent role may not maintain that role. Non-governmental Organizations (NGOs) may implement

Table 1. The five service sector and community agents with the highest in-degree centrality in each research site.

	2010 In-degree			2014 In-degree		
Position	Molo	Kween	Kitale	Molo	Kween	Kitale
1	Other farmers	Other farmers	Agrovet	Agrovet	Other farmers	Agrovet
2	Vet	Vet	Vet	NGO	Extension	Vet
3	Extension	vendor	farmers	Politician	vendor	Urban vendor
4	Agrovet	Agrovet	Tractor owner	Farmer group leader	Religious leader	Extension
5	Mkt. vendor	Mkt. vendor	Extension	Extension	Politician	Political

intensive short-term projects in an area but change locations entirely once the project has come to a close. Political leaders may play a larger role in information dissemination and resource distribution while running a campaign. Agrovet and agricultural inputs shops may close or change locations.

Indeed, Table 1 provides evidence that survey respondents had different agricultural information and resource contacts in 2014 than they did in 2010. Just over half of the highest in-degree categories in 2014 do not appear in the top categories for 2010. Some contact categories do maintain their position, such as the agrovets and vets in Kitale, Kenya. In Kween, Uganda, farmers identified "Other farmers" as an agricultural contact more often than they identified any actor with a formal role.

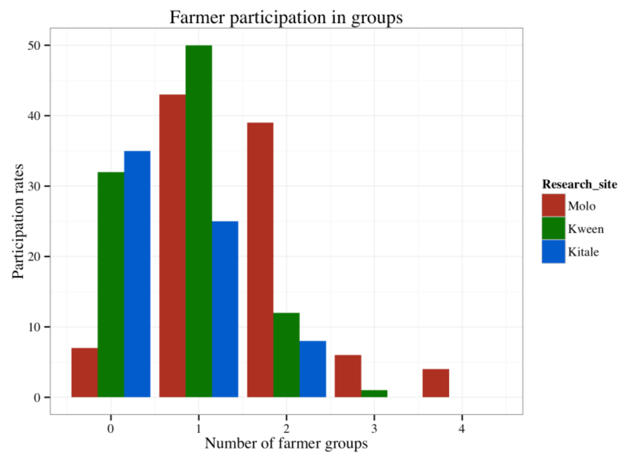

Figure 3. Participation by number of groups

Important to note is the role of the private vendors as sources of agricultural information. The "Agrovet" category appears in the top five highest in-degree centrality nodes in all but one of the surveys. This category may refer to small agricultural input shops located within the village, but it was also interpreted as agrovet or input shops in nearby towns that serve clients from several villages. Some agrovet shops are run by just one individual or family, but others, such as the majority of the agrovet shops in Kitale, Kenya, have over ten employees. Because of this, it was sometimes difficult to distinguish between the "Urban vendor" and "Agrovet" categories during the data collection process.

Collectively, the "Agrovet", "Urban vendor", and "Weekly market vendor" account for 40% of the highest in-degree contacts in 2010 and 26% in 2014. Farmers visit local stockists and agrovet shops to purchase agricultural inputs but also to learn about new technologies. Larger agrovet shops, such as those in Kitale, hold seasonal field days in which they act like extension agents and visit the surrounding villages to promote a certain seed variety, chemical, or other input. In Molo, Uganda, a local agrovet had established an information center at his shop and received daily text messages about market prices.

Micro level network structure

The in-degree measures show that farmers value the information and advice of other farmers and community leaders as well as the information they get from more formal sources. In recent studies on social networks among groundnut growers in Kenya and Uganda, Thuo et al. (2013; 2014) found that local farmer groups and associations were deeply embedded in social network structures and that the majority of farmers were involved with at least one group or association. The data from this study confirms that farmers had high rates of participation in groups, as shown in Figure 3. In Molo, Uganda, 92% of respondents to the endline survey belonged to at least one group or association. Overall participation rates are lower in Kween, Uganda, and Kitale, Kenya, at 66% and 48%, respectively, but still high enough to suggest that farmer and community groups are important components of farmer information networks in these sites.

Local savings groups, by their nature, require an elevated level of trust between individuals. During each meeting of groups that save together, individual farmers contribute small amounts of money to their group fund. Eventually, when the group has saved enough money, it can invest in something that is likely to raise the income of the whole group, such as a cow. The income the groups gain through milk sales is put back into the group fund to eventually purchase more cows or participate in other income-generating activities. The savings activities, in many cases, take place completely within the village and lack any sort of external accountability. Other groups, such as Farmer Field Schools and growers' associations, typically have some sort of outside influence, at least at their inception. In Uganda, the national Extension agency encourages farmers to form groups and associations. Farmer Field Schools are often formed in partnership with NGOs or Extension agents. Larger producer organizations with corporate connections, such as to national brewing companies, are sometimes involved in the formation of smaller farmer groups. For example, since barley grows well in Kween, Uganda, a Ugandan brewing company visited the area and encouraged farmers to form a growers' association and grow barley together. Farmer group leaders play a pivotal role in the micro and meso-levels of horizontal and vertical farmer information networks. Hermans et al. (2013) use the term "innovation brokers" to refer to individuals who facilitate linkages between different levels of the agricultural system. In this case, farmer group leaders can be considered innovation brokers, connecting the vertical and horizontal diffusion processes. They help identify farmers that fit specific criteria

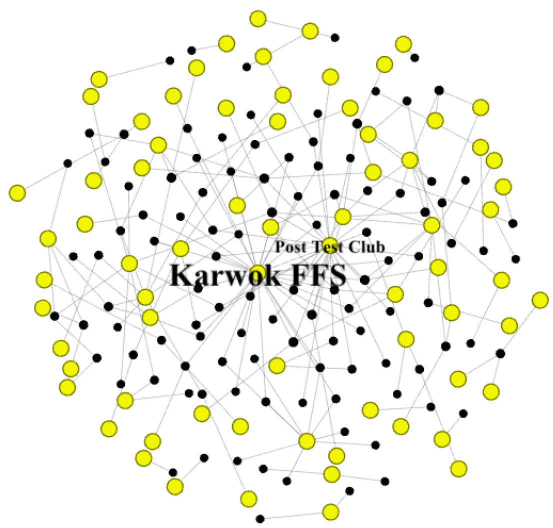

Figure 4. Bipartite graph of farmer groups and associations in Molo, Uganda in 2014.

to qualify for Extension and NGO resources and programs, but they also coordinate endogenous savings and agricultural activities within the group.

Thuo et al. (2014) argue that interventions to improve agricultural productivity should involve participatory work with local groups and associations. Our findings in the *Meso-level network structure* section on farmers' preference for other farmers and farmer group leaders as advice contacts support this conclusion. Key farmer groups and their leaders may serve as important intervention points at the nexus between vertical and horizontal innovation diffusion. Understanding the structure of community groups in an area would be a useful part of a baseline survey for stakeholders interested in promoting a technology such as CA at the micro or village level. Figure 4 illustrates the network of individuals connected by savings, women's, and farmer groups in the Molo research sites. Small nodes represent farmers, and the larger, labeled nodes represent the groups to which they belong. The two most active groups with the highest degree were the Karwok Farmer Field School and the Post Test Club (labeled). While several of the groups pictured in the periphery had only one member in the study sample, others were densely interconnected, with members who were involved in several different groups. The structure of the affiliation network in Figure 4 suggests that identifying the largest farmer and savings groups in Molo could be a useful strategy for determining intervention points to promote a farming technology such as CA. Farmers will often wait to adopt a perceived risky or abnormal behavior, such as changing one's way of farming, until they see that their peers have been successful with it (Udry & Conley, 2004), or until the innovation diffuses throughout their producer (horizontal) network (Isaac, 2012). If leaders and members from the central groups are included in co-innovation processes, they may be more likely to involve or inform their fellow group members. However, if closed trainings are held or physical resources are given to members from only one farmer group or association and not to others, members from peripheral groups may feel alienated or be deterred from becoming involved themselves. The formation of a consortium of group leaders or representatives from a variety of groups in Molo could be a useful strategy for extending the reach of a single outside agent, such as a development or extension agent. In Kween, high participation rates in community groups suggest that such groups may be viable intervention points for regional and national agricultural and development agents, but the lack of interconnectivity between the groups indicates that more leaders may need to be involved to reach the many smaller isolated farmer groups.

reasons respondents listed for practicing crop rotation included to increase food security, to get income from short-season crops, and to minimize weeding.

Table 2. Summary of findings in 2014 survey on minimum tillage practices in each of the research sites.

Adoption measure	Molo, Uganda (*n*=92)	Kween, Uganda (*n*=94)	Kitale, Kenya (*n*=65)
Heard of min. tillage (%)	86 (93%)	84 (89%)	46 (71%)
Adopted min. tillage (%)	30 (35%)	28 (33%)	15 (33%)
Mean (*s*) years implemented	2.6 (1.4)	2.1 (1.1)	3.7 (2.5)
Disadopted min. tillage (%)	11 (12%)	12 (13%)	6 (9%)

Note. Participants who reported adoption of minimum tillage on some or all of their land were then asked to self-report the date they began implementing the practice. The table above reports the average time between minimum tillage implementation and the time of data analysis for each site. Standard deviations are presented in parentheses.

The relatively simple and straightforward data collection process for an affiliation networks study makes it a viable tool for determining network structure at the micro level. Better knowledge about the structure of local networks and the identity of innovation brokers would allow extension and development agents to tailor their programs to be more participatory, inclusive, and effective.

Adoption of Conservation Agriculture

A variety of factors may have contributed to significantly higher adoption rates of minimum tillage between the baseline and endline surveys, but the rates of farmers practicing crop rotation and cover cropping remained largely unchanged over the study period.

The baseline survey did not include questions about farmers' use of crop rotation because it was thought to already be a common practice. The follow-up survey confirmed this: 99% of farmers in Molo, 94% in Kween, and 79% in Kitale practiced crop rotation. Qualitative responses revealed a widespread understanding that rotating crops leads to increased soil fertility, pest and disease control, and higher yields. Other

No significant increases in adoption of cover cropping ($p > 0.05$) occurred between the two surveys. There are several reasons for this. One goal of the demonstration gardens was to determine the appropriate cover crop for each agro-ecological zone. Seeds for the cover crops that were chosen (macuna and lablab) were often not locally available. Some farmers also listed the size of their land as a limiting factor. Fewer respondents had heard of cover cropping than of minimum tillage.

In both of the Uganda sites, an exact McNemar's Test ($p < 0.01$) determined that there was a significant increase in adoption of minimum tillage among survey participants between 2010 and 2014. In the Kenyan site, adoption of minimum tillage did not increase significantly among survey respondents ($p > 0.01$). The number of survey participants who had heard of minimum tillage increased significantly between the data collection points in all sites ($p < 0.01$). In Molo, Uganda, only 4 of the 61 respondents who had not heard of minimum tillage in 2010 still had not heard about it in 2014. Of those farmers who had adopted minimum tillage and were practicing it at the time of the second survey, those in Molo, Kween, and Kitale had been practicing it for an average of 2.6 years, 2.1 years, and 3.7 years, respectively.

Those farmers who have disadopted can also play an important role in shaping local knowledge about the technology and perhaps blocking horizontal diffusion. Nine to twelve percent of farmers in each site who were not practicing minimum tillage at the time of the second survey had practiced it in the past and stopped. The most commonly listed reason for disadoption in the Uganda sites was the expense of the herbicide. In Uganda, farmers usually understood minimum tillage as a system where herbicides were used to kill weeds instead of tillage. Since ploughing the land is expensive (three times more expensive than the cost of herbicides in these research sites), minimum tillage is promoted by NGOs and local media sources as a money-saving technology. However, because most farmers who adopted minimum tillage only did so on a portion of their land, they end up paying for both herbicides and ploughing and thus perceive it as an expensive or cost-prohibitive technology. Additionally, the benefits of minimum tillage may not be immediately evident (Giller, Witter, Corbeels, & Tittonell, 2009), which may contribute to farmers' decisions to cease the practice after initially trying it out. Indeed, some farmers listed their reason for disadopting as “failed to see benefit”.

To address these barriers to adoption, those promoting CA or minimum tillage should be sure to educate farmers on the long-term benefits of the technology and on the other principles of CA besides minimum tillage that help to limit weed growth. The take-away message should not be strictly that herbicides save time and money, but that they can be incorporated into an agricultural system that can help to mitigate soil erosion and other harmful effects of farming activities, especially for smallholder farmers who have few acres for themselves and their families. Many farmers misunderstood minimum tillage to be ploughing the land almost as much as they usually would and then also spraying herbicides, which would indeed increase the overall cost of production. If CA and/or minimum tillage is to be promoted as a money-saving technology, its proponents must preemptively address this common misunderstanding.

Minimum tillage is a relatively new concept in Kenya and Uganda (Moore et al., 2014), but farmers are learning about it from contacts at the meso- and micro levels and from local media. In Kween, Uganda, farmers who had heard of minimum tillage were asked where they heard about it. Of the 66 farmers who responded to this question, 44% heard about minimum tillage from other farmers or neighbors, 20% from radio or other media, 18% from the local demonstration plots of the NGO that was promoting CA, and 18% from various other sources. This supports the findings of Thuo et al. (2013), who found that farmers in Kenya and Uganda utilized demonstration plots and media as sources of agricultural information, but more often sought information from informal strong ties within their networks and village meetings. Indeed, “Other farmers” as a category appears frequently in Table 1 as a high in-degree node.

Since information about minimum tillage is coming from multiple sources, farmers are likely getting mixed messages about how best to implement it. This is important for those promoting CA and/or minimum tillage in the region to consider, since it could be confusing to farmers. One way to mitigate this potential problem would be to hold small-scale periodic surveys with farmers who are not involved in any demonstration garden or training activities to learn about farmers' knowledge of the CA and/or minimum tillage, instead of the traditional approach of one large baseline and one large endline survey.

Additionally, we considered whether respondents belonged to a farmer group that had outside influence (such as from Extension, an NGO, or the private sector) or not and whether respondents had adopted minimum tillage or not. Using Pearson's Chi-squared test and Fisher's Exact test, we found that there was no significant relationship between the outside influence of a group and adoption of minimum tillage ($p > 0.05$), providing further evidence that the combination of both formal (vertical) and informal (horizontal) diffusion processes are critical to the spread of the technology.

Conclusions

Since farmers access information through multiple knowledge sources, they often receive mixed messages about the principles and implementation of Conservation Agriculture. By focusing on the structure of farmer information and technology networks at the micro and meso-levels, we gain important insights into elements of vertical and horizontal knowledge transmission processes in three sites in Kenya and Uganda. A diverse group of agents at the meso-level serve as formal sources of agricultural information for village level networks, where horizontal diffusion then takes place as farmers adapt technological advances according to local knowledge. Sources of vertical knowledge go beyond Extension agents and agricultural NGOs to include private vendors, religious leaders, local politicians, and farmer group leaders, and the structure of farmer information networks at the meso-level changes over time. Affiliation networks are a seemingly underutilized tool for estimating farmer networks at the micro level through shared group membership in farmers', savings, and women's groups. Such groups play an important role in the intersection between vertical and horizontal knowledge exchange and innovation diffusion. Studies of affiliation networks by farmer group membership could be used to quickly identify local agricultural knowledge hubs and understand network structure at the micro level, and the methods and findings from this work could inform future studies on the diffusion of a technology such as CA through networks of smallholder farmers.

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References

Arcand, J., & FaFchamps, M. (2011). *Matching in rural producer organizations*. *CERDI* (Vol. 200626). Retrieved from http://hal.archives-ouvertes.fr/halshs-00562629/

Bultena, G., & Hoiberg, E. (1983). Factors affecting farmers' adoption of conservation tillage. *Journal of Soil and Water Conservation*, (13). Retrieved from http://www.jswconline.org/content/38/3

/281.short

Erbaugh, J. M., Donnermeyer, J., Amujal, M., & Kidoido, M. (2010). Assessing the impact of Farmer Field School participation on IPM Adoption in Uganda. *Journal of International Agricultural and Extension Education*, *17*(3), 5–17.

FAO. (2015). Conservation agriculture. Retrieved February 16, 2015, from http://www.fao.org/ag/ca/

Giller, K. E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E., & Tittonell, P. (2011). A research agenda to explore the role of conservation agriculture in African smallholder farming systems. *Field Crops Research*, *124*, 468–472.

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*, 23–34.

Hermans, F., Stuiver, M., Beers, P. J., & Kok, K. (2013). The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. *Agricultural Systems*, *115*, 117–128.

Hobbs, P. R. (2007). Conservation agriculture: what is it and why is it important for future sustainable food production? *The Journal of Agricultural Science*, *145*(02), 127.

Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *363*(1491), 543–55.

Isaac, M. E. (2012). Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. *Agricultural Systems*, *109*, 9–15.

Jacomy, M., Venturini, T., Heymann, S., & Bastian, M. (2014). ForceAtlas2, a continuous graph layout algorithm for handy network visualization designed for the Gephi software. *PloS One*, *9*(6), e98679.

Jasny, L. (2012). Baseline Models for Two-Mode Social Network Data. *Policy Studies Journal*, *40*(3), 458–491.

Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of Conservation Agriculture: justification, sustainability and uptake¹. *International Journal of Agricultural Sustainability*, *7*(4), 292–320.

Knowler, D., & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy*, *32*(1), 25–48.

Lamb, J., Mills, B. F., Moore, K. M., & Alwang, J. (2011). *Food Security and Social Networks : Impacts for Smallholder Farmers in the Mount Elgon Region of Kenya and Uganda*. Virginia Tech.

Marongwe, L. S., Kwazira, K., Jenrich, M., Thierfelder, C., Kassam, A., & Friedrich, T. (2011). An African success: the case of conservation agriculture in Zimbabwe. *International Journal of Agricultural Sustainability*, *9*(January 2015), 153–161.

Moore, K. M., Lamb, J. N., Laker-ojok, R., Nyachwo, J., Sikuku, D. N., Ashilenje, D. S., & Mukhwana, E. J. (2012). *Agricultural Actors , Networks and Mind-sets :* (No. Working Paper No. 03-12). Retrieved from http://www.oired.vt.edu/sanremcrsp/wp-content/uploads/2013/11/working.paper_.03-12-ag.actors.in_.KenyaUganda.pdf

Moore, K. M., Lamb, J. N., Sikuku, D. N., Ashilenje, D. S., Laker-Ojok, R., & Norton, J. (2014). Multiple Knowledges for Agricultural Production: Implications for the Development of Conservation Agriculture in Kenya and Uganda. *The Journal of Agricultural Education and Extension*, *20*(3), 291–307.

Rogers, E. M. (2002). Diffusion of preventive innovations. *Addictive Behaviors*, *27*(6), 989–93. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/12369480

Simpson, B. M., & Owens, M. (2002). Farmer field schools and the future of agricultural extension in Africa. *Journal of International Agricultural and …*, *9*(2), 29–36. Retrieved from http://www.aiaee.org/attachments/article/265/Simpson

Thuo, M., Bell, A. a., Bravo-Ureta, B. E., Lachaud, M. a., Okello, D. K., Okoko, E. N., … Puppala, N. (2014). Effects of social network factors on information acquisition and adoption of improved groundnut varieties: the case of Uganda and Kenya. *Agriculture and Human Values*, *31*(3), 339–353.

Thuo, M., Bell, A. a., Bravo-Ureta, B. E., Okello, D. K., Okoko, E. N., Kidula, N. L., … Puppala, N. (2013). Social Network Structures among Groundnut Farmers. *The Journal of Agricultural Education and Extension*, *19*(4), 339–359.

Triplett, G. B., & Dick, W. a. (2008). No-Tillage Crop Production: A Revolution in Agriculture! *Agronomy Journal*, *100*(Supplement_3), S–153.

Udry, C., & Conley, T. (2004). Social networks in Ghana. Retrieved from http://books.google.com/books?hl=en&lr=&id=jRlct_3QrR0C&oi=fnd&pg=PA232&dq=Social+Networks+in+Ghana&ots=CvJbpR980b&sig=oUEvX4hjh1a0zVtP-UmBL3uMKfE

Valente, T. W., & Fosados, R. (2006). Diffusion of innovations and network segmentation: the part played by people in promoting health. *Sexually Transmitted Diseases*, *33*(7 Suppl), S23–31.

Wolf, S. (2006). Commercial restructuring of collective resources in agrofood systems of innovation. In S. Frickel & K. Moore (Eds.), *The New Political Sociology of Science: Institutions, Networks, and Power* (pp. 91–121).

Wood, B. a., Blair, H. T., Gray, D. I., Kemp, P. D., Kenyon, P. R., Morris, S. T., & Sewell, A. M. (2014). Agricultural science in the wild: A social network analysis of farmer knowledge exchange. *PLoS ONE*, *9*(8).

Zeitlin, A. (2011). Identification and estimation of peer effects on endogenous a liation networks : An application to Ghanaian agriculture, 1–46. Retrieved from http://sites.google.com/site/andrewzeitlin/research/networks_paper.pdf