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# The Role of Information and Interaction Processes in the Adoption of Agriculture Inputs in Uganda

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**Abstract:** Agriculture is an essential component of food security, sustainable livelihoods, and economic development in sub-Saharan Africa (SSA). Smallholder farmers, however, are restricted in the number of crops they can grow due to small plot sizes. Agriculture inputs, such as fertilizers, herbicides or pesticides, and improved seed varieties, could prove to be useful resources to improve yield. Despite the potential of these agriculture technologies, input use throughout much of SSA remains low. This paper aims to better understand the process of innovation diffusion through information and interaction processes at the individual, social network, and community levels. A total of 203 participants were surveyed using a semi-structured interview method in four rural communities located in the Mbale, Lira, Kabale, and Masaka districts of Uganda. Participants were asked about their access to information technologies, information sources via social network ties, level of engagement in the local community, and agricultural input use. Results indicate households with higher levels of information access through cell phone use and weak-tie information sources are more likely to use inputs. Significant findings also include the interactional effect of cell phones and weak ties on fertilizer adoption. This research could inform policy makers of cost-effective methods of disseminating agriculture information and encouraging innovation diffusion.

**Keywords:** smallholder farming; sustainable rural livelihoods; innovation diffusion; information and communication technologies; community interaction; agriculture inputs; sub-Saharan Africa; Uganda

## 1. Introduction

Smallholder farming is an essential component of food security, sustainable livelihoods, and economic development in sub-Saharan Africa (SSA). Given its importance, increasing agriculture production may be one of the most pressing development priorities on the continent. As land is often a limiting factor for farmers, innovation in the form of agriculture inputs (fertilizers, pesticides/herbicides, and improved seed varieties) has the potential to significantly improve yields. Adoption of inputs, however, remains extremely limited throughout SSA, while agriculture production throughout much of the continent remains stagnant [1,2]. For instance, in 1980, SSA's cereal yield was 1064 kilograms per hectare. By 2014, nearly twenty-five years later, production rates had risen to just 1451 kilograms per hectare [3]. Limited growth in agriculture production is especially troubling given the continent's population growth, which is projected to reach 2.7 billion people by 2060 [3].

Smallholder farmers, defined as those that earn their incomes from small plots of land or livestock holdings, play an important role in increasing food security and the availability of nutritious foods, contributing to sustainable agricultural intensification and economic development [4]. Smallholder farming, which represents an estimated 80 percent of all farms in SSA [5], is also a source of stability for rural communities, as it provides a source of food, regardless of economic conditions, and can be used

in reciprocal relationships within the community. For geographically remote regions, such as much of SSA, information and communication technologies (ICTs) could benefit smallholder farmers through increased information access and agricultural input use. While radio is the most prominent ICT in much of SSA, the explosion in cell phone ownership, which showed a ten-fold increase between 2005 and 2015, offers a new tool for development and information diffusion [3]. Cell phones are linked with reduced costs, improved extension services and yields, and poverty reduction for smallholder farmers around the world [6–8]. The potential of mobile phones to connect rural and marginalized communities has even sparked its own form of development, known as information and communication technologies for development (ICT4D).

Communication channels fostered by ICTs have shown themselves to be an important component of the adoption process [9–12]. Similarly, social network and interaction-related factors, such as the influence of an actor within their social network [13], network embeddedness [14], network hubs [15], strong and weak ties [16], and community interaction [17], have all been explored as possible avenues of communication and innovation diffusion. An integrative analysis of the influences of information access on the process of innovation adoption through ICTs, social networks, and community participation or involvement, however, is underrepresented in the current literature on the diffusion of agricultural technologies. The goal of this research was to better understand the role of various information and communication channels in agricultural input adoption decisions. The study used data collected from household surveys in four districts throughout Uganda and focused on mobile phone access, social networks, and community interaction. Taken together, these processes do not just provide platforms for information access, but also enhance and build on the benefits that each component offers individual smallholder farmers.

Uganda was chosen as the study site as agriculture is an especially important component of the country's GDP and rural livelihoods, but agriculture input use remains exceptionally low. Uganda's agriculture sector is made up predominantly of smallholder farmers that own small plots of land, except for the northern region of the country, where pastoral-based agriculture means that much of the land is owned communally. Traditional cash crops include coffee, cotton, tea, cocoa, tobacco, and sugarcane, with non-traditional crops, such as maize, rice, beans, soy, and palm, becoming increasingly important [18]. As of 2015, over 70 percent of Ugandans found employment through agriculture, with the sector being responsible for 26 percent of the country's GDP [3]. However, the average fertilizer use-rate is 2.2 kilograms per hectare, which includes both input users and non-users, compared to the global average of 119 kilograms per hectare [3]. Only three percent of households in Uganda report using any type of agro-chemical [19].

While improved crop use is relatively low in many SSA countries, there are indications that farmers are open to innovation. Sheahan and Barrett [20] note that more than 50 percent of land for the staple crops maize and groundnuts are underimproved varieties. Increased input use has the potential to improve yields and prevent some losses, especially with the use of improved seed varieties, an opinion echoed by the International Fund for Agriculture Development (IFAD), which cites the low use of agriculture inputs and the lack of technology adoption as a key issue restricting the development of rural SSA [21]. In Uganda, similar to much of SSA, food security, rural livelihoods, and economic development are intrinsically tied to agriculture. Stagnating agriculture production coupled with a rising population will continue to be a barrier to development in both the country and the region. Given these factors, rural communities in Uganda were ideal for studying the role of information and interactional processes in agriculture input adoption.

## 2. Literature Review

The innovation diffusion process is a focus of study for various fields, including sociology, psychology, communications, and organizational or management studies. Although the theory of innovation diffusion can be traced back to early sociology, the field was irrevocably altered by the work of rural sociologist Everett Rogers, whose seminal work, *The Diffusion of Innovations*, originally

published in 1962, is a classic diffusion theory text [10]. Rogers illustrated the adoption process using a bell curve, with early adopters clustered at the left tail of the curve, followed by the bulk of the population, and finally laggard adopters, who may not adopt the innovation at all. As noted by Rogers and subsequent theorists, whether or not an innovation is adopted depends on much more than the innovation's improvement over current technologies or processes. The characteristics of innovation, individual adopters, and organizations have all been studied in an attempt to understand the diffusion process.

While intuitively innovations that provide an advantage, either real or perceived, over current tools or processes are more likely to be adopted, other characteristics, including the innovation's consistency with the current system, how difficult it is to learn, the potential for the innovation to be adapted to other uses, and its observability are all factors in adoption [10]. Individual adopter characteristics can provide some explanation for adoption decisions. Research from Kenya found a positive relationship between the user of ICT-based market information services and age, household-size, varieties of crops grown, and market participation [22]. In Uganda, the use of ICTs to access information was related to access to loans and location to urban centers, and in contrast to the study by Ogutu et al. [22], age was negatively correlated with information access through ICTs [23]. Abebe et al. [24] also found a positive relationship between the education level of the household's head and the adoption of improved potato varieties in Ethiopia. Additionally, institutions have an important role in the innovation adoption process. Research from Malawi links the lack of fertilizer use to the failure of government to take into account the needs of farmers [25].

With the advent of social network analysis and its widespread use, beginning in the mid-1950s, researchers began to examine the role of networks in information access and adoption decisions (e.g., [26,27]). Social networks are complex, self-organizing systems that describe dyadic ties and social interactions between individuals [28]. Rather than just considering the individual characteristics of actors, theories of social networks examine the structure of relationships, including those between individuals, informal and formal groups, and organizations [29]. While strong ties (intimate relationships in which individuals rely on others for a number of purposes) often provide a sense of security, weak ties (transitory, often single-purpose, interactions between individuals) create a broader network range compared to strong ties, as they allow individuals to have greater access to information and outside networks [16]. Conceptually, strong and weak ties are similar to bonding and bridging or linking social capital [30]. Building on Granovetter's work [16], Valente [31] describes the process of innovation adoption through weak ties, paying special attention to opinion leaders and arguing that individuals base their adoption decisions on their direct interactions with others in a social network.

An individual's location within a network, however, can also serve as a limiting factor to the quantity and quality of information they receive. Abrahamson and Rosenkopf [32] argue that both network links and idiosyncrasies within a network can explain the diffusion process, suggesting internal boundaries segment networks and serve as a barrier to information. Network segmentation was also offered as a reason for differing contraceptive diffusion rates between two villages in Bangladesh, as it is "the tendency of social norms to influence behavior within relatively bounded, local subgroups of a social system rather than the system as a whole" [14]. Increased communication beyond place-based interactions, similar to that provided by ICTs, could override network barriers, especially for geographically restricted communities. ICTs have been studied as both an innovation and a factor in the diffusion process of other innovations [33]. The relationship between ICTs and agriculture input adoption remains limited, although notable examples do exist, such as a recent study that found household access to radio and television was correlated with agricultural input use in Ethiopia [24].

The effects of ICTs on social networks have been noted by a number of researchers. Sheller [34] lends the term "gelling socialities" to describe the ability of mobile phones to allow users to move in between various social contexts. Building on Sheller's work, and the importance of weak ties proposed by Granovetter [16], Dickinson et al. [35] argues that theories of network structure benefit from the

inclusion of communication as a network component. Burt's research [9] on innovation and social networks indicates the importance of individuals situated near "structural holes" and argues that communication, especially in the modern world, is a key component of innovation. A number of studies have supported the advantages that ICTs provide restricted communities. Wasserman and Faust [36] note the potential of ICTs to foster social networks between smallholder farmers. A 2007 study, which examined the relationship between economic growth and mobile phone use by fishers in India, found that mobile phone use was related to a decreased feeling of isolation [37]. The link between ICTs and information hubs was also suggested by a study on rural radio in Benin, which found a relationship between participatory radio programming and farmer access to agriculture experts [38].

Researchers that examine the relationship between ICTs and social networks are far from consensus on whether ICTs support, weaken, or simply reinforce networks. Research examining sociability or the combination of relationships or interactions that make up a society has found a positive relationship between possession of a computer, mobile phone, and access to the internet with some forms of sociability, but found a decrease in in-person visits with family and friends [17]. In an examination of network diversity, Hampton et al. [39] found an additive effect between participation in traditional settings (e.g., knowing one's neighbor and attending religious services) and network diversity; on the other hand, ICTs had a positive but indirect association with network diversity. Similar to social networks, social capital requires social interactions or transactions based on reciprocity, cooperation, and trust [40]. Building on Nahapiet and Ghoshal's model of social capital [41], which includes structural, cognitive, and relational dimensions, Hazleton and Kennan [42] substitute a communication dimension in place of a cognitive one, emphasizing the essential nature of communication in the social capital model.

The importance of social networks and ICTs for information access, innovation communication, and diffusion can also be situated within broader community settings. Tönnies [43] described social ties within the context of *Gemeinschaft* and *Gesellschaft*, which generally translates to "community and society." *Gemeinschaft* refers to the community setting, where relationships, and similarly belief systems and values, are more homogenous. Contrary to this, *Gesellschaft* describes the formal rules and impersonal relationships (e.g., weak ties) found within a structured, commerce-based society. The use of an interactional community perspective can illustrate the degree to which these various components influence the processes and dynamics underpinning community [44]. Information exchange and peer influences through general community interactions also provide an important angle from which to understand individuals' innovation adoption.

As indicated by the current literature, the process of innovation diffusion is multifaceted and dynamic. Early research on diffusion theory investigated the relationship between the characteristics of both the innovation and users on diffusion rates. The use of social network analysis offered researchers a new way to conceptualize individual and institutional relationships. The importance of various types of network ties and shapes became apparent as researchers investigated information channels within networks. The use of ICTs, especially access to new forms of communication technologies, have become an important component of understanding these information channels. Nevertheless, thus far, there is limited research on the interaction effect of ICTs and information access through social networks on innovation adoption. Finally, community participation and interaction add another dimension of social networks and information processes related to innovation diffusion. This research strives to understand the associations between adoption decisions and information access through ICTs, social networks, and community interaction using data collected from four districts throughout Uganda. Building off theories of innovation diffusion, social networks, and community interactions, this study explored the role of multilevel information processes in innovation adoption.

### 3. Materials and Methods

#### 3.1. Study Communities

This study aimed to evaluate the role of information and interaction processes on input adoption by collecting qualitative and quantitative data through semistructured household surveys in four villages within the Mbale (East), Lira (North), Masaka (Central), and Kabale (Southwest) districts of Uganda (see Figure 1). These districts were selected based on advice from local experts on the types of agriculture practiced and the geographic locations in order to improve the representativeness of the final sample of study communities. Subsequent sub-districts were selected based on their proximity to district centers, while villages were in turn selected within the study sub-districts [45]. The field data was collected between October and December 2016. Village 1, found in the subdistrict of Busiu, is located east of the urban center of Mbale. Major crops grown in the area include maize, beans, groundnuts, cassava, matoke, and coffee. While agriculture is the primary source of income for a majority of the population, the district also boasts a small but growing tourism industry. Village 2 is situated outside of Lira Town in the subdistrict of Ngetta, located in north Uganda. The village is located near an agriculture institute, which often provided free inputs to households near the main road so they could serve as demonstration plots. Some farmers also saw the agriculture institute as a source of information, and visited it when they were having trouble with their own crops. Major crops grown in village 2 include soy and rice. Village 3, located in Kabale District, is situated in the southwestern region of Uganda, bordering Rwanda. The altitude in Kabale ranges from 3999 to 7700 feet above sea level. With a daily average temperature of about 64 degrees Fahrenheit, the climate in Kabale is much cooler compared to the rest of the country. A much more diversified range of crops were grown in village 3, with major crops including beans, sweet potatoes, cabbage, Irish potatoes, and sorghum. Finally, village 4 is situated in the central region of Uganda in Masaka District. Major crops grown in the area include maize, beans, and coffee. Most of the households in Mbale engage in agriculture as a primary source of income. Recognizing this, the local government has identified the need to enhance agriculture production, citing the potential of improved animal and crop varieties as an intensification method [46].



**Figure 1.** Map of the study sites (1:10,000,000 scale). The map was created using ArcGIS and data from the World Resource Institute (<https://www.wri.org/resources/data-sets/uganda-gis-data>).

### 3.2. Survey Administration and Measurement of Major Variables

Research began with a site visit to each sub-district, including at least two focus groups with members of farmers' groups at each site (for a total of nine focus groups). This initial research allowed for the collection of background data on each region and an opportunity to meet with local leaders. Findings from focus groups were used to develop and refine the survey instrument. Household surveys were conducted during follow-up visits to the four study villages. Beginning with a randomly selected house on the main road, the principle investigator, along with a translator fluent in the local language, administered the surveys by visiting every third household. A similar process was followed further into each village so as to capture households that were not located on a main road. Approximately 215 houses were contacted, with 12 households skipped because nobody 18 or older was available or the household did not participate in crop-based agriculture. Interviews took roughly between 45 min to 1 h to complete.

The survey began by collecting sociodemographic variables about the respondent, including: age, gender (male coded "0" and female coded "1"), level of education (number of years of school), and comparison of income (income compared to others in local area: 1 = lower, 2 = about the same, or 3 = higher). A comparison of income was selected in lieu of a raw number for household income due to the lack of records and consistent income that most households experienced. Respondents were also asked about the size of their household, including number of adults and children, the size of their farm, and the types of crops they grew. Agriculture input use was gauged by asking if participant's household had used fertilizers, herbicides or pesticides, or improved seed varieties in the last year (0 = no, 1 = yes). These categories were then collapsed into one dummy variable, which indicated any input use (coded "1") or no input use (coded "0"). For those that reported that they had not used an input in the past year, a follow-up question asked for the main reason why that input was not being used.

Information on access to ICTs (0 = no, 1 = yes), including mobile phones, radio, television, computers, and the internet, was also collected. Cell phone access was focused on in the data analysis due to recent literature suggesting the increasing importance and prevalence of cell phones in information access by smallholder farmers, as well as the potential interaction effect between cell phone use and social-network-based information access. Because of the particular interest of the interaction between cell phones and social networks, participants that reported having access to a mobile phone were also asked about their cell phone use, including if they used their phone to contact agricultural dealers, buyers, government or extension agents, or non-governmental organization (NGO) representatives. Participants were also asked if they believed having a cell phone increased their communication with their buyers, government or extension agents, or other farmers. Agriculture information accessed through social networks was gauged by asking respondents about their sources of information or agriculture advice (0 = no, 1 = yes), such as parents, siblings, adult children, close friends, members of farmer's groups or cooperatives, and governmental officials [47]. These connections were then further identified as either strong or weak ties, with family members and close friends labeled as strong ties and connections with neighbors, farmer group members, extension agents, government officials, and NGO representatives considered weak ties. The data on information access through social ties was aggregated into two separate variables, namely the total number of information sources through strong ties and the total number of information sources through weak ties, by summing the answers to individual responses. Finally, community interaction, operationalized as the involvement in local community activities or events in the survey, was measured as a self-described point on a five-point scale, with one being the lowest level of involvement and five being the highest.

### 3.3. Analytic Procedures

Qualitative data was recorded by the investigator with the aid of a translator during interviews. The data was then thematically analyzed and incorporated in the interpretation and discussion of quantitative results. Quantitative data was analyzed with Stata, SPSS Statistics, and R software. The

presence of significant correlations among major variables was tested accordingly using a chi-square test (for relations between dichotomous variables), an independent *t*-test (for relations between dichotomous and numerical variables), and a Pearson's *r* statistic (for relations between numerical variables). After examining the bivariate correlations between major variables, logistic regression was used to further evaluate the effects of information access gained through the use of cell phones, social networks, and community interaction on agricultural input use (one aggregate and three specific input use variables), while controlling for the effects of main demographic indicators, including gender, age, education, and relative income. The interactional effects between access to a cell phone and the numbers of strong- and weak-tie information sources on input use were also tested. Non-significant interaction terms were removed from the models for parsimony purposes. The analysis set a 0.10 significance threshold instead of the more conventional 0.05 significance level due to the exploratory nature of this study. The consideration of cell phones, social networks, and community relationships allowed for a more comprehensive understanding of innovation diffusion, moving away from previous research, which had focused on single characteristics to explain diffusion. The interactional component of this research was included to incorporate multiple factors when considering why individuals make an adoption choice and to address the research gap in the interactions between ICTs and social networks regarding information access.

## 4. Results

### 4.1. Descriptive Analysis

#### 4.1.1. Basic Demographics

Of the 203 respondents, 32.5 percent of the sample were men and 67.5 percent were women. The high percentage of female respondents was not necessarily indicative of a female-headed household, as many of the women respondents reported that their husbands spent portions of the year living outside of the household due to work. The survey did not capture the sharing of resources between spouses. The age of respondents ranged from 18 to 84 years, with an average of 26 years old. The mean education level was 6.9 years, with men reporting relatively higher education levels (7.9 years) compared to women (6.4 years). When asked about their income compared to others in the area, a little more than half of respondents (53.2 percent) reporting earning less than those around them, 30.5 percent said they earned about the same, and 12.3 percent said they earned more than those around them. The average farm size was small at about two acres, meaning that farmers often had to rely on renting or planting on someone else's property in order to meet household needs. Households averaged 6.1 people, including an average of 2.9 adults and 3.2 children. The majority of crops grown for sale were beans (grown by 42.9 percent of respondents), maize (41.9 percent), and coffee (22.1 percent), especially in the districts of Mbale and Masaka. In Kabale, due to having a distinct climate compared to much of the country, the types of crops grown were much more diversified, with cabbage, potatoes, and tomatoes making up the bulk of the produce grown for sale.

#### 4.1.2. Input Use

The most common type of input used was improved seed varieties, with 65.0 percent of farmers reporting that they had used them in the last year [48]. Herbicides and pesticides were the second most commonly used input, with 61.0 percent of respondents using one of these products during the last year. The least used input was fertilizer, with 34.5 percent of respondents using the product in the last year. Input use was limited most significantly by cost, which could include actual cost of these products, as well as cost to access the products (i.e., travel expenses, time needed to travel, etc.). Of the forty-seven respondents that reported using no agro-chemical inputs or improved seed varieties in the last year, nearly 81.0 percent cited cost as a limiting factor. Additional factors that restricted input use included the belief that the chemicals found in herbicides, pesticides, or synthetic fertilizers

were harmful for the soil. Women reported being especially wary of pesticides due to their fear of the chemicals posing a threat to their reproductive health. Input use also differed significantly between villages. Respondents from Lira reported using the least amount of inputs and those from Masaka reported using the most. Others reported that they did not see a reason to use inputs, explaining a lack of pests or fertile soil. The lack of information or access was a problem for nearly 11.0 percent of respondents.

#### 4.1.3. Access to ICTs

Participants reported that their most accessed communication technologies included mobile phones (78.3 percent of respondents), radio (76.9 percent), and television (17.7 percent). Access to computers and the internet were the most limited, with 6.4 percent of respondents reporting that they had access to the internet and 2.5 percent reporting access to a computer. The vast majority of cell phone use for agriculture-specific activities was to contact buyers, with 47.1 percent of respondents with access to a mobile phone reporting that they called their buyers to schedule pick-up times. About a quarter of respondents used their cell phone to contact agricultural dealers, and just 16.3 percent used their phone to communicate with extension agents on a regular basis. A little less than 13.0 percent of respondents with access to a mobile phone reported ever using their phones to access SMS-based agriculture information. Moreover, 79.6 percent agreed that having a cell phone increased how often they communicated with other farmers, 49.7 percent agreed that access to a cell phone increased their communication with their buyers, and 21.3 percent agreed that access to a mobile phone increased how often they communicated with government or extension agents.

#### 4.1.4. Social-Tie Information Sources and Community Interaction

Survey respondents reported a wide range of agriculture advice and information sources, with siblings being the most relied on strong-tie information source; 58.1 percent of respondents reporting they received agriculture information from their brothers, 57.1 percent from sisters, 35.5 percent from sisters-in-law, and 34.0 percent from brothers-in-law. Relationships with parents, especially mothers, also yielded agriculture information, with 36.0 percent of respondents reporting they received agriculture information from their mother. For weak-tie information sources, the majority of respondents (77.3 percent) received agriculture information from their neighbors, 47.3 percent from agricultural dealers, and 40.4 percent from their membership in a farmers' group or cooperative. Overall, respondents reported an average of 4.5 strong-tie information sources and 2.2 weak-tie information sources. An important source of weak ties included farmers' group or cooperatives, with 39.6 percent of respondents reported that they belonged to one. The top reasons for belonging to a farmer's group or cooperative included savings and shared knowledge, with 47.0 percent of group members reporting this as their reason for membership. Additional reasons for belonging to such groups include social welfare and support, collective marketing, and group purchases. As might be expected, participants with access to a cell phone used it most often to keep in contact with strong ties, especially those that lived far away. Finally, regarding participants' level of community interaction, the average community interaction score was 3.2 on a 1–5 point scale (1 = lowest level of interaction to 5 = highest level of interaction).

#### 4.2. Bivariate Analysis

Table 1 shows the relationships among input use measures and variables that represent significant channels of information for smallholder farmers, including ICTs (particularly cell phones), information sources based on social networks, and community interaction. There were significant correlations between the adoptions of various input types, suggesting that farmers that used one type of input were more likely to adopt additional inputs. Results indicated that the four input use variables were significantly and positively correlated with access to cell phones, numbers of strong- or weak-tie information sources, and community interaction (except for the correlation between fertilizer use and

the number of strong-tie information sources), suggesting that households with access to a broad range of information processes were more likely to adopt inputs. There was a positive correlation between cell phone access, social-network-based information sources, and community interaction. Negative *t*-test statistics in Table 1 actually indicate positive relationships between relevant variables (see the table footnotes for further detail). Demographic variables were also tested against major study variables. A positive correlation was found between level of education and comparison of income, and all types of input use and cell phone access. Analysis also indicated a positive relationship between age and improved seed use. There was no relationship between the community interaction score and any demographic variables, with the exception of gender, where female respondents reported a higher level of community involvement.

**Table 1.** Bivariate correlations between major variables.

Variables	1	2	3	4	5	6	7
1. Any input use							
2. Fertilizer use	0.398 ****a						
3. Herbicide/pesticide use	0.687 ****a	0.473 ****a					
4. Improved seed use	0.748 ****a	0.453 ****a	0.453 ****a				
5. Access to mobile phone	0.307 ****a	0.242 ****a	0.242 ****a	0.191 ****a			
6. Number of strong-tie info sources	-1.975 **b	-1.095 <sup>b</sup>	-2.275 **b	-2.269 **b	-1.990 **b		
7. Number of weak-tie info sources	-7.509 ***b	-3.196 ***b	-7.485 ***b	-6.264 ***b	-1.707 *b	0.448 ****c	
8. Community interaction	-2.619 **b	-2.002 **b	-3.391 ***b	-2.243 **b	-4.166 ***b	0.214 ****c	0.369 ****c

Note: (\*)  $p < 0.10$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$  \*\*\*  $p < 0.001$ ; <sup>a</sup> given as Cramer's V statistics; <sup>b</sup> given as independent *t*-test statistics. A negative *t* value means the second group ("1" yes) has a higher mean than the first group ("0" no); <sup>c</sup> given as Pearson's *r* coefficients.

#### 4.3. Multivariate Modeling

A series of logistic regression models were computed to better understand the relationships between major variables (see Tables 2 and 3). The variance inflation factors of independent variables, ranging from 1.118 to 1.416, indicated no multicollinearity. Access to a cell phone and the number of weak-tie information sources had positive effects in the models for all types of input use. More specifically, with all else being equal, mobile phone access can lead to an increase of 46.4%, 20.1%, 14.2%, and 21.5% in the probability of using fertilizer, herbicides or pesticides, improved seed, and any of these inputs, respectively. By contrast, information access through strong ties was negatively associated with the use of fertilizer, herbicide or pesticide, while the level of community interaction was not significant in the analysis. The results can also shed light on the associations between individual sociodemographic characteristics and agricultural input use. Age and relative higher income were significantly and positively related to the adoption of herbicides or pesticides, improved seeds, or any agriculture input. Gender and education level, on the other hand, were non-significant in their effects on all types of input use.

Interaction effects were run for all four models, but significant results were only found between access to a cell phone and strong- or weak-tie information sources in the regression on fertilizer use (see Model 1 in Table 2). These results indicate cell phone access may mitigate the constraints of strong-tie information networks on fertilizer use, and that weak ties were relatively less important to fertilizer use for respondents with cell phone access than for those with no access. On average, every one unit increase in the number of strong-tie information sources is accompanied with a decrease by 12.1% in the likelihood of adoption for respondents without cell phone access, but with a slight increase of about 0.3% for those mobile phone users. Accordingly, for every unit increase in the number of weak-tie information sources, the probability of fertilizer use increases by about 4.7% and 33.4%, respectively, for respondents with and without access to cell phones.

Table 2. Logistic regression models of different input uses.

Variables	Model 1: Fertilizer Use		Model 2: Herbicide/Pesticide Use		Model 3: Improved Seed Use	
	Coefficients	Average Marginal Effect <sup>a</sup>	Coefficients	Average Marginal Effect	Coefficients	Average Marginal Effect
<b>Sociodemographic Controls</b>						
Age	−0.009	−0.002	−0.008	−0.001	0.041 **	0.007 ***
Gender	−0.156	−0.031	0.058	0.010	−0.222	−0.036
Level of education	0.034	0.007	−0.017	−0.003	0.028	0.005
Income comparison (same) <sup>b</sup>	0.377	0.076	0.121	0.022	0.509	0.090
Income comparison (higher) <sup>b</sup>	0.376	0.076	1.465 *	0.226*	2.557 *	0.326 ***
<b>Independent Variables</b>						
Access to mobile phone	2.320 <sup>c</sup>	0.464 <sup>c</sup>	1.201 *	0.201 **	0.873(*)	0.142 (*)
Number of strong-tie information sources	−0.604 (*) <sup>d</sup>	−0.121 (*) <sup>d</sup>	−0.137 (*)	−0.023 (*)	0.004	0.001
Number of weak-tie information sources	1.671 * <sup>d</sup>	0.334 ** <sup>d</sup>	0.969 ***	0.162 ***	0.745 ***	0.121 ***
Community interaction	−0.035	−0.007	0.009	0.002	−0.132	−0.021
Interaction between cell phone and strong-tie information sources	0.620 (*)	0.124 (*)	— <sup>e</sup>	—	—	—
Interaction between cell phone and weak-tie information sources	−1.436 *	−0.287 *	—	—	—	—
<b>Pseudo R<sup>2</sup> <sup>f</sup></b>		0.191 **		0.366 ***		0.365 ***
<b>Cases</b>		190		190		190

Note: (\*)  $p < 0.10$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ; <sup>a</sup> average marginal effect (AME) indicates the average change in probability with one unit change in a control or independent variable; <sup>b</sup> relative lower income is the reference category; <sup>c</sup> not statistically significant due to interaction terms, but has the largest AME among all four models; <sup>d</sup> the combined AMEs of strong-tie and weak-tie information sources for respondents with cell phone access are:  $-0.121 + 0.124 = 0.003$ , and  $0.334 - 0.287 = 0.047$ , respectively. Aggregates AMEs are the same with the two here for respondents with no cell phone access; <sup>e</sup> non-significant interaction terms were removed from the analysis; <sup>f</sup> given as Nagelkerke R<sup>2</sup>. All models are statistically significant based on the Omnibus tests of model coefficients.

Table 3. Logistic regression model of any input use.

Variables	Model 4: Use of Any Input	
	Coefficients	Average Marginal Effect <sup>a</sup>
<b>Sociodemographic Controls</b>		
Age	0.031 *	0.004 *
Gender	−0.285	−0.033
Level of education	−0.005	−0.001
Income comparison (same) <sup>b</sup>	0.549	0.067
Income comparison (higher) <sup>b</sup>	1.578	0.157 *
<b>Independent Variables</b>		
Access to mobile phone	1.842 ***	0.215 ***
Number of strong-tie information sources	−0.121	−0.014
Number of weak-tie information sources	1.172 ***	0.137 ***
Community interaction	−0.107	−0.013
<b>Pseudo R<sup>2</sup> <sup>c</sup></b>		0.405 ***
<b>Cases</b>		190

Note: (\*)  $p < 0.10$ ; \*  $p < 0.05$ ; \*\*  $p < 0.01$ ; \*\*\*  $p < 0.001$ ; <sup>a</sup> average marginal effect (AME) indicates the average change in probability with one unit change in a control or independent variable; <sup>b</sup> relative lower income is the reference category; <sup>c</sup> given as Nagelkerke R<sup>2</sup>. The model is statistically significant based on the Omnibus tests of model coefficients.

## 5. Discussion

Communication is a key tenant of innovation diffusion theory [9,10], as it provides information to potential adopters, allowing them to learn about the existence of an innovation, its benefits, and how to use it. Building on previous approaches that stress the importance of communication and social interaction in the process of innovation adoption [11–17], this study examined the relationship between input adoption and farmers' information and interaction processes, with the goal of understanding how different information channels could foster an environment that is conducive for input adoption. Findings indicate a significant relationship between input adoption and increased information access, particularly through cell phone access and weak-tie information sources. Taken together, these results could contribute to solutions to increasing yields throughout SSA.

Overall, farmers surveyed for this study also showed a willingness to adopt agriculture inputs. Given the small plot size of most farmers, input use is a key method of increasing agriculture production, and some inputs, especially improved seed varieties, may help farmers adapt to climate change through drought- and disease-resistant crops. Findings from this research revealed high overall use of inputs by respondents, especially when compared to the country's average [19]. Many respondents, however, used inputs in a haphazard manner. For example, several used improved seed varieties because the seeds were given to them free of charge through government programs, especially the Operation Wealth Creation (OWC) program, suggesting that farmers are interested in using inputs, but may not have the resources or knowledge to use them consistently. For farmers interested in adopting inputs, income was the major barrier to adoption, especially purchasing inputs on a regular basis, as cash was often not available when needed. In this case, increased access to credit could play a major role in bolstering input use. There was also a gap in the technical training of farmers. In seed dispersion programs, such as OWC, farmers reported that they were not always certain of the differences of the improved seeds they received or why they were selected to receive the seeds. The irregular dispersion of inputs, coupled with the lack of access to extension workers and information, could lead to improper use of inputs, potentially disrupting livelihoods and making farmers less likely to risk adopting new inputs in the future.

Results from this study indicate the continued and growing prominence of ICTs as facilitators for information access and agricultural input adoption [22–24]. The proliferation of cell phone access in Uganda is a testament to the potential of new information channels and the willingness of smallholder farmers to adopt new technologies. As cell phone access across the continent continues to rise, with nearly 75 percent of the population having access to one, it is an important technology to consider when planning for information diffusion. One constraint determined by this research, however, is farmers' limited use of cell phones as a direct method of receiving agriculture information, putting into question the likelihood of success for widespread SMS- or hotline-based information services for agriculture information dissemination. At the same time, radio remains an essential method of diffusing agriculture information. Another important characteristic of radio is that unlike a mobile phone, it can be used by more than one person at a time, demonstrating the importance of continuing to utilize multiple ICTs when dispersing information. As evidenced by research on innovation diffusion, innovations that are not compatible with established behaviors, institutions, or social systems are not likely to be adopted, regardless of the advantages they may offer [10,24,49–51]. In this case, the lack of precedence for using mobile phones to access specific agriculture-related questions may serve as a barrier for using the ICT as a conduit for information diffusion. Radio, on the other hand, is a current source of information for many farmers. Using radio and mobile phones in conjunction, such as call-in radio shows, could increase the use of mobile phones as information sources. For instance, in a study conducted by Farm Radio International, a Canadian-based non-profit organization that works with radio stations throughout SSA, farmers that used ICTs to participate in radio programming, either through the design or application of that programming, quadrupled their likelihood of adopting featured agriculture ideas [52]. Overall, the relationship between ICT use and input adoption suggests farmers are leveraging communication technologies to access information, either through interactions with others or through information hubs, such as websites. Given the lack of access to internet, however, it seems more likely that farmers who use their mobile phones to access information are doing so through interactions with others.

In addition to the ICT effect, social networks also played an important role in information access and weak-tie information sources were consistently associated with input adoption in the analysis. Information accessed through weak ties may have allowed farmers to access a broader range of information about inputs, increasing their likelihood of adoption. The relative importance of weak ties is further supported by the lack of significant relationships between strong-tie information sources and input use in most of the multivariate models; as strong ties tend to be homogenous, they are less likely than weak ties to introduce new information into a social network [16,53]. In fact, the analysis revealed strong ties might have an important role in the lack of adoption. Over 90 percent of respondents received agriculture information from a strong-tie member of their social network, such as a family member or close friend. These individuals often lived in close proximity and engaged in similar types of agriculture, potentially limiting the amount of new information that could be shared. This was especially true for fertilizer use, which was the least likely input to be adopted. Farmers that did not use fertilizer reported that the impact of fertilizer on the soil was a main reason for avoiding it. The majority of those that reported the damaging impacts of fertilizer on soil had never used fertilizer and had often received information about the harmful effects of it through strong-tie communication channels.

These findings suggest the importance of diverse information sources, most often found through weak ties, which allow farmers to weigh the benefits and drawbacks of adopting fertilizer. Farmers that primarily depended on strong ties within their social networks to access information are often constrained by the amount and type of information available to them. Again, as only the logistic regression model of fertilizer use showed a significant interaction effect of social-tie information sources and cell phone access, it suggests the lessened role that both strong and weak ties play in fertilizer adoption in the increasing presence of ICTs.

Furthermore, while community interaction alone was not a significant factor for input adoption, its significance in the bivariate analysis, coupled with its relationship with weak-tie information

sources, suggests an indirect route to adoption decisions. As community interactions underpin the social relationships that create community [44], this research implies the potential for information dissemination between residents of a community and their collective action. With the goal of increased agriculture yields touted at various levels of international, national, and local governments, as well as institutions of all sizes, the community interaction process can provide another important component of targeted information campaigns.

Increasing information channels and the confluence between them, including technology-based tools, social networks, and community interaction, allows farmers to access and make sense of more information. The increased presence of ICTs, especially cell phones and (albeit extremely limited) internet access, offer smallholder farmers new avenues through which to communicate with experts, other farmers, and stakeholders, such as their customers. At the same time, it is important to note the overwhelming reliance on non-agriculture-specific resources for agriculture information, which may limit input adoption. As farmers with a higher number of weak-tie information sources and access to a cell phone were more likely to adopt a wide range of inputs, this research suggests the need for multiple information dissemination approaches in adoption decisions. While ICTs allow farmers to move between various information sources, shifting between in-person experts (e.g., extension agents and ICT-based information sources), social networks, and the communities they make up are also integral to the adoption process. Attempts to successfully diffuse information about inputs should take into consideration not just individual information avenues, but also how various processes may interact and synergize with each other.

## 6. Conclusions and Implications

The relationship between information access and innovation diffusion was supported by this study, with the roles of access to cell phones and weak ties being especially important for the innovation adoption of smallholder farmers. Our analysis helps bridge the gap between new technologies, such as ICTs, and longstanding theories of innovation diffusion, social networks, and community interactions. These results stress the complicated nature of innovation adoption and the necessity of incorporating multiple levels of information and interaction processes when describing innovation diffusion patterns. For instance, the focus on cell phone use as a development tool may overlook key interaction processes that provide farmers with information. Findings from this analysis suggest that an integrated and comprehensive approach to understanding innovation diffusion should include a multi-layered process. In other words, while cell phones are useful tools, their presence alone is not enough to meet development goals. Instead, considering the benefits of cell phones along with social networks and the community interactions that farmers take part in may provide community leaders and development professionals with more efficient strategies for distributing information and encouraging innovation adoption.

The high rate of cell phone access and the growing comfort level that farmers have in using them to obtain information suggests that farmers will continue to adopt and utilize ICTs for their information needs and input adoption decisions. This is an especially exciting proposition, as access to the internet is becoming more prevalent. Our findings revealed a consistent relationship between ICT use and input adoption, suggesting that farmers with access to ICTs, especially two-way forms of communication such as cell phones, have a greater opportunity to interact with their social network ties and broaden their access to communication channels in local communities. Broadened access and use of ICTs by smallholder farmers underscores the importance of these tools in disseminating information and promoting communication between farmers and experts. Increased access to information, however, can also serve as a hindrance to innovation adoption, as indicated through adoption patterns of fertilizer. Negative information about an input may dissuade farmers from trying it in the first place, especially if that information comes from a trusted source. As the role of ICTs continue to grow in rural areas of SSA, tools and education to assist farmers with making sense of multiple sources of data and information may become necessary.

Weak ties also exhibited an especially significant relationship with input adoption, further illustrating their importance in introducing new sources and types of information within a social network. Farmers with fewer weak ties or those overly dependent on strong ties for information could limit their ability to access new information and come into contact with new information sources. The strategic targeting of information to community or thought leaders could not only offer a more cost- and time-effective method of filtering information throughout a network, but could also help information reach farmers with closed-off networks. Additionally, this research highlights the need for development professionals to proactively incorporate ICTs into their practices. The significant negative interaction effect between cell phone access and the number of weak-tie information sources suggests that some long-standing sources of information, such as extension agents, could become less important to farmers as they use their cell phones to obtain information more intensively from fewer sources.

While this research supports the importance of information and communication for innovation adoption, it also suggests several additional areas of research that could improve understanding of these processes. For instance, focusing on gendered differences in information access could provide further insights on the relationship between information access and agricultural input use. Additionally, although farmers were asked about their membership in farmers' group and cooperatives, and although this was considered a weak-tie source, the process of information dissemination through these groups was not specifically examined. A deeper understanding of these information conduits could further inform the innovation diffusion framework, especially in the SSA context. Finally, due to budget constraints, the selection of sub-districts was based on near district centers. Therefore, the sub-districts tended to be peri-urban. Future research could examine information flows, networks, and interactions in more remote regions.

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