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Knowledge Diffusion and the Adoption of Fertilizer Microdosing in Northwest Benin

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Abstract

Soil degradation and low crop productivity negatively affect the food security of smallholder farmers in West Africa. Various agricultural techniques have been developed as components of food security interventions, but their effectiveness in addressing food insecurity in part depends upon farmers' abilities to adopt these techniques. In this paper we present the results of a social network analysis that tracked the flow of information on fertilizer microdosing from our Project Research team (PRs) to Demonstration Farmers (DFs), and from DFs to other Village Farmers (VF) in the village of Koumagou B in northwest Benin. Our findings indicate that both adoption and project awareness of microdosing were low following two years of field trails. Overall, the DFs failed to spread information or promote learning over the trial period, with only 3 of 20 DFs diffusing knowledge to a significant degree (i.e., out-degree >5). After 2 years of trials, the efforts of PRs and DFs were insufficient to mobilize the network to adopt the microdosing technique.

Keywords: agricultural technology adoption, demonstration farmers, social network analysis, food security, West Africa

1. Introduction

For the majority of Sub-Saharan Africa (SSA), agriculture remains the backbone of the economy, employing the majority of the population and providing roughly 70% of Africa's total food supply (IFAD and UNEP, 2013). Smallholder farmers—defined generally as those farming on two hectares or less—comprise 80% of all farms in Africa (Delaney et al., 2011). Smallholder farmers work the land to provide enough food to satisfy domestic household needs and ideally are left with some surplus to sell through local or regional markets. Due to small land holdings, coupled with increasing population pressures, smallholder farmers cannot rely on agricultural extensification or long fallow periods to increase agricultural output, but rather must intensify production on existing agricultural lands (Bationo et al., 1998). Although a necessary condition of improving SSA agriculture (Vanlauwe et al., 2010), intensification has led to environmental degradation, such as decreasing ground and surface water quality, and declining soil fertility (Tilman et al., 2002). The effects of agricultural intensification on soil fertility in particular have contributed to the depreciation of farmers' natural capital in ways that threaten the regenerative capacity of the land and puts at risk the livelihoods of farming households. To avoid these conditions, farmers struggle to find a balance between intensifying agricultural production and minimizing declines of soil fertility. In pursuit of this balance, farmers employ a number of strategies collectively termed Integrated Soil Fertility Management (ISFM), which include the application of organic and inorganic amendments (Vanlauwe et al., 2010), crop rotation, intercropping, and the use of nitrogen-fixing crops in rotations and as an intercrop (Place et al., 2003).

In terms of fertilizer applications, the United Nation's Food and Agriculture Organization (FAO) recommends the 'judicious use of mineral fertilizers,' using precision approaches to promote soil health (Collette et al., 2011). The targeted application of small quantities of fertilizer has been promoted as a sustainable 'step up the ladder' of agricultural intensification (Aune & Bationo, 2008). While recommended dosage levels have been determined (ICRISAT, 2009;Vanlauwe et al., 2010), these levels are often unaffordable for many rural farmers, or unattainable given limited or sporadic supply of fertilizer in some countries. In response, a technique known as fertilizer microdosing has been developed that involves the precise in soil application of small quantities of inorganic fertilizer (a third to a fourth of the recommended dosage) after crop emergence. The primary differences between microdosing and the recommended dosage are (a) the quantity-less than six grams of fertilizer (equivalent to a bottle-cap full or a three-finger pinch) placed at the base of each plant (b) the timing-microdosing requiring an earlier application after planting and (c) the application method-microdosing is placed into the soil at an optimized depth and distance from the crop. Previous studies in SSA, and West Africa in particular, have found microdosing to be more economical compared to application of recommended dosage levels, while the reduced application amounts have helped to overcome obstacles associated with access and supply of fertilizer (Camara et al., 2013; Hayashi et al., 2008; Tabo et al., 2011; Twomlow et al., 2010). Among other West African countries, microdosing was first introduced in Niger, Mali, and Burkina Faso as early as 1998, and has since been widely promoted to smallholder farmers (Tabo et al., 2011). However, microdosing has received limited uptake in other regions of SSA, particularly in Benin.

To determine why microdosing has not been widely adopted in Benin, a multidisciplinary research team from Benin and Canada collaborated on the Integrated Nutrient and Water Management project (INuWaM). Initiated in 2011, the project field-tested the microdosing technique in six villages in northwest Benin, after which members of the research team provided periodic technical assistance over three growing seasons that spanned a two-year period. The intention of the two-year trial was for villagers to observe the demonstration plots and inquire about the application of the microdosing technique. At the end of each growing season, the yields from the demonstration plots were weighed for the community to see. Twenty Demonstration Farmers (DFs) were also trained in the microdosing technique and were expected to share information about microdosing with other village farmers, who might then recognize the benefits and adopt the technique for their own lands. It was felt that the involvement of DFs would facilitate the dissemination of information through existing social networks within the village.

Our approach was informed by other research that has found that the adoption of new agricultural technologies is dependent on farmers' access to credible information that is considered advantageous to their livelihoods (Feder & Slade, 1984). Farmers gain access to information on new technologies through a range of sources—technical training, public meetings, oral transmission, media, and extension technicians—all of which influence the farmers' decision to trust a new technology. Through these sources of information, farmers engage in processes of 'incomplete learning' where the proportional value of adoption is weighed against the potential risks involved (Conley & Udry, 2001). This approach differs considerably from 'learning by doing' where accurate knowledge of the performance of a technology under local conditions are known, for instance in relation to labour demand or effects stemming from soil quality. The decision to adopt a new technology is also influenced by observing the experimentation and innovations of other farmers. In fact, farmers in Africa typically cite other farmers as their most trusted and reliable source of information (Magnan et al., 2015; Rogers, 2010), and one's decision to adopt a new technology is positively affected by the experience of others (Foster & Rosenzweig, 1995; Todo et al., 2012). For example, Conley and Udry (2001) found that when Ghanaian farmers improved yields by adjusting fertilizer use, other farmers within their respective social networks were more inclined to adopt similar adjustments. The social network of farmers therefore served as a conduit of knowledge that influenced the decision of other farmers to adopt similar adjustments. In this way the decision to adopt a new technology is embedded in, and affected by, a complex web of social relations (Abizaid et al., 2015).

The social networks of farmers are generally comprised of family members, friends, and personal or professional associations who are linked through various ways, such as the flow of information (Natcher, 2015). Because these networks are social in nature, there are benefits of being a part of a network, including access to information and other livelihood benefits. There are also more intangible benefits of network involvement, including trust building and norm formation that can facilitate coordinated actions (Putnam et al., 1993). Lin (2001), however, suggests that it is not merely the network that is important, but rather the actual transmission of information that is embedded within those social relationships that are of most value. In this way personal associations serve as channels through which information, and other forms of material aid can flow. Individuals that are involved in more complex social networks are able to draw on personal networks whose 'actors' have access to a more diverse set of resources than would otherwise be available (Borgatti & Foster, 2003). In these cases, farmers are better positioned to utilize personal connections to gain access to information and other valued resources. One's social network can therefore serve as channels through which individuals or households can access information, thereby allowing farmers to exploit new technologies when they become available. Conversely those farmers that are on margins, or even excluded from social networks, can be characterized as 'network impoverished' (Lahn, 2012), and potentially vulnerable to social and economic exclusion and ecological disruption.

In 2013, two years following the project's inception, our research team returned to one of the six project villages - Koumagou B - to determine the rates to which microdosing had been adopted by village farmers (VFs) and traced the flow of information from Project Researchers (PRs) to DFs and from DFs to other VFs. Through the completion of a social network analysis we identified how information on the microdosing technique permeated through village networks, and if those networks contributed to heightened levels of adoption.

2. Method

This research was conducted in the village of Koumagou B. Located in Northwest Benin, Koumagou B is roughly 16 km from the larger village of Boukoumbé on the Benin/Togo border (Figure 1).

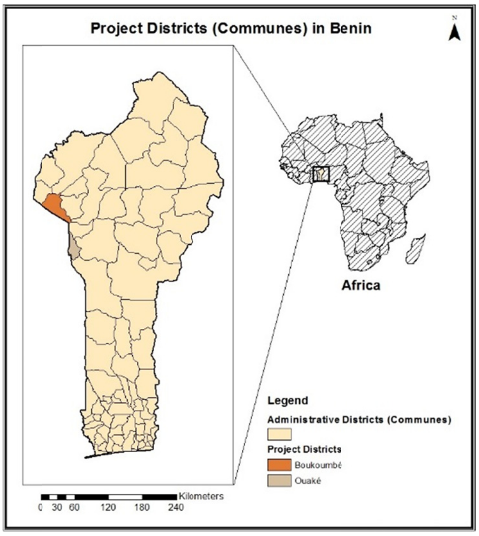


Figure 1. Location of project site in Benin

Koumagou B was chosen as the research site for a number of reasons: 1) it is located in one of the major agro-ecological zones of the Sahel region; 2) the village is located in relative proximity to local and regional markets; 3) there is an existing network of rural development and farmers' organizations that could potentially help to maximize or 'scale-up' the results of the project; and 4) village residents had collaborated with members of the research team in previous research on rainwater harvesting techniques.

The population of Koumagou B is approximately 580, although men regularly leave the village for seasonal employment, including employment opportunities found in Nigeria. The smaller population was an important consideration since it allowed for a complete census to be conducted of all village households (n = 77). This meant that a more context specific data set could be developed. Moser and Barrett (2003), for example, argue that conducting more focused and census-style assessments of single villages and enumerating the precise number of adopters, non-adopters and dis-adopters obviates the possibility of selection bias, which they claim is ubiquitous among adoption studies. Knowler and Bradshaw (2007) similarly argue that there are few, if any, universal variables that can explain adoption across multiple sites, therefore macro adoption studies are in their view, misguided. Rather, studies examining local conditions, with appreciation of the socio-economic and ecological context yield higher returns on research investment. Guided by these recommendations, it was decided that a more detailed analysis of Koumagou B would be conducted in order to gain a deeper appreciation of the factors that either facilitated or impeded adoption. Yet equally important for members of our research team was the opportunity to collaborate with a single village, over an extended period of time, thereby building relationships with village members and establishing a basis for a more respectful and long-term research partnership.

The research project was initiated in 2011, and was launched through a village meeting in Koumagou B that included members of the research team, the village Chief and secretary, and representatives from village households. During this meeting the objectives of the project were presented, as was a request for participants to host demonstration plots on small parcels of their land. The only condition for participation was that the demonstration plot had to be near a road to maximize visibility and encourage information dissemination on the microdosing technique.

Following this initial meeting, the village Chief held another village-only meeting to discuss the project in more detail. Following this meeting a list of volunteer farmers was provided to the research team who were willing to allocate parcels of land as demonstration plots. The list included 20 of the 83 Koumagou B eligible farming households. These 20 households were then given assistance in dividing a parcel of their land into two equal plots of $12m^2$ or $24m^2$, one for the microdosing technique and one for the recommended dosage. The project researchers prescribed the management of each demonstration plot to help ensure standardization. Maize was chosen for the demonstration trials. Farmers did not receive seed from the project but were provided fertilizer in sufficient quantity for the conduct of the trial. The participants received subsequent technical visits from the local project coordinator, who was trained in the microdosing technique.

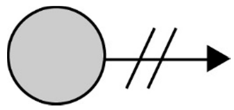
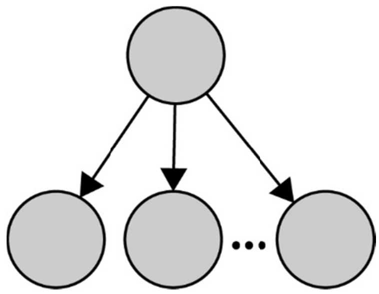
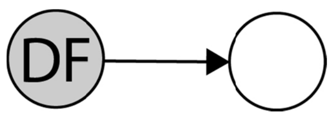
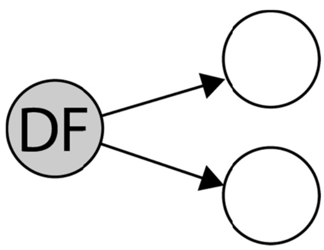
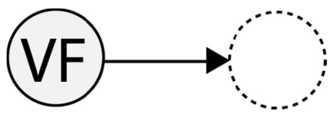
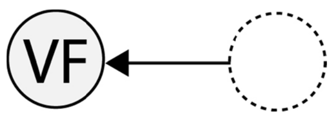
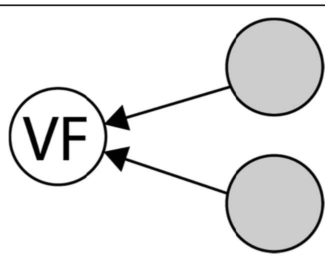
In 2013, following two years of demonstration trials, the research team conducted a census of Koumagou B households to determine the rate at which microsdosing had been adopted. Field research took place between May and August 2013. During this time a household survey was administered to 73 of the 83 village households (95% response rate of 77 contacted households with 4 abstentions). Two members of our research team (1 male and 1 female) administered all surveys in person, with translation provided by the male research team member. This approach allowed for a high response rate as well as the collection of additional information gathered through semi-structured interviews. The survey included detailed questions on household assets and characteristics, including gender, age, labour and household size, education, total cultivatable land, credit, access to inputs, use of communal water as opposed to private water source, and number of spouses. Based on these data indices of household socio-economic status were developed.

There are a number of theoretical and practical advantages to discern household status in network studies. Other research has found that household attributes can affect the flow of information through social networks (Rehman et al., 2013). Those individuals or households with higher socio-economic status can influence the behaviour of others in the network, including the decision to adopt new technologies (Barrett, 2005; Jackson, 2008). In this case, correlated attributes were used to differentiate the socio-economic status of DFs and other VFs, determine how or if that status influenced the flow of information, and identify whether VFs acted on the information they received from DFs.

In addition to identifying household assets, the survey was also used to track the flow of information about the microdosing technique, and knowledge of the microdosing project in general. Heads of households were first asked if they had heard about the microdosing technique and if so, from whom did the information originate? Household-heads were then asked if they then shared that information with others, and if so, with whom. These data were then used in a social network analysis that tracked the flow of information on the microdosing technique. Based on this analysis, a sociogram was created through the use of UCINET and NETDRAW software. Network data were then analyzed using Exponential Random Graph Models (ERGMs) in MPNet software (Wang et al., 2014). The ERGMs are a class of stochastic social network models that can account for complex social structures and processes (Lusher et al., 2013). The ERGM was used to assess the importance of various network effects in producing the observed network. Network effects refer to patterns of social network ties, and ERGMs function as a pattern recognition tool that can help predict why observed relational ties occur and what may be the underlying structural processes driving tie formation (Lusher et al., 2013). The particular strength of ERGMs lies in their ability to treat village social networks as relational and dependent rather than independent, which aligns more appropriately with network theory than standard statistical procedures (Lusher et al., 2013). For our purposes, we examined a number of network effects related to the spread of project information within the village (Table 1). Our focal effects covered a range of possible structural processes leading to the observed network, such as the likelihood of actors to be a popular source of information (e.g., source popularity) and the increased information dissemination expected from DFs versus VFs (e.g., DF sender). Furthermore, we accounted each effect in relation to the other effects by estimating parameters in a model fitted simultaneously with all focal effects.

The ERGMs estimate the importance of each network effect relative to other configurations using maximum likelihood techniques. The observed network is compared to a sample of randomly generated networks with the same characteristics (e.g., number of nodes). For our purposes, we also ensured that the random networks had the same density as the observed network to assist in model convergence (i.e., to ensure random graphs were drawn from a stationary distribution). An ERGM is ‘fitted’ when the statistical distribution of the random graphs is centred over that of the observed network (Lusher et al., 2013). Regression techniques are used to calculate parameter estimates, which determine if the network effects are more or less present in an observed network than would be expected by chance (Snijders et al., 2006). If estimates are positive (negative), the effect is more (less) abundant in the observed network than in the distribution of random networks. Estimates greater than twice their standard error are considered significant (Lusher et al., 2013), and thus the theoretical processes underpinning the effect are said to contribute to the formation of the observed network.

Table 1. Network effects evaluated with ERGMs

Effect	Image	Description
Information sinking		The tendency for information to be sunk or not transmitted further within the network after it is initially received from Project Researchers.
Source popularity		The tendency for a node to be the source of information for multiple other nodes.
DF sender		The tendency for the sender to be a DF.
DF popularity		The tendency for DFs to transmit information to multiple receivers.
VF activity		The tendency for the sender to be a VF.
VF receiver		The tendency for the receiver to be a VF.
VF information access		The tendency for a VF to receive information from multiple sources.

3. Results and Discussion

Based on the results of household surveys it was determined that only one household outside the original 20 trial participants had adopted microdosing in the 2 years since its introduction to the village. The results of the household survey indicate that DFs were marginally better off in terms of social and economic status than those represented in the VF category. DFs have greater amounts of cultivable land and have larger household labour forces. Interestingly, DF were more likely to cite difficulty finding additional labour, though the difference between the two groups was not statistically significant. It is possible that by having greater amounts of cultivable land, DFs have increased their production levels to a point where household labour is no longer sufficient. Education was not significantly different between the two groups. However, education status in general is low at a village level, with more than two-thirds of the surveyed farmers being illiterate. This has important implications for the diffusion and uptake of technology for the village in that low levels of literacy in SSA have been shown to inhibit the process of dissemination of soil fertility information, influencing farmers' access to the information (Adolwa et al., 2012; Ofuoku et al., 2008). Credit constraints have also been shown to hinder the process of technology adoption (Abdulai & Huffman, 2005; Beke, 2011). However, there was no statistically significant difference between the two groups in terms of membership in a credit-granting organization. This membership was generally low at the village level, with only 18% of surveyed farmers reporting membership.

Table 2. Socio-economic status between demonstration and village households

Household Assets	DF (n=20)			VF (n=53)			Dif.
	Mean	Prop.	St. Dev.	Mean	Prop.	St Dev.	P Val.
Male Household Head	--	1.00	--	--	0.84	--	--
Female Household Head	--	0.00	--	--	0.16	--	--
Age	40.77	--	12.22	41.12	--	12.40	0.912
Household Labour	4.73		2.14	3.78		1.81	0.070
Education Illiterate=0; some-1	--	0.32	0.47	--	0.29	0.46	0.837
Cultivable Land	2.84		1.04	2.24		1.11	0.020
Use of Organic Fertilizer (1=Yes)	--	0.91	0.29	--	0.75	0.44	0.112
Use of Synthetic Fertilizer (1=Yes)	--	1.00	0.00	--	0.59	0.49	N/A
Labour Shortage (1=Yes)	--	0.41	0.49	--	0.27	0.45	0.256
Membership in Credit Org. (1=Yes)	--	0.18	0.39	--	0.18	0.38	0.956
Access to Credit (1=Yes)	--	0.55	0.50	--	0.43	0.38	0.956
S-E Status (Min=1.93; Max=18.28)	10.78	--	3.45	8.21	--	3.27	0.003

The results of the network analysis show that both the adoption of the microdosing technique and general awareness of the project was low. Nineteen VFs (26%) reported that they were unaware of the microdosing technique or the project. Overall, the use of DFs and the network in general failed to spread information or promote learning among VFs regarding the microdosing technique. Forty percent (n=8) of the DFs failed to disseminate information about the microdosing technique to any VFs (i.e., their out-degree being 0). However, three DFs withdrew from the project during the first year of the project – two DFs leaving for employment opportunities in Nigeria, and one DF finding their involvement too bothersome to continue. Of the remaining 17 DFs only three played a key role in dissemination (i.e., out-degree >5), one of which was responsible for sharing information with thirteen VFs. Only 6 VFs received information from more than one DF, thus indicating very limited closure in the network. Last, our findings indicate that only two VFs spread information about the microdosing technique after receiving it from a DF. In other words, the spread of information stalled within the first step away from the source. Despite their relative socio-economic status, the DFs showed no influence on VFs to adopt the microdosing technique. Therefore, the intention of the project to use DFs to mobilize VFs to adopt the microdosing technique failed to achieve the desired goals.

The results of the ERGM further support this conclusion. As shown in Table 3, there was significantly more information 'sinking' than would be expected by chance. Information was not transmitted to other nodes once it was received. There were also significantly fewer VFs receiving project information than would be expected by chance, and fewer tendencies for DFs to be the source of information for multiple VFs than would be expected. Although there are a few key DFs acting as information sources, there are also many isolated DFs that did not disseminate project information (Figure 2), which would help explain to ERGM estimates.

Table 3. ERGM effects and estimates

Effect	Description	Estimate (Standard error)
Information sinking	The tendency for information to be sunk or not transmitted further within the network after it is initially received.	1.0133(0.477)*
Source popularity	The tendency for a node to be the source of information for multiple other nodes.	-1.5473(0.58)*
DF sender	The tendency for the sender to be a Demonstration Farmer.	0.223(19372660.348)
DF popularity	The tendency for Demonstration Farms to transmit information to multiple Village Farmers.	-0.8935(1.307)
VF activity	The tendency for the sender to be a Village Farmer.	-0.0057(19372660.34)
VF receiver	The tendency for the receiver to be a Village Farmer.	-1.0927(0.374)*
VF information access	The tendency for a Village Farmer to receive information from multiple Demonstration Farms.	0.2723(0.347)

* Significant effect (i.e., the estimate is more than twice the standard error).

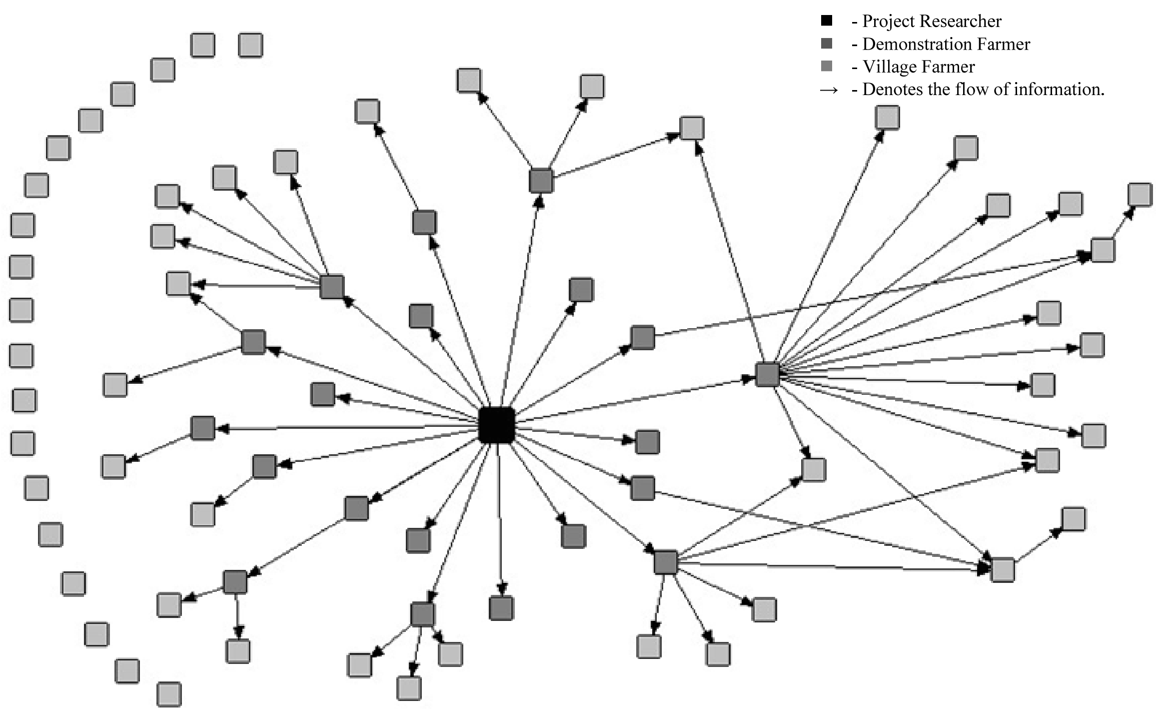


Figure 2. Microdosing information flow

4. Conclusion

The diffusion of knowledge pertaining to new agricultural technologies has proven critical to alleviating conditions of food insecurity in Africa. One such technology is fertilizer microdosing. Introduced to West Africa as early as 1998, microdosing has since proven to be more economical compared to recommended dosage levels, while the reduced application amounts have helped to overcome obstacles associated with access and supply. However, in Benin microdosing has not been widely adopted by smallholder farmers.

In 2011, we field-tested the microdosing technique in the village of Koumagou B in northwest Benin, after which members of the research team provided periodic technical assistance over three growing seasons. Twenty Demonstration Farmers (DFs) were trained in the microdosing technique and were expected to share information about it with other village farmers, who might then adopt the technique for their own lands. In 2013, two years following the project's inception, a census of Koumagou B households (n=73) was completed to determine adoption rates and to track the flow of information from Project Researchers (PRs) to Demonstration Farmers (DFs) and from DFs to other Village Farmers (VF). Our results indicate that since its inception, only one Village Farmer had adopted the microdosing technology. Results also indicate that knowledge of the microdosing technique did not propagate efficiently through village networks and its diffusion was limited. The involvement of DFs did not promote learning within the village nor did they motivate adoption among Village Farmers. Applying a two-step flow of information from Project Researchers to Demonstration Farmers, and from Demonstration Farmers to Village Farmers failed to achieve desired effects, with only 3 of 20 DFs diffusing knowledge to a significant degree (i.e., out-degree >5).

There is an important caveat. Our research was conducted only two years (three growing seasons) after microdosing had been introduced to the village. It is possible that more time is simply needed for knowledge of the microdosing technique to diffuse throughout the village social network. Village farmers who did not adopt the microdosing technology during the research period may be engaging in strategic delays, i.e. waiting to see if the benefits of microdosing exceed the costs, by observing the experimentations of others. If the benefits of microdosing are found to outweigh the costs, adoption may be more broadly achieved over the longer term. Notwithstanding the possibility of strategic or delayed adoption, issues of profitability and general supply conditions of fertilizer may ultimately constrain village-wide adoption.

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