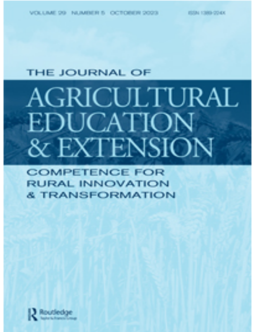

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Farmers' innovativeness and positive affirmation as main drivers of adoption of soil fertility management practices – evidence across sites in Africa

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ABSTRACT

Purpose: Declining soil fertility is worrying in sub-Saharan Africa. Various technologies serve to mitigate or rebuild soil fertility, but uptake by farmers, especially smallholders, is low. The study addresses this adoption problem in a novel way, assessing empirically many factors from various domains (economic, socio-demographic, individual, institutional, networks and information sources) to identify what drives adoption.

Design/Methodology/Approach: The panel study used data from baseline and endline surveys with 1870 smallholders in Ghana, Kenya, Mali, and Zambia. Quantitative data were analysed simultaneously via logistic regression, complemented by qualitative interviews. The study demonstrates the advantage of panel studies, as they can measure changes in practice or in farmers' attitudes.

Findings: Individual factors, for example innovativeness, perception about soil fertility and correct knowledge, have the biggest influence on adoption. Socio-demographic and economic factors, by contrast, play hardly any role, as do individual information sources.

Practical implications: Future research should focus on in-depth studies of individual factors, e.g. innovativeness and knowledge, and on the information environment of farmers. Communication efforts must primarily target innovative farmers, ensure high quality, address competing messages, and communicate through many different channels.

Theoretical implications: The importance of 'intrinsic' factors that have previously been overlooked in adoption studies in SSA becomes clear.

Originality/Value: The study is one of very few that empirically assesses a wide range of independent variables to identify the drivers of adoption. It reports not only significance but also effect sizes.

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Introduction

Soil degradation is a major agricultural problem in many parts of sub-Saharan Africa (SSA) (Vanlauwe et al. 2017; Wheeler and von Braun 2013). It is the '*principal constraint to production in smallholder farming in Africa*' (Vanlauwe and Giller 2006, 34), and a '*major biophysical root cause of declining per capita food availability*' (Mugwe et al. 2009a, 61). Many initiatives have been launched with the objective of managing crops and soil in a sustainable way (Pretty, Toulmin, and Williams 2011; Tittonell 2014). International agricultural research has intensified the development of technologies that aim to prevent further degradation or to increase soil fertility (Chivenge, Vanlauwe, and Six 2011; Mugwe et al. 2009b; Vanlauwe et al. 2017; Willer and Lernoud 2017). However, the uptake of new agricultural practices by smallholders in SSA has remained low (Andersson and D'Souza 2014, 116; Brown, Nuberg, and Llewellyn 2018; Gwandu et al. 2014, 80; Meijer et al. 2015). Adolwa et al. (2017, 454) highlight '*the discrepancy between the prolific generation of agricultural knowledge on one hand, and minimal awareness and application of that knowledge by smallholder farmers, on the other*'.

Against this background, the research project "Farmer-driven organic resource management to build soil fertility and improve food security" (ORM4Soil) aimed to identify the factors driving uptake of soil fertility practices in a novel way, by examining a large set of factors from various domains simultaneously (social, economic, cultural, institutional, informational, and social capital factors), and by reporting significance levels and effect sizes of factors, in order to identify their strengths in interaction with other factors. Previous studies have focused on a very limited number of factors, mostly from socio-demographic and socio-economic domains, as will be shown below.

This study focussed on smallholder farmers, as they are the backbone of food production and income generation in SSA (Muzari, Gatsi, and Muvhunzi 2012, 69), and on knowledge-intensive, not capital-intensive soil fertility practices. It used data from a panel study comprising more than 1800 farmers from four African countries (Ghana, Kenya, Mali and Zambia). The focus of the research was to determine the drivers of adoption of five soil fertility management (SFM) practices that 'work' across sites, rather than the differences between sites. Insights into those drivers will help to increase the adoption of practices that maintain or improve soil fertility as an important element in productivity growth in SSA. The article first reviews the literature on the adoption of agricultural innovations, particularly in SSA, and then presents the research design and methodology followed by data analysis, interpretation of results, and conclusions.

Theoretical background on adoption of innovations

Identifying the factors that determine the adoption of innovations by smallholder farmers in developing countries is an important and challenging topic (Leeuwis 2004) and has been on the research agenda for decades (Arslan et al. 2014, 74). Various adoption models have been developed across disciplines (for an overview see Montes de Oca Munguia, Pannell, and Llewellyn 2021) and have mainly focussed on economic (Griliches 1957) or psychological (Ajzen 1991) factors or a combination of these to explain the decision-making process (Rogers 2003). In addition, the innovation systems literature

(Spielman 2005; Spielman, Ekboir, and Davis 2009) departs from a linear approach in explaining adoption and provides instead an analytical process-based system approach exploring complex relationships among diverse actors, organisations, and institutions, to better understand the adoption of innovations. Recently, innovation platforms were installed as one practical approach in agriculture to initiate institutional change as a necessary condition to enable adoption and achieve productivity growth (Hermans et al. 2017; Hounkonnou et al. 2012).

Many empirical adoption studies in SSA are non-recurrent cross-sectional studies that investigate only a few factors (Adolwa et al. 2012; Gwandu et al. 2014; Massresha et al. 2021; Melesse 2018; Mugwe et al. 2009a; Mwaura et al. 2020; Ngwira et al. 2014; Pamuk, Bulte, and Adekunle 2014). Those dealing with soil fertility practices such as 'Integrated Soil Fertility Management' (ISFM), or 'Conservation Agriculture' (CA) show that the contribution of demographic and socio-economic factors that are believed to be essential for adoption, such as age, education, land ownership, access to credit, farm size, are inconclusive. Most of the studies assessed by Meijer et al.'s meta-study (2015, 45–49) show partly contradictory results, when the same factor plays a role in one case but not in another, or even has a negative influence. Mwangi and Kariuki (2015) support this conclusion. They report on adoption studies, mostly from Africa, and show that commonly cited factors such as farm size, education, age, and gender are not conclusively related to adoption. In some studies, larger farms are more likely to adopt a new technology, whereas in other studies, smaller farms have a larger motivation to adopt, and still other studies report an insignificant or neutral relationship with adoption (Mwangi and Kariuki 2015, 210). The same applies to off-farm income (ibid., 211) education level, and age (ibid. 212). We conclude that some of this inconsistency is related to the limited type and number of factors investigated in those studies.

Meijer et al. (2015) claim that studies often focus on 'extrinsic' factors only such as socio-demographic characteristics (age, gender, education, wealth, status), environmental (geographical setting, societal culture) and economic factors (benefits, costs). They argue that 'intrinsic' factors (farmers' knowledge, perceptions, personality, and attitudes) need to be considered together with communication processes to learn more about the innovation process. Information and farmer communication studies have identified that farmers prefer inter-personal communication channels with direct contact with extension workers, participation in farmer field days being the most important (Adolwa, Schwarze, and Buerkert 2018; Gwandu et al. 2014; Kimaru-Muchai et al. 2011; Nyambo and Ligate 2013). However, only Adolwa, Schwarze, and Buerkert (2018) and Murage et al. (2012) correlated communication with adoption itself, identifying also radio as an important mass medium for farmers. In addition, media effect studies show that 'multi-mediality' (Bonfadelli 2000, 104) including inter-personal communication is an important element of successful information campaigns. Diversity of channels increases the chances of reach and effect (McQuail 2005, 441).

Nowadays, there is consensus that a variety of influences are responsible for adoption. In addition to economic factors that focus on profitability, risk, access to credit and inputs or farm size (Sunding and Zilberman 2001), there are social, cultural and communication factors as well as the institutional context in agriculture (government policies, land tenure arrangements, strong farmer organisations, value chains) that drive or hinder innovation (Curry et al. 2021; Hounkonnou et al. 2012; Pamuk, Bulte, and

Adekunle 2014; Wheeler et al. 2017). Other fields of research have focussed on personality characteristics (self-confidence, independence, see Meijer et al. 2015), social capital (membership in groups, Hunecke et al. 2017; Van Rijn, Bulte, and Adekunle 2012) and social networks (Beaman and Dillon 2018; Leeuwis 2004; Maertens and Barrett 2013; Shikuku 2019; Udry and Conley 2004) as important drivers of adoption. However, current knowledge of the actual factors that drive innovation is still limited (Glover, Sumberg, and Andersson 2016; Meijer et al. 2015), especially in relation to the combination of factors that may work in different contexts.

As Antonakis et al. (2010) have shown, overlooking relevant factors will lead to false regression coefficients, significance values and effect sizes, so that results do not represent 'true' relationships. In addition, many studies report significance only, but rarely effect sizes, overlooking the fact that significance is not synonymous with large effects (see Meijer et al. 2015).

Considering those learnings from existing adoption studies, we designed our research in a specific way to observe changes in the adoption of SFM practices. We used a panel study and assessed a wide range of the above-mentioned factors (including communication) that are likely to influence adoption. We also report statistical significance (*p*-values) and substantive significance (effect sizes) as both are necessary in interpreting studies (Sullivan and Feinn 2012). Nevertheless, we cannot make causal claims (Antonakis et al. 2010), as we did not work with treatment and control groups and can thus not guarantee that we have managed to cover all factors.

The selection of relevant factors was guided by Pannell et al. (2006) and Kuehne et al. (2017), who emphasise that farmers' adoption of innovations is influenced by factors from the domains of

(a) socio-economics (farm size, access to credit, off-farm income),
(b) socio-demography of farming household (age, education, gender, household size),
(c) individual farmer (awareness of problems, knowledge, perception, management capacity, innovativeness),
(d) institutions (security of investment in land)
(e) communication (access to extension and other information sources) and
(f) social capital (membership in groups, networks).

Our research focussed on examining the contribution of the following factors:

- Individual farmer characteristics (**RQ1**): We hypothesised that influence on adoption would increase with higher awareness of soil fertility as a problem, with higher perception of degradation, with correct soil fertility knowledge, and with higher innovativeness.
- Socio-economic factors (**RQ2**): We hypothesised that influence on adoption would increase with farm size.
- Socio-demographic factors (**RQ3**): We hypothesised that the direction of their influence on adoption would decrease with age and increase with higher education.
- Communication and information (**RQ4**): We hypothesised that the diversity of information channels (extension, radio, field days) and some of the sources (extension, radio) would play a positive role in adoption.

- Institutional context (**RQ5**): We hypothesised that adoption increases strongly with land tenure security, and a positive vision about the future of farming.
- Social capital (**RQ6**): We hypothesised that adoption increases strongly with belonging to groups.

We tested those hypotheses based on survey results, by correlating the above factors as independent variables via logistic regression with the adoption of various soil fertility practices as dependent variables.

Material and methods

Project areas and practices

ORM4Soil aimed to improve soil fertility through an interdisciplinary approach, bringing together researchers from agronomy, sociology, and communication studies. It took place in Ghana, Kenya, Mali and Zambia, in two sites in each country. It firstly developed jointly with farmers better adapted SFM practices and secondly investigated what factors drive the adoption of those practices by smallholders.

The selection of the sites was guided by the aim of covering a range of different climate zones and rainfall patterns (unimodal versus bimodal). Within each country, the two sites showed diversity of agricultural zones and crop production, soil types and fertility status, as well as livestock availability. The sites were also pragmatically identified by the existence of an agricultural research station. The variation across sites should enable examination of whether specific factors hold in different contexts, i.e. whether they are robust to change or not (Table 1).

Table 1. Main agricultural features of research sites.

Country	Sites	Agricultural Features:
Kenya	Murang'a	Rainfall, crops, soil fertility and livestock
	(1°02′15.5″S 37° 04′52.7″E)	bimodal rainfall, 900–1400 mm; coffee, tea; livestock, weathered soils, moderate fertility
	Tharaka-Nithi (0°19′16.7″S 37° 39′20.5″E)	bimodal rainfall, 1200–1400 mm; mixed crops; livestock, weathered soils, poor nutrient storage capacity
Zambia	Chipata (13°38′10.8″S 32° 38′41.0″E)	unimodal rainfall 800–1000 mm; maize, livestock, moderately weathered soils
	Kasama (10°12′48.2″S 31° 11′05.8″E)	unimodal rainfall 1200 mm; maize, cassava, coffee and groundnuts, few livestock, heavily weathered soils
Ghana	Kade (6°08′31.9″N 0° 45′43.5″W)	bimodal rainfall 1200-1400 mm. cocoa, oil palm, and maize; rarely livestock, weathered soils
	Sege (5°52′42.8″N 0°21′33.9″E)	bimodal rainfall, 750 mm; tomato, pepper, watermelon; livestock, sandy weathered soils, poor nutrient availability
Mali	Koulikoro (12°57′59.8″N 7° 36′ 20.1″ W)	unimodal rainfall 700 mm; sorghum; livestock, soils of low fertility;
	Sikasso (11°33′14.5″N and 5° 38′29.7″W)	unimodal rainfall 1000 mm; cotton, large diversity of soils

[*NAME PROJECT*] identified various practices for maintaining or increasing soil fertility. In this paper, we focus on the adoption of five 'general' practices that were feasible in all the eight sites across the four countries. These are:

- Intercropping with legumes
- Agroforestry with soil fertility enhancing trees
- Crop rotation
- Mulching with crop residues
- Minimum (or zero) tillage

It was expected that these practices would be taken up due to information sharing, for example by extension services, specific radio broadcasts on soil fertility, field days, NGOs, innovation platforms, and general sharing in farmer networks.

Data collection

Data were collected in the form of a panel survey, conducted in two stages (baseline 2016 and endline 2019). The panel design was chosen to observe changes during the project, for example in farmers' awareness, knowledge or practice. In a one-time cross-sectional study, this personal change cannot be observed. A standardised questionnaire was used, which was administered during face-to-face interviews with farmers by ten trained enumerators in each site. To ensure validity and reliability of data, enumerators with knowledge of vernacular languages were trained by principal investigators and extension workers with knowledge of the local context. Test interviews with farmers were conducted to ensure correctness in understanding and to re-phrase questions if necessary. The questionnaires covered the entire range of factors as shown in Table 2. Additionally, farmers were asked open-ended questions about reasons for their decisions, for example for not applying a specific practice.

The farmers were randomly selected from a geographical area within a radius of 25–30 km around the locations of the project's agronomic research with on-station and on-farm trials. In each area, 300 farming households were targeted, excluding participants in on-farm trials. The study used the random walk approach to select farming households. The random route method is standard for sampling and empirically investigating households for in-person surveys (Diekmann 2004, 332). It consists of firstly identifying various administrative units within an area and then specifying starting points in each unit from which enumerators start walking the area. Enumerators must follow precise walking rules concerning the selection of the households. In ORM4Soil, enumerators selected every 4th household as a potential interviewee and conducted the interview immediately.[1] The entire procedure should ensure a random selection of interviewees comparable to other random selection methods like using complete lists of farmers (see Bauer 2014 for critical review) that were not available here. The respondents were household heads identified as responsible for making key agricultural decisions. For the endline survey, the same farmers were visited. Attrition against the baseline study was 23%, due to non-availability, discontinuation of agriculture or death. In total, data from 1870 farmers who participated in both studies were assessed.

Table 2. Independent variables and statistical summary.

Variable	Description and operationalisation	Variable type and reference value	Origin	Mean or proportion
Socio-economic				
Farm Size	Total land size worked on	Continuous		10.72 acres
Socio-demographic				
Age	Age of farmer in 2016, transformed into three layers.	Ordinal 1 = young (up to 30, ref.), 2 = middle (31-50), 3 = old (51+)	Base	45% of farmers in the age group 51+
Education	Highest formal education, transformed into three layers	Ordinal 1 = no schooling (ref.), 2 = primary attended or completed, 3 = secondary attended and above	Base	29% no schooling at all
Gender	Gender of farmer	Categorical 0 = male, 1 = female (ref.)	Base	39% female heads in farming
Individual characteristics				
Innovativeness	Farmers indicated whether they had introduced a new crop or new practice.	Binary 0 = not innovative (ref.), 1 = innovative	End[b]	55% of farmers were innovative
Awareness of soil fertility	In both surveys, farmers assessed whether soil fertility is a 'minor', a 'major' or 'no problem at all' for them. It was possible to identify whether farmers saw an aggravation or alleviation of soil fertility as a problem between baseline and endline.	Nominal 1 = alleviation or no problem (ref.), 2 = aggravation or remaining problem	Base and End	57% saw soil fertility as an aggravating or remaining problem
Perception of change in soil fertility	In both surveys, farmers indicated how soil fertility in their own fields had changed over the last three years. It was possible to identify whether farmers saw improvement or decline in soil fertility between the two surveys.	Ordinal 1 = decline (ref.), 2 = stable, 3 = improvement	Base and End	38% of farmers seeing an improvement in soil fertility on their own fields
Soil fertility-oriented knowledge	Farmers picked three answers out of six options. Three answers were correct in terms of soil fertility enhancing; the other answers covered increasing yields. Soil fertility knowledge was only attributed when all three correct responses were selected.	Binary 0 = yield-oriented knowledge (ref.) 1 = soil-fertility knowledge	End	32% had correct soil fertility knowledge
Information and communication				
Frequent use of information sources ○ family ○ neighbours ○ extension ○ research ○ agrodealers ○ traders ○ Radio ○ TV	Both surveys required farmers to indicate which out of 15 different sources they used to obtain information on soil fertility, and to estimate the frequency of using this source on a 4-point scale: never; rarely (once in three months); often (3–5 times in three months); very often (at least weekly). Data were transformed into a 2-item scale: 'not or rarely using' and 'frequent using'.	Binary 0 = no or rare user (ref.); 1 = frequent user	End	

(*Continued*)

Table 2. Continued.

Variable	Description and operationalisation	Variable type and reference value	Origin	Mean or proportion
○ Internet and social media ○ Newspapers ○ Farmer groups ○ NGOs ○ Agricultural shows ○ field days ○ public gathering[b]				
Information seeking behaviour	Mean of frequent usage of above 15 sources	Numeric (1,2, … 15)	End	5.6 sources were frequently used
Institutional context				
Confidence in security of long-term investment in land	Farmers indicated whether they have confidence in land tenure security, in order to invest in long-term endeavours.	Binary 0 = no confidence (ref.), 1 = confidence	End	89% were confident
Vision on future of farming	Farmers explained whether they want their children to become farmers. Open answers transformed into two layers.	Binary: 0 = no future (ref.), (1,2,3)= positive future (constructed from original responses)	Base	36% said that farming has 'no future'
Site	Areas around research sites	Dummy		
○ Murang'a ○ Tharaka-Nithi ○ Chipata ○ Kasama ○ Kade ○ Sege ○ Koulikoro ○ Sikasso				
Social capital				
Belonging to groups ○ farmer group ○ savings group ○ women ○ youth ○ religious ○ commodity ○ cooperative	Farmers indicated whether they were a member or not in these groups	Binary 0 = no member (ref.), 1 = member	End	

[a]As specific sources (extension services, research, agrodealers, traders, NGOs, farmer groups, agricultural shows, field days, public gatherings) cannot be used often (because they occur only now and then), we assigned the 'once in three months' to the 'frequent using' category in order to compute regressions.
[b]Villagers are called in for a meeting by government agents.
Base = Baseline study; End = Endline study

To strengthen interpretation of results and conclusions, we also conducted intense exchanges about preliminary research results. Various face-to-face meetings were conducted with the members of informal groups that had worked as advisors for the research (local extension services, NGOs, research stations), and online meetings were conducted with researchers from agronomy and sociology involved in this research.

Data analysis

Definition of adoption as dependent variable

In both baseline and endline surveys, farmers were asked, based on a list of soil fertility management practices, which of them they applied[2], if any. By comparing 2016 and 2019 data, it was possible to determine whether a practice was newly adopted, continued, discontinued, or never practiced. We identified the following adoption groups:

- Newcomers (practice not applied in the baseline study, but used in the endline)
- Continuous practitioners (practice applied in baseline and endline)
- Outgoers (practice applied in baseline, but discontinued in endline)
- Deniers (practice not applied in baseline nor endline)

These types of adoption were binary-coded for use in the logistic regression models. Considering that implementation of a new practice occurs gradually and increases over time (Glover, Sumberg, and Andersson 2016), we identified the first two groups (newcomers and continuous practitioners) as adopters, and the last two groups (outgoers and deniers) as non-adopters. Additionally, an overall adoption result was constructed by adding up the number of general soil fertility practices (out of 5) adopted by a farmer, which varied between 0 and 5.

Independent factors excluded from data analysis

Some factors mentioned in the adoption model of Kuehne et al. (2017), e.g. practice complexity, trialling ease, or confrontation with social values, were not part of the surveys, as they were investigated by Participatory Rural Appraisal (PRA, Chambers 1994) exercises, before baseline data was collected. The PRA helped us to understand the site-specific context and to formulate the questions to farmers in a site-specific, yet comparable way. PRA results showed that the SFM practices investigated were not perceived as complex, but generally as easy to try. Furthermore, the practices did not question social values, except agroforestry in Mali for women farmers, but females are very rarely heads of farming there. PRA data revealed that soil fertility practices under investigation were perceived as knowledge-intensive, not capital-intensive, thus belonging to 'soft technologies' (Wheeler et al. 2017) not requiring larger financial investments. However, the observability of the benefits of soil fertility enhancing practices is rather limited, as improvements become manifest only after many seasons, unlike short-term improvements in yields. Some other factors were excluded from the analysis presented here, because they were identified as being either not relevant in the specific context, or difficult to measure:

- **Access to credit** has been skipped for two reasons: (a) the practices investigated here did not require large sums of money, so credit was not an issue; (b) in the baseline survey, most farmers said that they never applied for credit in the past for various reasons, fear of losing the collateral amongst them.
- **Farmers' income** is difficult to inquire about in surveys with smallholders, as (a) it is highly volatile from season to season, (b) it consists of monetary and in-kind elements, and (c) smallholders do hardly any book-keeping, which limits the reliability of responses.

- We had collected data on the percentage of **off-farm income** in the baseline study but could not find any significant correlation with soil-fertility practices in the baseline.
- **Household size** did not show any significant and strong correlation with soil-fertility practices.
- **Wealth** was covered in the baseline survey when respondents listed household items which were then used to calculate a wealth index. Since we focused on small scale farmers, almost all respondents appeared at the very low end of the index, with little substantial variance.

Independent factors included

Table 2 presents the factors included and how they were measured in the surveys and operationalised in correlational analysis. All factors are assumed to be exogenous, even if data stem from the endline survey. For example, the factor 'innovativeness' was calculated by the question as to whether farmers had introduced a new crop and/or a new practice. Farmers provided additional information on the type of new practices they had implemented, which enabled researchers to ensure that those practices were not the same as the one used as a dependent variable, i.e. successful adoption. Therefore, endogeneity was not an issue. It cannot be ruled out that our study may have overlooked important factors. Nonetheless, it has the advantage of having included many factors, which limits the occurrence of omitted variables. Multicollinearity was controlled but was not an issue. The highest generalised variance inflation factor (GVIF) was 1.75. Usually, variance inflation factors (VIF) above 5 indicate high correlation between factors.

Empirical model specification

As adoption was identified as a binary variable, it was analysed using logistic regression models of form $log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \beta_1 X_1 + \ldots + \beta_p X_p$ where Y presents the binary dependent variable adoption with 1 = adoption and 0 = non-adoption, $X_1, \ldots, X_p$ represent independent variables and $\beta_0, \ldots, \beta_p$corresponding coefficients. The model states that the logarithm of the odds $(\frac{P(Y=1)}{1-P(Y=1)})$ of adoption rather than non-adoption relates to a linear combination of the independent variables. Thus, coefficient β_j can be interpreted as the effect of increasing X_j by one unit on the logarithm of the odds or equally, $exp(\beta_j)$ or odds-ratios (OR) indicate the extent of change in the probability of adopting a practice compared to the probability of not adopting when the value of predictor X_j is increased by one unit or one level. Decimals above 1 in odds-ratios are interpreted as percentages of change: a coefficient of 1.768 means a 76.8% higher probability of uptake. For the overall adoption result, a logistic regression model was used too.[3]

Our analysis consisted of three steps. Firstly, binary correlational-analysis of survey data and theoretical considerations identified a basic model with nine factors as having the highest potential to explain the uptake of practices, in combination with 'site' as an additional variable. These were: farm size; innovativeness of farmer; awareness of soil fertility as an aggravating or remaining problem; perception of change in soil fertility; soil fertility-oriented knowledge; frequent use of extension services as source; information seeking behaviour; confidence in land tenure security; and positive vision of farming. Likelihood ratio tests indicate whether including the variable improves the fit of the model, and *p*-values indicate whether odds-ratios differ from 1. The dummy variables for the sites were coded by using sum contrasts, i.e. coefficients can be interpreted as the difference between the site and the grand mean.

Secondly, interactions between these factors and site were calculated to determine whether some factors were especially effective in specific sites. A stepwise forward selection process was conducted and applied to the overall adoption result (number of practices adopted) by looking for interactions that would reduce the Akaike information criterion (AIC, Akaike 1974) when added to the model. We only considered interactions when odds-ratios were significantly larger than 1.

Thirdly, additional explanatory factors were stepwise added to the model, using an AIC stepwise forward selection process. We calculated likelihood ratio tests on adding these additional factors individually to the basic models. Additional potential predictors were education level; age; gender; frequent use of all information sources listed in Table 2; belonging to farmers' group; and belonging to women's group. The models had the same equations, including the main effects for the nine factors and the sites.

Results

Adoption of SFM practices

Table 3 shows the percentage of newcomers, i.e. farmers implementing the general SFM practices for the first time and then the overall adoption rate, i.e. the percentage of newcomers plus farmers that continued using the practice. The soil fertility practice with the highest proportion of 'newcomers' was minimum tillage reported by 58% of farmers in Kade, Ghana. We found the lowest proportion of newcomers for agroforestry (3%) in Sege, Ghana; the next lowest proportion of newcomers was reported for minimum tillage (8%) at Sikasso in Mali. Surprisingly, many farmers discontinued the use of specific practices (Table A1, Appendix). In some sites, the number of outgoers was larger than newcomers, for example for minimum tillage in both sites in Mali and in Sege; for agroforestry in Chipata; and for mulching with crop residues in Murang'a, Tharaka-Nithi and Sikasso.

Descriptive results independent factors

The sample was equally distributed among countries and sites (Tables A1 and A2, Appendix). Nevertheless, some factors showed strong differences, for example on farm size (very small in Kenya, and large in Mali) which were mostly due to different socio-cultural settings ('individual household' farms in Kenya, and 'enlarged family' farms in Mali[4]) and agricultural potential; education level (e.g. low level of schooling in Mali); confidence in land tenure security (only one region in Zambia showed a low level), awareness of soil fertility as a problem, and perception of change in soil fertility, as well as innovativeness of farmers and knowledge of soil fertility (both largest in Zambian areas).[5]

Table 3. Newcomers and overall adoption rates.

	Murang'a		Th.-Nithi		Chipata		Kasama		Kade		Sege		Koulikoro		Sikasso	
	N = 273		N = 267		N = 255		N = 196		N = 214		N = 211		N = 216		N = 225	
	Newcomers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption	New comers	Overall Adoption
Intercropping with legumes	22%	71%	29%	76%	24%	33%	32%	65%	21%	22%	23%	28%	38%	52%	24%	29%
Agroforestry with SF trees	29%	32%	23%	39%	11%	18%	28%	28%	30%	38%	3%	3%	38%	59%	26%	46%
Crop rotation	38%	65%	19%	85%	15%	86%	38%	87%	14%	15%	23%	35%	14%	84%	13%	88%
Mulching with crop residues	16%	24%	17%	32%	35%	78%	42%	66%	41%	86%	43%	92%	23%	73%	21%	66%
Minimum tillage	14%	18%	39%	55%	27%	45%	26%	27%	58%	94%	9%	10%	15%	64%	8%	46%

Overall adoption rate = Newcomers + Continuous practitioners.

Exposure to information from various sources was largely diverse between sites and countries, suggesting different availability and attractiveness of sources in those locations. In general, radio was the most popular source of soil fertility information across all countries, used by 78% of farmers, followed by fellow farmers as sources (51%). The channel with the smallest proportion of farmers making frequent use of it was newspapers (3%) followed by Internet and social media (5%).

Findings on adoption

Table 4 shows the results of a regression analysis of the number of listed general SFM practices out of five adopted by farmers and the adoption of each of them.[6] OR coefficients show the strength of influence of factors regarding probability of adoption.

Regarding **RQ1** we see that **individual factors** play the largest role in adoption of SFM practices. Innovativeness of farmers was the strongest factor in explaining adoption. For every practice, it was significant and showed a rather high probability (OR from 1.44 to 2.32, which equals between 44% and 132%) of taking up a practice when a farmer had introduced innovations before. According to Sullivan and Feinn (2012, 280), odds-ratio coefficients above 1.5 are small, above 2.0 are medium, and above 3 are large. Therefore, OR coefficients for innovativeness show at least medium effect sizes (above 2, or more than +100% in relative probability) for agroforestry, mulching and minimum tillage.

Other individual factors were significant but with smaller effect size (OR above 1.5) and only for some practices: farmers' perception of improvement of their soil fertility enhanced the relative probability of uptake for intercropping (OR 1.33, + 33%), minimum tillage (1.499, + 58%), crop rotation (OR 1.78, + 78%) and agroforestry (OR 1.84, + 84%) significantly at a 5% level. This result contradicts our initial hypothesis. It appears that farmers seem to be more motivated to use SFM practices by achieved improvements in soil fertility than by 'alarming' perceptions that soil fertility still declines. Nevertheless, it should be noted that the factor 'perception of change in soil fertility' could be at least partly endogenous because it is not clear from the data whether this perception was established before or after implementing specific practices. Therefore, causality may be reversed, i.e. implementation led to the perception of improvement, not vice versa.

Soil fertility-oriented knowledge supported the relative probability of uptake in agroforestry (OR 1.33, + 33%), intercropping (OR 1.49, + 50%) and minimum tillage (+31%). Awareness of soil fertility as an aggravating or continuous problem significantly increased the adoption of crop rotation (+36%) and minimum tillage (+36%), but the effect size was small. Nevertheless, this supports our initial hypothesis that awareness of soil fertility as a problem stimulates uptake. It is worth mentioning that only the interaction between site and awareness of soil fertility was significant, especially for overall adoption, crop rotation and agroforestry. Odds-ratio coefficients in Tharaka-Nithi and Koulikoro were significantly higher than the average, implying that soil fertility awareness was a more important factor at these sites, confirming that soil fertility in those sites is low (Table 1). All other site-factor interactions were not significant.

Socio-economic factors (RQ2) played a negligible role. Farm size was only significant for crop rotation and this rather weak (OR 1.037, +4% per additional acre).

Table 4. Results of logistic regression on SFM practices.

		Number of adopted practices out of five	Crop Rotation	Agro-forestry	Inter-cropping	Mulching	Min. Tillage
Constant	OR	0.364***	0.244***	0.065***	0.276***	0.702	0.256***
Farm Size	LRT	4.2**	15.8***	0.4	0.1	3.3*	0.9
Numeric	OR	1.003*	1.037***	1.002	1.001	1.009	1.003
Innovativeness	LRT	78.0***	14.8***	27.2***	8.2***	27.2***	36.0***
Yes, innovative	OR	1.590***	1.765***	2.022***	1.440***	2.037***	2.321***
Awareness Soil-Fert.	LRT	6.7***	3.3*	*0.4*	2.7	0.0	*3.7**
Degradation	OR	1.167***	1.361*	1.098	1.264	1.026	1.353*
Perception Change in soil fertility	LRT	18.3***	11.8***	15.6***	7.1**	0.1	8.1**
Stable	OR	1.137	0.971	1.906**	0.740	1.050	1.612
Improvement	OR	1.305***	1.783***	1.839***	1.328*	0.965	1.58***
Soil Fertility knowledge	LRT	6.1**	0.1	4.1**	9.4**	0.0	3.4*
Knowledge is soil fertility-oriented	OR	1.146**	1.055	1.329**	1.499***	0.977	1.311*
Information Seeking	LRT	7.8***	25.9***	8.2***	1.7	0.1	1.4
Number of different sources used	OR	1.029***	1.165***	1.075***	1.032	0.993	0.968
Access Extension	LRT	6.7***	1.0	0.8	1.2	2.1	4.0**
Yes, frequent use of extension services	OR	1.191***	1.208	1.161	1.196	1.289	1.446**
Confidence Investment in Land	LRT	11.7***	7.5***	0.7	0.3	12.1***	1.7
Yes, confident about land tenure	OR	1.345***	1.944***	1.211	1.118	2.132***	1.344
Future of Farming	LRT	0.6	5.1**	6.1**	1.5	3.3*	3.5*
Positive	OR	0.956	0.679**	1.441**	1.185	0.760*	0.750*
Site	LRT	110.4***	283.2***	156.3***	216.8***	275.6***	424.1***
Murang'a	OR	0.795***	1.329	1.296	3.397***	0.180***	0.311***
Tharaka-Nithi	OR	1.321***	2.766***	1.717***	3.996***	0.214***	1.636***
Chipata	OR	0.890*	2.646***	0.328***	0.392***	1.930***	0.951
Kasama	OR	0.928	2.692***	0.605***	1.960***	0.736*	0.290***
Kade	OR	1.074	0.055***	2.094***	0.406***	2.820***	19.190***
Sege	OR	0.572***	0.314***	0.120***	0.585***	7.202***	0.100***
Koulikoro	OR	1.577***	1.*258*	3.177***	0.825	1.119	2.801***
Sikasso	OR	1.192*	1.772**	2.840***	0.490***	0.801	1.333
No. of observations		1'376	1'415	1'396	1'410	1'416	1'398
No. of coefficients		18	18	18	18	18	18
Correct Prediction		0.202	0.799	0.721	0.*701*	0.766	0.760
Nagelkerke R^2		0.337	0.454	0.236	0.251	0.369	0.410
Cohen f^2		0.509	0.883	0.308	0.336	0.584	0.695

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$; OR = Odds-ratio coefficient incl. p-value from Wald test; LRT = Likelihood ratio test statistic incl. corresponding p-value.

Also, many **socio-demographic factors (RQ3)** did not play a role for adoption: Education level, age and gender had no effect on uptake in any of the practices.

Naturally, the sites were an important factor for adoption. The odds-ratios indicate which site was more suitable for uptake of practices compared to the average of sites. For example, the Kenyan sites and Kasama are much more appropriate for intercropping, the Zambian sites and Tharaka-Nithi for crop rotation, the Ghana sites for mulching, and the Malian sites for agroforestry. Kade and Koulikoro are prone to uptake of minimum tillage. The site effect is most probably due to differences in agro-ecological potential, socio-cultural patterns and traditions, cropping patterns, or quality of services in extension or research.

With regard to **RQ4 (information)**, a greater variety of information sources consulted by farmers (information seeking) was only relevant for crop rotation and agroforestry, but not for other practices. Moreover, the use of extension services was only significant for minimum tillage (+45%), representing a rather small effect. This was contrary to our expectations. Also, the frequent use of field days didn't affect adoption, nor did the frequent use of radio, television, social media, or newspapers as single information sources. Similarly, a high frequency of communication with family members, neighbours, and other farmers about soil fertility had no influence on uptake.

From exchanges with extension services and local researchers on interpretation of preliminary results, we expect that the low importance of information might have to do with the following:

- Farmers are often confronted with contradictory messages. In Zambia, for example, some NGOs and private companies promote the sole use of inorganic fertilisers, and others in the same area promote organic inputs or conservation farming. The contradictory messages can also stem from extension services that tend to emphasise yield increases more than soil fertility management.
- Sometimes, competing messages are strongly supported by input subsidies, which is the case for Zambia with its fertiliser support programme, and partly for Ghana.

Confidence in the security of investment in agriculture **(RQ5)** played a significant role for crop rotation (OR 1.94, + 94%) and for mulching (OR 2.13, + 113%), and in both cases with medium effect size. For other practices, the influence of confidence was positive, but not significant. The long-term positive view of the future of farming only played a role for agroforestry (+44%). For other practices, the factor 'positive vision' showed 'negative' signs as odds-ratios were significantly smaller than 1.

Regarding **social capital (RQ6),** the membership in groups played hardly any role in adoption. The only factor positively associated with uptake is 'belonging to a women's group'. It was significant at 5% level for overall adoption (OR 1.25, + 25%) and for intercropping (OR 1.788, + 79%). Other results contradict our hypotheses. For example, using the farmers' group as a source of information is significant, but negatively for crop rotation and agroforestry (OR below 1), suggesting that it lowers the probability of uptake. Only regarding minimum tillage did the use of a farmers' group as an information source have a positive effect. It appears as if farmers' groups discuss other issues than soil fertility.

Regarding the generally low adoption rates, local researchers stressed that some of those SFM practices have been promoted and were taken up by farmers previously, but discontinued now, for example planting SFM trees in Chipata/Zambia, which was once a centre of agroforestry. However, to the best of our knowledge, farmers' disappointing experiences with agroforestry have not been addressed by research. In addition, intercropping with legumes can be hindered when minimum tillage is supported because the use of herbicides prevents the growth of legumes in the same (or neighbouring) fields. Furthermore, some sampled farmers live within a short distance of regional centres, for example in Murang'a and Chipata. This may prevent farmers from investing long-term in soil fertility, as their land may get a much higher value for urban or commercial developments soon.

Discussion

Our study demonstrates that innovativeness, i.e. the fact that an innovation has been tried before, plays the largest role in SFM adoption – a factor that has been largely overlooked in previous adoption studies. Other individual factors play a smaller role (perception of soil fertility change, awareness of soil fertility as a problem, correct knowledge about soil fertility) but still show significant and sizable effects as well. These are also often not considered in adoption studies. In sum, individual farmer characteristics have a very strong effect on SFM adoption (RQ1). Our study confirms the view of Meijer et al. (2015) that intrinsic variables are of paramount importance. It has to be noted that regarding perception, our data contradict our initial hypothesis that perception of soil fertility must be related to further soil degradation to become a motivation for change. The opposite is true. Those who perceive an improvement are likely to invest further in soil fertility. In addition, our data show that correct knowledge about soil fertility among smallholders tends to be limited and is wanting (to say the least), which is a new insight because most adoption studies fail to examine whether farmers' knowledge is correct or not (Spurk et al. 2020).

The simultaneous assessment of many factors from different domains revealed that **socio-demographic factors (RQ3)** do not play a role at all, which has been demonstrated by some, but not all SFM adoption studies in SSA. In general, it can be stated that smallholders are not victims of their socio-demographic setting (gender, age, education) but they can adapt and change individually. These results on socio-demographic factors confirm findings of previous research (Mugwe et al. 2009a; Mwangi and Kariuki 2015; Mwaura et al. 2020) showing no conclusive correlations with adoption. Apparently, farmers can compensate individua 1994 lly for lack of formal education or find other ways to learn. Neither did age play a role: not only are young farmers willing to adopt new practices, but older ones are as well. Farm size also played a minor role. This may be surprising but looks reasonable due to the nature of soft technologies studied here (Wheeler et al. 2017). Economic factors may play a larger role in the adoption of capital-intensive technologies.

Regarding **information and communication (RQ4)**, we learned that – contrary to our hypothesis – hardly any single information sources (except access to extension in a few cases) had a significant and sizable effect on SFM adoption. This is valid even for field days, often quoted as effective channels to increase adoption (Adolwa, Schwarze, and Buerkert 2018; Murage et al. 2012), or radio or family (Kimaru-Muchai et al. 2011). This may appear surprising at first sight. However, in most studies dealing with agricultural communication, the quality and correctness of information of those various sources is not checked (including partly our study). Hence, we must admit that information can often be at least partly false or pointing in the wrong direction. In discussions about our research results, we learned from local stakeholders that in many sites farmers are constantly exposed to conflicting messages from various sources with their own interests. This may result in confusion for farmers but has not been considered so far in current adoption studies. Against this background, we found that frequent use of various information sources can partially mitigate the effects of conflicting messages and therefore has sometimes a positive effect. It also means that farmers who are eager to get access to various information sources are more likely to apply new practices.

Our results confirm that land tenure security **(RQ5)**, as part of the **institutional context**, promotes adoption. However, our sample showed little variation in this factor of land tenure security, which may limit the reliability of this result. **Group membership (RQ6)** showed little effect, contradicting our hypothesis of being of high relevance. Similar to the above-mentioned challenge with correctness of information, our study did not check what topics were discussed and what information was shared in those groups. Thus, if the agenda of those groups is different from soil fertility, the association with SFM adoption is naturally weak. Finally, and surprisingly, a positive vision about the future of farming had no influence on adoption, except for agroforestry. This might be due to agroforestry being the most long-term endeavour of the SFM practices investigated here.

Conclusions

Our study found that across sites and countries, socio-demographic or socio-economic factors are not the most important drivers of adoption of SFM practices, but individual farmer characteristics. Contrary to our expectations, communication factors played a minor role. These results have several implications:

For theoretical thinking on adoption: The study confirms that smallholders' adoption can only be understood by looking at many factors from various domains. This contrasts with many previous and current studies conducted in SSA, looking mainly at socio-demographic (age, gender, education, household size) and socio-economic factors (farm size, occupation) in explaining adoption. The statistical significance of those factors fades away when other factors are examined simultaneously, not to mention the fact that effect sizes of those factors are often not provided. Thus, the study confirms Antonakis' et al. (2010) warning that overlooking relevant factors may lead to bias in results, showing incorrect relationships.

For policy: With respect to policy implications, our study points to the need to strengthen farmers' basic knowledge about soil fertility. This will help for adoption, not only because correct knowledge supports uptake, but also to enhance farmers' resilience to confusing messages. At various stages during this research, it became obvious that many smallholders lacked correct knowledge, which impeded their understanding of the natural processes working in soils and the differences between feeding plants and feeding soils.

Another policy requirement is to raise soil fertility as an important issue on the farmers' agenda, as a long-term challenge that may become even more important than markets or other topics currently dominating the agenda. This would also have consequences for extension and research. It may even influence the agendas of other farmer groups (cooperatives, savings clubs, women and youth groups). It may help if government agencies speak about soil fertility, which will be taken up by other information sources, which in turn may support adoption because our study confirms that as many information channels as possible should be used when communicating soil fertility to farmers.

A policy is also needed to develop strategies to mitigate the problem of declining soil fertility and help other stakeholders in doing so. For example, support to extension and to farmers' mass media (radio) in developing and imparting basic lessons on soil fertility could be entailed within a 'soil fertility support strategy'.

For extension and education: Like any other information source, extension workers can impart incorrect or confusing information. This needs to be avoided because extension workers are usually trusted by the farmer communities as providing the latest, correct information. In addition, our results may change the focus of extension work towards innovative farmers, independent of education level, age or gender, and to show those innovative farmers as examples of change, at least for an overarching issue like improving soil fertility.

The insight that positive affirmation (perception of improving soil fertility) and awareness of soil fertility (as a challenge) plays a role calls for the intensive and regular use of soil fertility analysis in extension and education. This offers the chance to improve awareness of soil fertility and to let farmers know whether some measures have worked or not.

For research: Future studies on SFM adoption should include individual factors that Meijer et al. (2015) have identified as 'intrinsic'. They play an overarching role in the implementation of innovations, at least for soft and knowledge-intensive practices. On the other hand, future studies should be cautious in treating socio-demographic data as independent factors. Certainly, socio-demographic data need to be collected but mainly to check representativeness of samples, not as drivers of adoption.

In future studies, more data on correctness of knowledge of farmers are needed, although some researchers are cautious to test farmers' knowledge as this might look inappropriate. In addition, there is a need to study intensively the information environment of smallholders and check all competing messages on quality and correctness. Furthermore, studies collecting information on social capital and networks must ensure that the groups or networks under research are engaged with the topic being studied.

Some of the factors identified as highly relevant, such as innovativeness, need further investigation, for example by collecting more information about the personality traits of farmers concerning entrepreneurship, managerial capacity, self-efficacy and other factors associated with innovativeness (Kangogo, Dentoni, and Bijman 2021). It may also be useful to intensively investigate the decision-making process about adoption, using process-tracing (Beach and Pederson 2016; Maru et al. 2018) or other causal case study methods.

For design of technologies: It is essential to analyse farmers' past experiences with the practices in question. It would appear particularly relevant to explore in more detail farmers' reasons for abandoning SFM practices, as Grabowski et al. (2016) and Brown, Nuberg, and Llewellyn (2017) did for conservation agriculture.

For communication and information: Following the insight of this study about little effect of information on adoption and the hindering influence of incorrect messages, it is relevant to check the accuracy and quality of information provided to farmers before it is released. Only then can any positive effect on adoption be expected. When designing information campaigns, it is necessary to investigate farmers' information environment on a specific issue like soil fertility and refer directly to the conflicting information to raise farmers' awareness of this issue. Researchers should get opportunities to prepare applicable information to farmers and consult directly with involved extension services and other information providers, like radio stations, online platforms and NGOs. Editors of radio stations in rural areas need to get opportunities to consult with researchers on the correctness of specific messages.

Notes

1. Further details of this approach were published in Spurk et al. 2020, reporting also on results of the baseline study.
2. We also asked for the extent of the practice (in land area), but some answers by farmers were inconclusive (implementation on more than 100% of total farm size), which was only revealed during data analysis. We did not use those data.
3. As it varies between 0 and 5, the outcomes are assumed to be a result of a binomial experiment with 5 independent trials (one trial per outcome).
4. Nevertheless, the Mali farms are small, because baseline data show that the available land size per household member is very limited and similar to the ratio in Kenya, Ghana and Zambia.
5. It has to be noted that the research project has installed innovation platforms (IPs) in all sites on the topic of soil fertility, comprising actors from research, NGOs, extension services and private business. They met and worked differently in the sites. However, none of those IPs developed the dynamics expected in the beginning. Thus, an institutional change process was not initiated and farmers did not mention impacts of IPs in the endline study. The lack of dynamics might be because IPs were not on value chains but on soil fertility.
6. Summary statistics at the bottom show that the percentage of correct predictions of the outcomes vary between 0.7 (70%) and 0.8 (80%) for the individual practices. Nagelkerke R^2 is satisfying; Cohen's f^2 values show strong effects for the entire model: f^2 values of >0.02 are identified as small, >0.15 as medium, and >0.35 as large (Cohen 1992, 157). f^2 values were calculated using Nagelkerke R^2 and the formula $f^2 = R^2/(1-R^2)$.

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Appendix

Table A1. Newcomers and outgoers concerning G-SFM practices.

	Murang'a		Th.-Nithi		Chipata		Kasama		Kade		Sege		Koulikoro		Sikasso	
	N = 273		N = 267		N = 255		N = 196		N = 214		N = 211		N = 216		N = 225	
	New	Out	New	Out	New	Out	New	Out	New	Out	New	Out	New	Out	New	Out
Intercrop with legumes	22%	18%	29%	15%	24%	11%	32%	16%	21%	6%	23%	5%	38%	13%	24%	7%
Agroforestry with SF trees	29%	4%	23%	20%	11%	17%	28%	3%	30%	9%	3%	2%	38%	15%	26%	14%
Crop rotation	38%	11%	19%	10%	15%	9%	38%	6%	14%	8%	23%	22%	14%	8%	13%	4%
Mulching with crop residues	16%	19%	17%	21%	35%	9%	42%	17%	41%	4%	43%	4%	23%	18%	21%	24%
Minimum tillage	14%	13%	39%	11%	27%	20%	26%	1%	58%	3%	9%	13%	15%	26%	8%	41%

[a]new = newcomers, out = outgoers.

Table A2. Descriptive results on explaining factors.

	Kenya		Zambia		Ghana		Mali		
	Murang'a	Tharaka-Nithi	Chipata	Kasama	Kade	Sege	Koulikoro	Sikasso	Average
Farm Size (Mean in acres)	1.54	2.11	4.53	7.79	10.99	7.75	22.14	31.64	10.72
Age (% of 51+)	52%	42%	31%	29%	57%	29%	67%	49%	45%
Education level (% of no schooling)	10%	8%	10%	4%	12%	37%	78%	78%	29%
Female head of unit (%)	57%	58%	54%	39%	40%	44%	2%	6%	39%
Confidence in long-term investment (%)	96%	94%	71%	93%	93%	90%	88%	89%	89%
Awareness of soil fertility as aggravating or remaining problem (%)	42%	46%	48%	44%	49%	58%	87%	84%	57%
Perception of Change in soil fertility (% of farmers seeing an improvement)	52%	50%	54%	41%	33%	21%	16%	12%	38%
Vision future of farming (% of farmers saying that farming has 'no future')	23%	55%	15%	23%	66%	72%	15%	31%	36%
Innovativeness (% of farmers having introduced innovation)	46%	52%	65%	74%	47%	40%	65%	51%	55%
Information seeking (mean of using 15 different sources often)	4.2	5.9	7.3	7.1	4.5	2.7	7.1	6.3	5.6
Soil Fertility-oriented Knowledge (% of farmers)	30%	29%	54%	46%	36%	27%	22%	13%	32%