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Assessing the Adoption and Diffusion of Natural Resource Management Practices: Synthesis of a New Set of Empirical Studies

CGIAR
Independent Science and Partnership Council

Standing Panel on Impact Assessment (SPIA)

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The Independent Science and Partnership Council (ISPC) is a part of CGIAR, a global research partnership for a food secure future dedicated to achieving a world free of poverty, hunger and environmental degradation. The ISPC provides independent advice to CGIAR System Council which is comprised of funders and representatives of developing countries. The mission of the ISPC is to help strengthen the quality, relevance, and impact of CGIAR research by enhancing the System Council's capacity to make evidence-based decisions in support of effective agricultural research programs for sustainable.

ABOUT SPIA

The Standing Panel on Impact Assessment (SPIA) is a sub-group of the ISPC. SPIA's mandate is to provide CGIAR with timely, objective, and credible information on the impacts of research at the system level; provide support to and complement CGIAR centers in their ex post impact assessment activities; and, provide feedback to planning, monitoring and evaluation functions in CGIAR.

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EXECUTIVE SUMMARY

1. This paper provides the context and rationale for a set of new empirical studies estimating the adoption of natural resource management (NRM) practices that could have both private economic benefits and public environmental benefits following adoption. The nine case-studies covered here were commissioned by the CGIAR Standing Panel on Impact Assessment (SPIA) in 2016, and focus on practices that have been part of the CGIAR research agenda over the past decades and have been the subject of multiple claims in CGIAR annual reports regarding widespread farmer adoption of these innovations. They are: conservation agriculture; alternate wetting and drying; fertilizer micro-dosing; integrated soil fertility management; and agroforestry.
2. Summaries of the individual studies are provided as annexes to this report.
3. Widespread adoption is a necessary condition for generating impacts from an innovation. Adoption is not a sufficient condition for generating public benefits, as there are multiple contextual factors that will shape whether the expected positive environmental impacts are realized. However, widespread adoption is a strong signal that the innovation is profitable (i.e. delivers private benefits to farmers) and this formed the rationale for this new set of adoption studies of these specific high-priority NRM practices.
4. To identify the appropriate places to look for widespread adoption, SPIA took a census of all claims about NRM adoption from the annual reports of CGIAR centers from 2003 to 2014, finding 124 claims relating to adoption of specific NRM practices. Following review and a process of prioritization and grouping to ensure focus, SPIA issued a call for proposals in the fall of 2015. A total of 59 expressions of interest were received and were reviewed and scored against the criteria specified in the call document, and members of the 20 higher-ranked bidding teams were invited to attend a workshop at the Food and Agriculture Organization of the United Nations (FAO) in Rome in December 2015.
5. In the workshop, bidding teams presented their ideas for specific adoption studies and based on the subsequent group discussions, proposals were invited on the five practices for specific countries across nine specific work packages (stipulating NRM practice, country, method, budget envelope) and twelve proposals were subsequently received. Following peer review by an interdisciplinary independent panel, the nine studies reported here were accepted for funding. This process represented a hybrid competitive-collaborative model.
6. The results suggest that adoption rates of NRM technology packages promoted by various CGIAR institutions and their partners fell well below expectations based on CGIAR annual reports. Adoption of the full-fledged NRM practices are remarkably and consistently low, ranging from less than 1% to less than 10% in those areas where a variety of actors had been promoting these practices. Some of the NRM practices (e.g. conservation agriculture and integrated soil fertility management) comprise a combination of individual practices, and in those studies data were collected on the individual components. When the definition of these package practices is relaxed, so that adoption of part of the package is defined as "partial adoption" then adoption rates are higher but stay below 15%. Often theseindividual component practices are part of the gamut of options traditionally incorporated into cropping systems by farmers regardless of any intervention by researchers.
7. The implications of these findings for the NRM research agenda are discussed, and some reflections on the methodology used in these case studies are offered.

FOREWORD

The term Natural Resource Management (NRM) is used to describe a broad and complex body of research across CGIAR that has grown in importance since the 1970s. Research approaches to NRM issues cover a huge swathe of specialist expertise – including agronomy, soil science, hydrology, social science, ecology – applied at different spatial scales and with different entry points (policies, programs, and practices). Reflecting this diversity, the professional expertise on NRM is distributed across every single CGIAR Research Program and Research Center.

In this report, SPIA Secretariat member James Stevenson and SPIA consultant Paul Vlek examine a subset of this vast research portfolio in detail. They synthesize the results from a set of nine new adoption studies of on-farm NRM practices commissioned in 2016. The single objective of this set of studies was to estimate the extent to which specific NRM practices had been adopted by farmers. The selection of cases was motivated by a systematic search for claims of widespread adoption of specific NRM practices in countries of strategic importance for CGIAR.

The results are somewhat surprising and yet rather consistent across the different countries and NRM practices studied – adoption is lower than was expected, often much lower. The potential explanations for this finding are many. The original claims of widespread adoption for practices such as conservation agriculture, agroforestry, integrated soil fertility management, alternate wetting-and-drying, and fertilizer micro-dosing – claims often culled from annual reports of CGIAR centers – were overly optimistic. In many cases, assertions of large-scale adoption were based on a particular study documenting adoption in a non-representative population, the results of which were then extrapolated over the entire country.

In some cases, farmers have indeed adopted a component of what was presented to them as an integrated package of practices. This "partial adoption" or "adaptation" of the practices is consistent with the idea that farmers are rationally optimizing their activities. They take on the recommendations that work in their own farm and discard those practices that don't. However, the NRM "package" concept is typically grounded in the theory that a set of inter-linked component practices will, when implemented together or in sequence, bring about both a private benefit to the farmer and some kind of public benefit (e.g. reduced soil erosion, increased soil carbon sequestration, etc). Thus we cannot assume that the same flow of public benefits as observed for full adoption will be realized from partial adoption. The transformative environmental effect of the package as conceived by the NRM researchers may be lost.

The results presented in this important and timely synthesis report have prompted extensive debate among the NRM research community. SPIA convened a workshop at the International Food Policy Research Institute (IFPRI) in February 2018 dedicated to discussing the findings and debating what they mean. SPIA extends its sincere thanks to the fifty researchers in nine project teams from five CGIAR centers and partners who contributed the evidence base for this synthesis report. Their careful and innovative work is much appreciated, as is their willingness to confront disappointing findings and to work out the implications for future research.

Karen Macours
Chair, CGIAR Standing Panel on Impact Assessment

1 INTRODUCTION

International agricultural research focused on improving the management of natural resources (hereon NRM research) has been a key component of the CGIAR portfolio for many years. In their broad survey of the literature, Wright & Shih (2010) find that agricultural innovations primarily focus on higher yields or other production objectives that are expected to have private returns to adoption. However, under the Sustainable Development Goals (SDGs), publicly-funded research towards either inventing new agricultural innovations, or (more commonly) testing, adapting and facilitating the promotion of existing innovations, should also offer public benefits to ensure that environmental or social goals are met. Innovative NRM practices are considered special because they hold the possibility of delivering private returns to the adopter, as well as delivering public benefits.

NRM research spans a wide range of technologies, management practices, and policies including crop, soil, water, pest and livestock management practices, approaches to land use management, land and forest governance and related policies. Innovative NRM practices rarely result from a single, focused research effort alone and similarly diffuse through multiple mechanisms. The invention – be it technological or institutional in nature – often requires a process of fine-tuning to fit local farming conditions, a process that is typically undertaken by many of the same local organizations that are involved in the diffusion of the new practice. Despite this tailoring and fine-tuning of specific practices, farmers may nonetheless choose only a subset of a recommended package of practices to adopt, or may combine the innovation with their traditional management system in unexpected ways. CGIAR researchers are aware of these complexities in the "impact pathways" for their research programs but at the same time are under pressure to demonstrate that the investments made in NRM research by the donor community are yielding results on the farm and for the farmers' natural resource base. This is complicated when the technology as such becomes difficult to discern.

Much research effort is invested in examining these NRM practices under certain conditions to examine the extent of private returns (e.g. yield gains) and social returns (e.g. reduction in soil erosion) to adoption. It is thus an important empirical question as to whether promising results for practices studied on-station, or in on-farm trials, hold for a wider population of farmers. Are the gains from adoption sufficiently greater than the costs? Are there barriers that limit a farmer's ability to adopt an otherwise profitable new practice?

This paper provides the context and rationale for a set of new empirical studies estimating the adoption of natural resource management (NRM) practices that could have both private economic benefits and public environmental benefits following adoption. The case-studies covered here were commissioned by SPIA in 2016, and focus on practices that have been part of CGIAR research agenda over the past decades and have been the subject of multiple claims in CGIAR annual reports regarding widespread farmer adoption. They are: conservation agriculture; alternate wetting and drying in rice production; fertilizer micro-dosing; integrated soil fertility management; and agroforestry (in particular, *Faidherbia sp.*, often referred to as "fertilizer trees").

The paper will set these studies in the context of the impact pathway for NRM research (section 2), outline concepts in adoption and diffusion (section 3), review methods used in estimating adoption, both in general and in the case of this new set of adoption estimates (section 4), present key results (section 5), discuss the implications and possible interpretations of the findings (section 6) and finally draw conclusions for future studies of adoption and, more broadly, the NRM research portfolio in CGIAR (section 7). Summaries of the studies are provided in the annexes, and many of them are forthcoming in peer-reviewed journals.

2 THE IMPACT PATHWAY FOR RESEARCH ON NRM PRACTICES

The innovation process entails a series of steps along an impact pathway, and research organizations, entrepreneurs and donors seek guidance as they weigh the alternative options for investments at different points in this pathway. Assessing the impact of innovation has a long tradition in economics as a means of providing feedback on the rates of returns on such investments. Impact assessment typically addresses the desirable, direct, primary, anticipated and medium-term impacts (Kelley, Ryan, & Gregersen, 2008) of innovations and traditionally has focused on efficiency and the cost-benefit analysis of the investments made. In recent years, impact assessment has shifted more towards a focus on rigorous causal identification linking adoption of a particular innovation and a single outcome of interest (e.g. household income, child nutrition)[1]. Once the impact of an innovation is placed in a longer-term context and includes the impact on future generations, the environment, or society-at-large, the techniques of assessment become mired in discount rates and valuation of externalities for which markets do not readily exist. Waibel & Zilberman, (2007) describe the multiple benefits of NRM technology adoption as comprising market benefits (farmer surplus, manufacturer surplus and consumer surplus) as well as non-market benefits (human health, natural resources and environmental). Impact assessment of innovations thus becomes more complex when a wider range of benefit and cost streams are considered part of the calculus, and questions about the realized public benefit from adoption abound.

Widespread adoption is a necessary condition for generating impacts from an innovation. Adoption is not a sufficient condition for generating public benefits, as there are multiple contextual factors (including how trade-offs play out) that will shape whether the expected positive environmental impacts are realized. However, widespread adoption is a strong signal that the innovation is profitable (i.e., delivers private benefits to farmers) and this formed the rationale for this new set of adoption studies of specific NRM practices that are high-priority for CGIAR.

Farmer and farm heterogeneity affect *ex post* adoption studies due to selection bias - the more skilled farmers are commonly the first to adopt improved technologies and often apply them on their best plots (Barrett, Moser, Mchugh, & Barison, 2004). This is perhaps most pronounced with new technologies that solely reflect improved farmer cultivation and natural resource management practices. This phenomenon of selection into adoption

[1] See (Stevenson, Macours, & Gollin, 2018), for a review of the “rigor revolution” – the shift in methodology and standards of evidence in impact assessment over the past decade

(Barrett et al., 2004; de Janvry, Dustan, & Sadoulet, 2011) makes it difficult to use single cross-sectional comparisons of adopters to non-adopters to understand the process of adoption of a new technology beyond the "snapshot" provided of the year studied. As recommended by Doss (2006), wherever possible, panel data are to be preferred.

Implicit to the continued pursuit of data on adoption rates is the reasonable assumption that the adopter realized private benefits. The actual economic gains are not easily quantified in a single survey, owing to self-selection, absent an explicit research design to capture them. Experimental approaches (i.e. randomized control trials) are increasingly used to estimate the short-run economic benefits of adoption for the population that are targeted to receive information about, or access to, a new technology. Simulation and other modeling approaches are also used (e.g. Pannell, Llewellyn, & Corbeels, 2014) although these may not be representative of the true benefits (or dis-benefits) that the farmers derive from the innovation. Short-term social and environmental benefits of adoption may enter into such calculations if they were part of the objectives and measured from the start. However, the long-term consequences of adoption, particularly for NRM practices, are rarely studied.

Ideally, any innovation, before it is the subject of a laborious process of promotion and distribution should have a clearly defined set of agronomic or environmental benefits, and undergo a market analysis to identify the potential adopters within the farming population. The cost associated with adopting the technology will need to be set against the private and public benefits it may yield. Changes in factor and output prices may alter the fraction of potential farmers for whom it is profitable to adopt the technology. Once the domain of potential adopters has been properly identified and is judged to constitute a critical proportion of the farm population in a region, distribution efforts by extension or other means can be properly targeted if the expected benefits from aggregate adoption exceed the costs of the associated research and dissemination efforts. *Ex ante* analysis of the potential adopters in a population is rare and complex as both observable and unobservable characteristics of farmers and their farms influence NRM technology adoption decisions. Instead, *ex post* adoption studies, examining the micro-economics of profitability and technology choice are used to shed light on why farmers adopt or reject a technology, and thus offer an explanation for the aggregate diffusion patterns over time. Ruttan, (1996) points out that few studies have been able to pull together both adoption (i.e. an examination of individual decision-making) and diffusion (aggregate, representative picture for a population). The situation is arguably changing with many recent academic papers now looking at the role of social networks in diffusion of technologies, though rarely at a large geographic scale (Beaman et al., 2016; Emerick, 2017).

If private benefits alone are insufficient to induce adoption, incentives may need to be created to stimulate adoption in order to realize the public / social benefits of an innovation. This can either be in the form of a subsidy associated with the implementation of a particular practice (i.e. means-based), or a payment to farmers for delivery of a public benefit (i.e. ends-based). A growing literature examines payments for ecosystems services (e.g. reviews by Jack, Kousky, & Sims, 2008; Pattanayak, Wunder, & Ferraro, 2010) wherein farmers are paid for delivering positive environmental externalities, though the practical and political challenges of implementing such schemes are formidable. The presence of temporary conditional subsidies (e.g. fertilizer subsidies tied to soil conservation practices) may bias our view of adoption if a study is conducted only during the period of the subsidy (e.g. Andersson & D'Souza, 2014, on conservation agriculture in Southern Africa). Once a conditional subsidy, for example from an non-governmental organization (NGO) program or from the government, ends, or when an NGO promoting NRM exits from extension and training, farmers may abandon the practice in question.

3 CONCEPTUALIZING ADOPTION AND DIFFUSION

Following Ruttan (1996), one can make a distinction between adoption studies and diffusion studies. Adoption studies examine the decision of individuals over whether to use a new technology, whereas diffusion studies assess the overall level of adoption by individuals within a specific sector. Empirical studies of farmer adoption of new technology typically focus on the role of farm or farmer characteristics such as farm size, land quality, or education whereas diffusion studies rely on aggregate data to examine the rate of diffusion of different types of technologies, or the same technology in different geographic areas (Fuglie & Kascak, 2002). Diffusion studies are inspired by the seminal work of Griliches (1958) on hybrid corn, and take as their starting point the perspective that the technology must be privately profitable, therefore the analyst's role is to study both the features of the innovation in question and the external factors that help or hinder the process of its diffusion.

The canonical text on diffusion of innovations is by Rogers (1962) who lists a set of attributes of any given innovation that will shape the speed and overall extent of diffusion of the innovation as follows:

1. Relative advantage – How much better is the innovation than the farmer's current practice?
2. Compatibility – How easily does the innovation fit in, both in terms of how she currently manages her resources and the context in which she farms?
3. Complexity – Is the innovation relatively simple or does it require multiple changes to implement?
4. Trialability – Can the innovation be practiced and piloted on a small-scale before being adopted?
5. Observability – How easy is it for the farmer to observe others using the innovation and to infer correctly as to the expected benefits of their own adoption of the same? Are the signs that public / social benefits are accruing easy to observe?

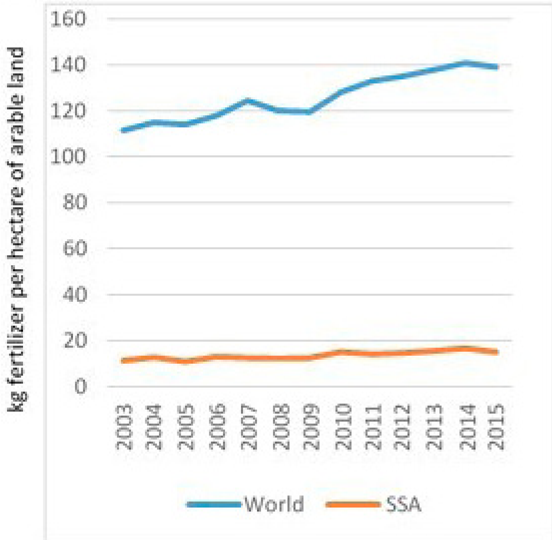
The first category relates to the expected private returns to adoption in only the narrowest sense whereas categories 2 – 5 can all be conceptualized as costs associated with adoption (Caswell, Fuglie, Ingram, Jans, & Kascak, 2001). Nested above these attributes of the technology in Rogers' scheme are contextual factors that shape the adoption decisions of individuals, and in aggregate, the path of diffusion of the innovation.

Arguably very few management practices at any level of generality exist that can be considered to be universal "best" practice in agricultural production. Few technologies are silver bullets, and a technology may work in some systems and not in others. The agroecosystems in which a technology is expected to work can sometimes be poorly defined, and the private returns to adoption of a technology can vary significantly within a region or a community due to soil heterogeneity.

Griliches (1957) famously showed that the profitability of hybrid maize seed was the most important determinant that drove its adoption across the United States. However, consider the complementary decision to hybrid seed adoption – the decision to apply fertilizer to one's field. Across Sub-Saharan Africa persistently low fertilizer adoption is evident (see figure 1 below). In the abstract, one can imagine that farmers in Sub-Saharan Africa *should* adopt the practice of applying fertilizer. However, when the baseline productivity is so low – partially owing to a lack of nutrients in soil but also a function of poor quality seed, biotic or abiotic constraints, lack of irrigation, etc. – even a doubling of yields from adding fertilizer may not result in sufficient return to offset the costs of buying and applying the fertilizer. Other changes in prevailing management may need to change, either simultaneously or phased over time, to accompany the decision to adopt fertilizer in order for fertilizer application to be profitable.

For example, Kaizzi, Ssali, & Vlek (2004) carried out a series of on-farm trials in Uganda, to study returns to fertilizer use in a representative sample of fields in two different eco-regions. Given the prevailing input and output prices at the time, the returns to fertilizer use were positive only under the most favourable of conditions (i.e. high rainfall and fertile soils) thus suggesting that the low rate of fertilizer use was a rational decision on the part of the farmers in the majority of the study areas. Suri, (2011), in a highly influential paper on heterogeneity of returns to technology adoption, came to a similar conclusion regarding hybrid maize adoption in Kenya, finding the observed adoption patterns to be broadly rational – a result that echoes David Hopper's recognition as far back as the 1950s that farmers in Asia are allocatively efficient but technically inefficient (Hopper, 1965). Despite large estimated gross returns for non-adopters, such returns are correlated with high costs of acquiring hybrid seed (due to poor infrastructure).

Figure 1: Aggregate fertilizer application rates for sub-Saharan Africa compared to the rest of the world, in kg ha-1 of arable land (FAO data). Note that the low average rates for Africa here are largely driven by the overwhelming majority of farmers who apply zero fertilizer

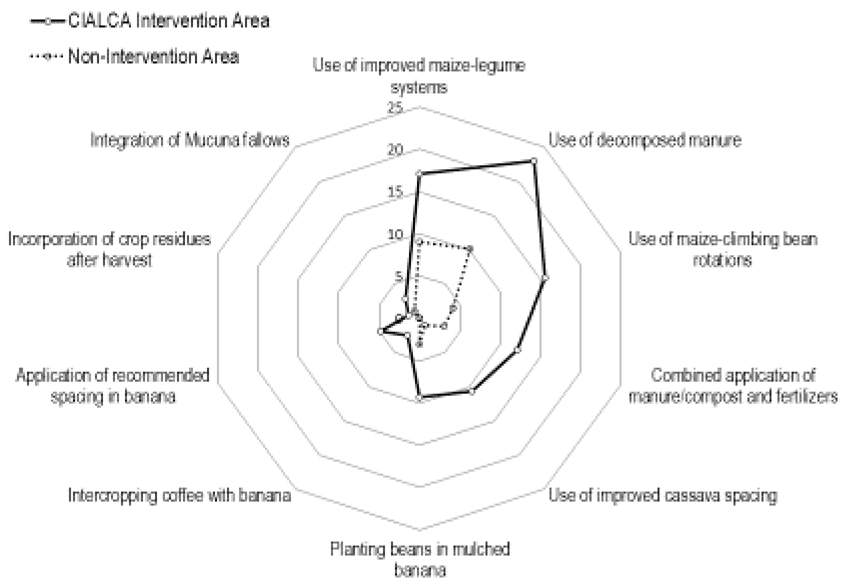


These examples illustrate the fact that differences in the environmental, economic or social realities of the conditions under which a technology is studied on-station or in on-farm trials, to those faced by the average farmer, may explain a low rate of adoption. Even when anticipated by the researchers, these contextual differences can be impossible to fully take into account.

The impact of environmental conditions on adoption rates was also highlighted by Fuglie & Kascak (2002) in a seminal study on how soil heterogeneity helps explain differences in the lag times for adoption of NRM practices in the United States. They found that conservation tillage, soil nutrient testing and integrated pest management (IPM) are all adopted more slowly on land with low inherent soil quality compared with land of moderate or high quality. Conservation tillage was adopted at a higher rate on moderately or highly erodible soils and IPM diffused more rapidly throughout the moderate and high rainfall areas, consistent with expectations of greater pest and disease pressure.

Arguably the major pathway for diffusion of an innovation takes place through farmers observing or seeking information from peers and neighbors, and there is a growing economics literature looking at the extent to which this process can be fostered through interventions e.g. (Beaman et al., 2016; Breza, 2016). The extension of NRM practices can encourage more farmers to adopt those practices if they are generally already known to them, as seen in the spider diagram in figure 2 – those practices that are adopted by large shares of farmers in project intervention sites (solid line) are to some extent already practiced in the absence of the intervention (dotted line). On the other hand, practices that are essentially foreign to the farming communities such as incorporating straw residues after harvest are likely not adopted even after a promotional effort.[2]

Figure 2. Uptake of improved crop and soil management practices by farmers in and outside intervention areas of the CIALCA (Consortium for Improving Agriculture-based Livelihoods in Central Africa). Presented values are percentages of the farming populations in the survey that have adopted the indicated practices. Source: Dontsop Nguezet et al. (2017) in Vanlauwe et al. (2017)



[2] It should be noted that in this particular example, rather than unfamiliarity of the technology to farmers in both sites, there may be factors such as a high opportunity cost of straw for other purposes that are common across intervention and non-intervention areas.

4 OVERVIEW OF METHODS USED TO ESTIMATE THE ADOPTION AND DIFFUSION OF NRM PRACTICES AT SCALE

4.1 HOUSEHOLD SURVEYS

Household surveys deliver a snapshot view of the rate of diffusion of a given technology. They can be tailored to a given technology and, provided the necessary ancillary data are collected, may offer some insight into the factors affecting the spread of the technology. However, many of the challenges outlined in section 2 are difficult to address without panel data. As Doss (2006) observes: "*Because collecting panel data-sets requires a major commitment of time and resources, we should not dismiss the need for cross-sectional analyses of individual sites. Yet, to understand the long-term dynamics of adoption, it is necessary to develop panel data for key locations. Generating the additional information will likely involve considerable expense, but the payoffs could be large in terms of our understanding of technology adoption.*" p. 211. The Living Standards Measurement Study – Integrated Surveys of Agriculture (LSMS-ISA) program of the World Bank is the only large-scale initiative that has taken up the challenge. LSMS-ISA surveys provide panel structure over a nationally representative survey of households in eight Sub-Saharan African countries: Malawi, Uganda, Tanzania, Ethiopia, Nigeria, Niger, Mali and Burkina Faso. As more of these data come on-stream, the prospects of analysing dynamics of adoption of NRM practices over time for a sample of farmers becomes possible.

Two factors limit the utility of nationally representative surveys for the purposes of understanding NRM adoption: low incidence of adopters in a nationally representative survey; and the limits to inclusion of additional data collection modules about NRM practices into surveys that are already long and complex. In many instances, the recommendation domain, and focus of the NRM research effort, will be restricted to one or two regions in a country. One solution to this problem is to carry out oversampling in certain areas, ideally in partnership with the same statistics offices (e.g. in off-years for the LSMS-ISA panel), in order to generate data with higher incidence of adopters beyond some critical threshold needed to have power for statistical analysis. This more targeted, "top-up" survey visit can be statistically linked to the larger sample through, for example, small-area estimation methods (Rao, 2015). The most fundamental constraint however, is that there are few countries with such well-institutionalized panel surveys so bespoke surveys will continue to be commissioned for specific purposes. All the studies reported here draw on some kind of household survey, of which four built on a previous wave, or waves, of a panel survey.

4.2 EXPERT-OPINION ESTIMATION

Generating rigorous data for the same NRM technology across multiple countries for the same time period is a daunting challenge – to our knowledge it has never been achieved. To carry out large, multi-country assessments of agricultural technology use, something has to give. Typically, it has been rigor that has been traded-off at the margin to reach large scale. Landmark studies in the literature on the Green Revolution such as Evenson & Gollin, (2003) relied heavily on the method of expert-opinion estimation, in order to deliver a single coordinated dataset on varietal release and adoption. In expert opinion estimation of diffusion of crop varieties, researchers convene focus groups of breeders, extension workers and other "knowledgeable people" to discuss farmers' use of varieties and gradually iterate towards a jointly-generated estimate for adoption of specific agricultural technologies. Walker & Alwang, (2015) describe the method and feature a number of new studies filling important gaps in the global literature on adoption of varieties for specific combinations of crops and countries.

The problem is that, in order to cover multiple technologies in multiple countries, rigor may be traded-off too much. Emerging evidence from the use of DNA fingerprinting in varietal adoption surveys (Floro, Labarta, Becerra López-Lavalle, Martinez, & Ovalle, 2017; Kosmowski et al., 2018; Maredia et al., 2016) shows us that the conclusions drawn from expert opinion estimation may need to be questioned. While expert opinion estimation has rarely been attempted for NRM practices, given the problems highlighted above, that may not be regrettable – other methods are to be strongly preferred.

4.3 REMOTE SENSING

The advantage of remote sensing is the potential to get large-scale estimates of adoption of NRM practices over time and across multiple countries. The number and acuity of satellite-based sensors launched by a range of public and private sector institutions is increasing all the time. Remotely sensed crop production and cultivated area estimates are now sufficiently accurate to closely approximate high-quality survey data, even for small irregular plots in Western Kenya (Burke & Lobell, 2017) – a development that offers many possibilities for more rapid diagnosis of productivity changes in agriculture. Nonetheless, there are two specific constraints to the use of remote sensing in understanding the adoption of NRM practices.

First, some NRM practices simply do not display phenotypic signatures that can be remotely sensed. Some practices are not directly observable, such as farmers' management decision-making regarding trees that happen to grow on the farm (in the case of agroforestry) or the spatial distribution of fertilizer in maize plots (in the case fertilizer micro-dosing). Second, remote sensing offers potential for documenting *diffusion* of certain practices, but offers little to understand the process of *adoption* without being linked to household survey data. Similarly, if one wants to study the impacts from adoption it is necessary to link the remotely-sensed data on the presence or absence of a particular NRM practice, to data on the developmental or ecological outcomes of interest in a causal framework. This is something that is difficult to do from space, but there is a lot of intellectual energy currently being devoted to the challenge of linking large, disparate, spatially-explicit datasets (Benyishay et al., 2017). Linking high-quality spatially-explicit survey data with remote sensing may offer the best of both worlds. Four studies in the set reported here use remote sensing methods as a central part of their study design (see table 3).

4.4 CELL PHONE-BASED SURVEYS

Given the rapid diffusion of cell phones across the majority of countries around the world, the possibility of collecting data using cell phones is attractive and feasible (Dabalen et al., 2016). The advantages of administering surveys through the cell phone network are obvious – it offers the potential for data to be collected in a more timely manner, and at a lower cost, than traditional household surveys. There are many factors that need to be carefully considered in order to realize this potential. In the "Listening to Africa" initiative, the World Bank trialled cell phone surveys with statistical agencies in six sub-Saharan African countries by giving respondents a cell phone, a solar charger, and provided an incentive in the form of call credit for every interview that they completed. Providing this combination of hardware and incentives to respondents is an explicit strategy to address concerns about the representativeness of the sample that select into any survey. The goal is to have a sample that is as representative of the population as possible.

Measurement error – typically because the respondent does not understand what is being asked of her or is unable to provide an accurate response – is always present in survey data, whether using cell phones or field enumerators. To attempt to mitigate against this, the Listening to Africa initiative used call centers with trained enumerators to help go through the questions with the respondents. Cell phones are particularly useful for collecting high-frequency data (e.g. on certain labor tasks) where measurement error may be a particular problem for traditional surveys. However, in the one study in the set reported here that uses a cell phone survey (the study on ISFM in Rwanda), the survey was implemented through SMS messages that were sent to the respondents. Severe problems of selection bias and measurement error are evident, perhaps not surprisingly, preventing the data from being usable. More details of this experience are provided in annex 9. This by no means rules out a future for cell phone-based surveys as there are much more promising examples emerging (e.g. Arthi, Beegle, De Weerdt, & Palacios-López, 2018, for agricultural labor measurement in Tanzania).

Table 1: Practice-country combinations identified as priority for new adoption studies, based on claims made by CGIAR centers in their annual reports

Priority NRM practices	Priority countries
Agroforestry	Kenya, Zambia, Zimbabwe, Rwanda, Malawi
Alternate wetting and drying (AWD) in rice production systems	China, Vietnam, Philippines, Indonesia, Myanmar, Bangladesh
Conservation agriculture	Zambia, Zimbabwe, Mozambique, Malawi, India, Pakistan, Nepal, Bangladesh, Kyrgyzstan, Uzbekistan, Tajikistan, Turkmenistan, Kazakhstan, Iraq, Mexico
Cocoa integrated crop and pest management (ICPM)	Cameroon, Cote d'Ivoire, Ghana, Liberia, Nigeria
Micro-dosing of fertilizer in maize-based systems	Kenya, Zimbabwe, Mozambique
Integrated soil fertility management	Kenya, Rwanda, Burundi, Democratic Republic of the Congo

4.5 PROCESS FOR COMMISSIONING NINE NEW STUDIES OF THE ADOPTION OF NRM PRACTICES

The aim of the set of NRM adoption studies commissioned under the Strengthening Impact Assessment in the CGIAR (SIAC) program was to obtain a measure of the adoption rate of selected NRM practices and to assess if the scale of adoption would warrant further resources being devoted for impact evaluation. SPIA took a census of all claims about NRM adoption from the annual reports of CGIAR centers from 2003 to 2014, finding 124 claims relating to adoption of specific NRM practices. Following review of these claims they were prioritized into the following combinations of practices and countries (Table 1) as the basis for a call for studies generating new empirical evidence of the adoption of NRM practices. The call was circulated widely and advertised on several CGIAR websites in the fall of 2015.

SPIA received 59 expressions of interest that were reviewed and scored against the criteria specified in the call, and members of 20 of the higher-ranked bidding teams attended a workshop at FAO in Rome in December 2015. In the workshop, bidding teams presented their ideas for adoption studies on the NRM technology of their interest. Group discussions clustered around each practice and explored the advantages of collaboration or specialization/competition among the teams. Based on these discussions in the break-out groups, proposals were invited on five of the six NRM practices[3], across nine specified areas of focus (stipulating NRM practice, country, method, budget envelope) that were eligible for proposals to be submitted. Twelve proposals were received and externally reviewed by a panel of four independent academics from different disciplines. Nine projects were accepted for funding by the SIAC Program Steering Committee , with contracting completed in spring of 2016, and with just over one year for design, fieldwork (if applicable), data analysis and report writing.

The studies reported here were undertaken by research consortia in order to ensure that a broad spectrum of scientific expertise and technological know-how would be brought to bear to address some of the challenges outlined above and to find insights into the motivation of farmers in adopting or rejecting a technology. Summary information on the funded studies is provided in table 2.

[3] Cocoa integrated crop and pest management (ICPM) was the practice that was dropped from the call for full proposals, primarily owing to a difficulty in distinguishing an adopter from non-adopter and a lack of research capacity independent of IITA for studying the technology.

Table 2: Summary information on the funded NRM adoption studies

Studies (see annex for details)	**Authors**	**NRM practice**	**Countries covered**	**Institutions** (Contracted in **bold**)	**Funding allocated by SPIA (USD)**	**Summary of methodology**
1	Bhargava, Boudot, Butler, Chomé, Gupta, Singh and Schulthess	Conservation Agriculture (CA)	India	**IFMR** U Michigan U C Louvain CIMMYT	199,999	New cross-sectional survey; remote sensing
2	Sonder, Schulthess and Chomé	CA	Mexico	CIMMYT	74,888	Remote sensing
3	Mutenje, Marenya, Fantaye and Mazvimavi	CA	Mozambique Zambia	**CIMMYT** ICRISAT	74,913	Expert elicitation; panel survey data
4	Holden, Katengetza, Fisher and Thierfelder	CA	Malawi	**NMBU** U Idaho CIMMYT	111,099	Panel survey data
5	Arslan, Alfani, Scognamillo, Ignaciuk, Asfaw, Conti, Grewer, Kokwe, Kozlowska, McCarthy, Phiri and Spairani	CA Agroforestry	Malawi Zambia	**FAO** (EPIC) IFAD ICRAF	129,400	Panel survey data; remote sensing
6	Michler, Mazvimavi, Kairezi, Liverpool-Tasie and Sanou	CA Fertilizer micro-dosing	Zimbabwe Niger	**ICRISAT** CIMMYT U Illinois	149,890	Multiple existing surveys including panel
7	Vågen, Masikati, Chiputwa, Parmutai, Franzel, Hughes, Jacobson, Kuntashula, Nhlane, Alfani and Arslan	Agroforestry	Zambia	**ICRAF** Penn State FAO (EPIC)	190,457	Remote sensing; existing surveys
8	Lovell, Thuy and Phong	AWD	Vietnam	**U Nong Lam** UC Santa Cruz	100,970	New cross-sectional survey; remote sensing
9	Nkonya, Azzarri, Kato, Koo, Nziguheba and Van Lauwe	ISFM	Kenya Rwanda Zambia	**IFPRI** IITA GeoPoll	199,999	Existing panel survey data (Kenya, Zambia); new SMS survey (Rwanda)

5 RESULTS

Table 3 summarizes the results of the commissioned studies by technology and country.

Table 3. Adoption rates for full adoption and partial adoption of the selected NRM practices. More details in annexes 1-9.

	Country	Innovation	Full adoption (%)	Partial adoption (%)	Data source(s) and methods	Remarks
1	India	CA	0	<3	Remote sensing (Sentinel 1A radar) and new HH survey	Only zero-till was adopted from the CA package and at only a modest scale across the Indo-Gangetic Plains. Higher adoption persists in Punjab. Remote sensing worked well, using method developed in study 2, but each region required its own process of ground-truthing to train the satellite sensors.
	Punjab	CA	0	<16		
2	Mexico	CA	n.a.	n.a.	Remote sensing (Sentinel 1A radar)	Zero-till only. Methods development only (feeding into study 1) based on radar imagery from Sentinel 1A and using specific method applied in Belgium. 94% average accuracy in predicting tillage type achieved for Sinaloa. Yet to be scaled out for major production areas of Mexico with field boundary data constraint at present.
3	Mozambique	CA	<6	<8	Meta-analysis, secondary data (TIA) and new qualitative data	Adoption rates in the National Agricultural Household Survey (TIA) in 2008 and 2012 are broadly comparable (9% partial CA adoption in 2008; 6% full CA adoption in 2012 + 2% partial adoption)
	Zambia	CA	<4	<10	Secondary survey data and new qualitative data	See study 5 for use of RALS data in panel framework. Rates from qualitative data in this study suggest higher adoption.
4	Malawi	CA	<1	<6	Three surveys – a) lead farmers; b) followers; c) random panel	Even among lead farmers, full adoption of all three component practices is low (<3%). Lead farmers do recommend individual practices to their "followers"
5	Malawi	CA	<1	<5	IHPS / SAPP (2013/2014)	Single cross-section data from two different sources
	Zambia	CA	<0.5	<4	RALS (2012 and 2015)	Two waves of Rural Agricultral Livelihood Survey

	Country	Innovation	Full adoption (%)	Partial adoption (%)	Data source(s) and methods	Remarks
6	Zimbabwe	CA	<2.5	<15	ICRISAT panel (2007/8 - 2010/11)	Not nationally representative samples, so numbers are biased upwards (both the FAO and VUNA – a DFID-funded agricultural program implemented by Adam Smith International – survey deliberately over-sampled farmers practicing CA)
			<9	<32	FAO (2015)	
			<8	<32	VUNA (2016)	
	Zimbabwe	MD	n.a.	n.a.	Existing HH survey	Almost all fertilizer use in the sample (88%) is spot-applied but the quantities are higher than for those using other application methods, so there is no real micro-dosing taking place
	Niger	MD	<3	<18	2013-14 survey by ICRISAT	Fertilizer mostly mixed with seed (29%) rather than spot application, and fertilizer adoption increasing but not MD adoption rate.
7	Zambia	AF	<15	n.a.	Remote sensing linked to existing HH survey (RALS 2015)	*Faidherbia albida* was present in 6% of more than 400 fieldwork sites, but in cultivated fields this increases to 15%.
8	Vietnam	AWD	<10	n.a.	Remote sensing (SAR) with new qualitative data	The monitoring pipe technology was rarely adopted, despite being free and accessible via extension services. AWD practices are variable, supporting the need for a scalar approach rather than binary adoption measurement.
9	Rwanda	IFSM	n.a.	n.a.	New SMS survey (GeoPoll)	Methodological innovation in data collection didn't work – highly unrepresentative subset of population respond to survey, plus high measurement error in self-report data obtained from those that did respond
	Zambia	IFSM	<6%	n.a.	RALS (2012)	Adoption rate highest for maize – less than 1% for all other crops
	Kenya	IFSM	<29%	n.a.	Ag Sector Baseline Survey (2013)	Adoption in potato 29% (a commercial crop), 27% for beans and 24% for maize

6 DISCUSSION

6.1 ADOPTION RATES

The adoption rates of the full-fledged NRM practices considered in these studies as elicited through field surveys are remarkably and consistently low, ranging from <1% to <10% in those areas where a variety of actors had been promoting these practices. Some of these NRM practices (CA and ISFM) actually comprise of a combination of practices, and in those studies the farmers were queried as to the use of the individual components. When the definition of these package technologies was relaxed so that the adoption of part of the component practices was defined as partial adoption, adoption rates increased but largely stayed below 15%. Often, the individual components are part of the gamut of options traditionally incorporated into cropping systems by farmers. As such, it is difficult to see to what extent adoption of these components is innovative and due to the efforts of the programs to diffuse the fully-fledged technology.

None of the studies conducted in this project incorporated counterfactual analysis for understanding the efficacy of promotion activities, in the sense of comparing an area where no promotional activities had taken place to those where they had. This would have allowed assessment of the adoption rates of the individual components due to the endeavors of the projects but this was not the objective of this exercise. SPIA placed an emphasis on gaining statistically representative data to respond to long-standing concerns about "cherry-picking" of sample frames (Doss, 2006).

In the case of CA, the technology is defined as a combination of zero till (or minimum till) with the retention of crop residues on the field and the inclusion of a legume crop in the cropping system. In the CA studies in four southern African countries listed in Table 3, the rate of full adoption ranged from 0.5 to 9%, with the highest adoption rates found in Zimbabwe owing to sample frames that likely bias the estimates upwards. The lowest adoption rates were reported for Zambia and Malawi. The adoption of two out of the three components in southern African studies was considered partial adoption. With this relaxed definition of CA, the rates of adoption were generally higher and reached up to 16% and in Zimbabwe, in two surveys where the sample frame deliberately over-sampled CA adopters, even 32%.

There are many possible interpretations of low adoption rates for conservation agriculture. Although there is no question that some farmers can benefit from a shift to minimum or zero-till systems (Reicosky, 2015), these benefits are largely realized through energy savings in mechanized farming from a reduction in diesel for ploughing (Pannell et al., 2014), and only if farmers have access to herbicides (Nyamangara et al., 2014). These conditions are met by a good proportion of the farmers in north and central Mexico and in the Punjab, India.. For small-scale farmers in Africa who work the land by hand or with animal traction (often equivalent to minimum tillage) the zero-till concept may offer no benefits, or might even lead to financial losses. Of the component practices of CA, farmers may be more open to integrating legumes in their cropping systems (figure 2) as many traditional systems integrate legumes in cereal systems as a means of minimizing drought risks (Ofori & Stern, 1987). It is more difficult to convince farmers to retain residues in their fields (figure 2) when in fact straw is valuable as feed and a construction material, and either provides an additional source of income for farmers, or is a resource over which customary rights are held by the community and not by the farmer (Valbuena et al., 2012). Given these circumstances, it may not be surprising that even partial CA adoption (i.e. two out of three of the CA components), has made limited progress, even though it is not possible to explicitly observe these causal factors in the data in the studies.

The NRM technology of alternate wetting and drying (AWD) is a water-saving and methane-emission reducing technology. It was designed for flood-irrigated rice where farmers have enough control over their flooding regime to allow the fields to dry. Water resources are called upon only when the water table is at 10 cm depth as determined with the use of a perforated pipe. The perforated pipe was the specific technology to assist farmers in determining the time of irrigation and therefore allowing them to practice “safe AWD”. However, in the study presented here AWD is defined more broadly as “irrigated rice production using non-continuous flooding when water is readily available”. This definition includes the practice of drying fields even if not motivated by water saving, as well as active drainage of rainfed flooded fields (mostly practised to counter aluminium toxicity). The use of the perforated tube as part of the technology was considered to not be an essential component of the AWD technology, but farmers were surveyed as to how they determined the timing of irrigation events. The survey revealed that full adoption of AWD as originally defined with the use of the perforated pipe was about 10%. Most farmers used other means to determine their irrigation schedule or had no control over the scheduling process at all, being part of a water users association. However, alternate wetting and drying is supported by government policy and any degree of practicing AWD is considered partial adoption in this study. To what extent non-continuous flooding was due to AWD promotion, government policy or traditional practice cannot be easily differentiated.

The fertilizer micro-dosing (MD) adoption reported for Niger and Zimbabwe can, as for CA, be considered fully adopted or partially adopted. The technology was developed by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) as a precision farming technique, where a small amount of fertilizer (1 to 4g) is placed with the seed, separated by a thin layer of soil, typically at planting. In Niger, where line spreading and broadcasting are the traditional chemical fertilizer application techniques, it is claimed that MD is more efficient, using about one third to one fourth of the application rate recommended by research or advisory services. Millet yield responses to MD in research trials using the recommended rate of 30 kg of N ha-1 have varied between 44 and 120%, however from a low average base of 400 kg ha-1. In addition to the traditional and MD techniques, this study also included a farmer invention of mixing millet seed with the equivalent of 2 – 8 kg ha-1 of fertilizer as a means of minimizing the cost of fertilizer use. The farm surveys were limited to the southern provinces of Niger where millet production is most feasible. On average, around 42% of the farmers used fertilizer. Less than 3% of all farmers used the MD application method as promoted by ICRISAT. As it turns out, farmers hedge their commitment to fertilizers until they can see an emergent plant and then “microdose” on the side. When the definition of MD is expanded to include this “late microdosing” the adoption rate comes close to 18%, which arguably constitutes partial adoption. The farmers’ innovation of mixing seed with fertilizer is by far the most popular with 28% of the farmers adopting this technique. The rationale for this preference is analysed in detail in the study by Michler et al, summarized in annex 6.

In the Zimbabwe study, the definition of microdosing is stretched beyond its purpose. Application rates of "microdosed" fertilizer are in excess of 100 kg ha-1 and are not significantly lower than for traditional application methods. This is at odds with the intent of MD as a "targeted application of small, affordable quantities of fertilizer using between one fifth and one third of the normally recommended application rate". Given the rates of application, it is not surprising that the original concept of MD as basal application is not followed in Zimbabwe as such quantities of fertilizer in the proximity of seed might inhibit germination. Instead, fertilizer is side-dressed at different times after germination. All such forms of fertilizer placement in this study are considered MD and by that definition, adoption rates go as high as 70% plus. However, these results are not included in Table 3. Farmer adaptation of NRM practices is to be expected and welcomed, and the fact that the farmers in the Zimbabwe sample can afford and can access such relatively large quantities of fertilizer is positive. However, in this case it is evident that adoption of the original micro-dosing concept is simply not occurring – farmers are managing their fertilizer through spot-applications, but they are not micro-dosing. It would be misleading to describe this as partial adoption.

The concept of integrated soil fertility management (ISFM) was launched and promoted by the International Center for Tropical Agriculture (CIAT)-Tropical Soils Biology and Fertility (CIAT-TSBF) institute. ISFM is defined as a set of soil fertility management practices that include the use of improved germplasm, mineral fertilizers, and organic inputs combined with the knowledge on how to adapt these practices to local conditions (Vanlauwe et al., 2015). This study included an attempt at an SMS survey on ISFM adoption in Rwanda (discussed in section 6.3). For Zambia and Kenya ISFM adoption rates were gleaned from the Rural Agricultural Livelihoods Survey and Agricultural Sector Baseline Survey respectively. The results are listed in Table 3. Though the self-reported adoption of individual components of ISFM can be high, for Zambia, as much as 60% and 40% for seed[4] and fertilizer respectively on the staple crop maize, the full ISFM package does not exceed 6%. In Kenya, individual components are adopted even more widely and the full combination of ISFM reaches as high as 29%, rates much higher than was reported by Nkonya, Johnson, Kwon, & Kato, (2016). One might question whether all three components are essential for the definition of the ISFM technology, but it is unclear to what extent a relaxation of the technology can be justified. For instance, if the use of organic manures were eliminated as an essential part of ISFM, the technology package resembles the standard Green Revolution technology package.

6.2 REFLECTIONS ON ADOPTION RATE

Overall, the adoption rates of the NRM technology packages promoted by various CGIAR institutions and their partners fell well below expectations based on CGIAR annual reports. Undoubtedly, part of the explanation rests with the incentives that CGIAR centers' communications divisions have to optimistically extrapolate the results of small-scale pilots up to larger geographies. However, leaving aside inflated expectations, the adoption rates are still low. For a technology to spread across a large recommendation domain, it should have a degree of context and scale neutrality and yet none of the practices in the studies reported here fit these criteria. For example, farmers and researchers developed zero-tillage and conservation agriculture for agricultural systems quite unlike those that were the focus in these studies. Some of the other practices were developed for rather specific systems with rather limited recommendation domains. Others are too complex to be readily fitted into existing systems. These are significant issues that suggest a mismatch between the practices and the aspirations that researchers had for them.

[4] Note that empirical research using DNA fingerprinting has raised serious concerns about farmers' ability to reliably identify improved vs local varieties (Kosmowski et al., 2018; Maredia et al., 2016)

Within this problem of limited effective domain for adoption, it is helpful to return to the criteria for explaining diffusion from Rogers (1962 - outlined previously in section 3), to look for insights on how the individual practices compare. Reading across the columns in table 4 below, "private benefits" relates to Roger's concept of relative advantage – how much better is the new practice compared to existing practice? With the exceptions of conservation agriculture ***for farmers that are already mechanized*** (and thus benefit from cost savings from reduced ploughing), and fertilizer micro-dosing ***in contexts where the counterfactual is no fertilizer of any kind***, arguably none of the five NRM practices deliver private benefits to the farmer sufficiently quickly to drive adoption absent a conditional subsidy. The other four Rogers criteria (Compatibility, Complexity, Trialability, Observability) can help explain the slow speed of diffusion of a profitable technology through a population. These features of the five practices are noted in table 4, as well as binding constraints and potential benefits to society, but these are of secondary importance to the problem of a lack of private benefit from adoption to drive the process along.

Table 4: Attributes of the NRM practices that facilitate or limit their adoption

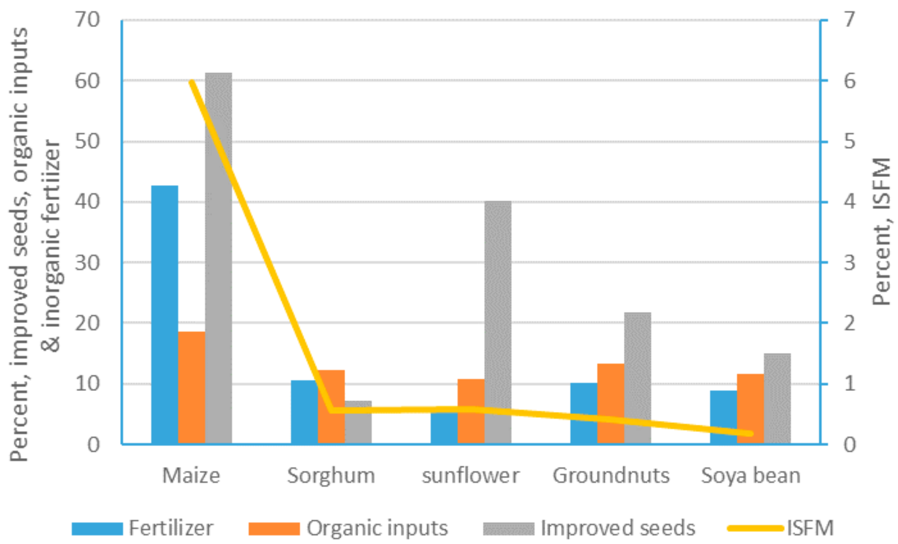
NRM practice	Private benefits	Attributes of the NRM practice related to adoption process (following Rogers, 1962)				Contextual factors constraining / facilitating adoption	Social benefits expected from adoption
		Compatibility	Complexity	Trialability	Observability		
Conservation agriculture	Short-run: Cost-savings from not ploughing if farmers currently mechanized Long-run: Greater soil fertility feeds higher productivity	Major changes often required to equipment	Three component practices make this a complex adoption process	Hard to trial individual components. Difficult to learn about labor implications when trialled on small scale. Time-scale for learning about yield performance may be long	Changes in the condition of the soil are quite visible so neighbors' adoption can be observed quite readily	Community rights to grazing of residue; High opportunity cost of residues; lack of market for legume; shifts in tasks across the agricultural season and labor burden between men and women	Long-term: reduced soil erosion; reduced carbon emissions in mechanised systems from less diesel being used in ploughing
Alternate wetting and drying	Lower fuel costs from reduced pumping, though may actually be traditional practice in some places	Moderate changes	Relatively simple concept to understand	Paddy plot cannot be partly given over to AWD – it is a case of all or nothing	Perforated pipe not a necessary condition for adoption so it can be hard to observe	Organization of water-user groups can make this a collective action problem	More efficient use of water; possible reduction in GHG emissions
Fertilizer micro-dosing	Yield increases over zero fertilizer application; Possible cost-savings relative to non-targeted fertilizer application	Easily fits into existing practice	Simple	A single plot can be monitored. May be difficult to learn about labor implications. Time-scale for learning about yield performance may be long	Observing neighbor's adoption is time-sensitive – the practice is only observable during application of fertilizer	Opportunity cost of labor	Reduction in life-cycle GHG emissions relative to non-targeted fertilizer application
Fertilizer trees (Agroforestry)	Benefit stream depends on type of tree – fruit trees provide food directly; fertilizer trees enhance productivity of cereal crop	Tree planting fits in easily in margins; within a plot, tree-planting can have moderate implications for operations	Moderate – effective tree management requires a range of skills	Not possible to trial – a commitment is needed	Visible in neighbors' plots once established, but the act of planting and managing trees doesn't happen often so timing is important	Access to seedlings. Perceptions about competition for light with crops. Tree and land tenure security, especially given long-term benefit stream	Multiple ecosystem services from additional trees in the landscape
Integrated soil fertility management	Yield increases from fertilizer combined with ability to sustain productivity from higher soil organic matter	Easily fits into existing practice	Complex with multiple component practices	A single plot can be devoted to ISFM and monitored. May be difficult to learn about labor implications	Hard to distinguish from general principles of good agricultural management	Lack of access to, or costs of, inputs	Long-term - possible carbon sequestration, reduction in soil erosion

Given that adoption of NRM practices is a prerequisite for attaining impact, it appears that the greater effort for now should be on targeting. Such efforts should be cognizant of the fact that farmers will adopt only if a technology is profitable. As the socio-economic and ecological conditions in and among farming communities can vary greatly, so can the profitability of new innovations.

Prior to promotion and diffusion of an NRM practice, to learn about the share of farmers that can economically benefit, better-designed field trials are needed in which a randomly selected control group and, depending on the technology, control plots allow for comparisons both across and within farms. By using Randomized Control Trials (RCTs) researchers can look beyond the benefit-cost calculation to study the farmers' behavioral reactions and adaptations that can, in turn, help test the efficacy of specific diffusion or learning mechanisms. Patience is needed while such real-world piloting is carried out, but the potential benefits of such a shift in scientific approach are enormous. The results of such studies can elucidate whether further promotion and diffusion programs are worth the effort and where. For example, an observed 35% adoption rate among all farmers in a region where no more than 50% of the farmers are actually expected to benefit from the technology would translate into an effective 70% adoption rate. The cost of conducting such regional verification studies may be high, but so are efforts to push a practice in regions or to farms where it has no chance of becoming common practice, or where the benefits from adoption are too small to justify the investment in diffusion efforts.

Defining the NRM innovation clearly and unequivocally is a second prerequisite for a clear insight in the rate of diffusion. The simpler the definition of the practice, the easier it will be to track its adoption. Unfortunately, the simpler technologies such as improved seed or use of fertilizer have had a long record of being promoted but even for those, the adoption record in Africa has been patchy (Walker & Alwang, 2015). If, as in the case of integrated soil fertility management, the added value of the practice is considered to derive from the combination of the component practices, one should be cognizant of the difficulties the individual components have encountered in the diffusion process – such difficulties are compounded when combined in a package. The results for Zambia (Figure 3), the country with the highest fertilizer subsidies of the continent (80%) (https://AfricaFertilizer.org/national, accessed Sept 2018), ISFM is being used on maize only, probably because the returns to fertilizer use on the other crops surveyed are still insufficient to cover the cost. The adoption of any innovative package can thus be held down by the low adoption rate of a single component in the package.

Figure 3. Adoption rates of the component practices (bars) and of the overall ISFM package (line) in Zambia for plots cultivating each of five major crops – maize, sorghum, sunflower, groundnuts and soya beans. Nkonya et al, 2017 (see annex 9). Calculated from RALS survey data (2012).



6.3 INNOVATION IN DATA COLLECTION

Five of the nine commissioned studies involved innovative data collection technologies to obtain a measure of the diffusion rates of selected NRM practices. Remote sensing tools were used to ascertain where conservation agriculture had been adopted in studies in Mexico (as proof of concept) and India. Remote sensing tools were also used to determine the extent of AWD adoption in Vietnam and to ascertain the presence of fertilizer trees on farms in Zambia. An SMS-based survey was trialed in Rwanda for estimating ISFM adoption status.

In Mexico, adoption of CA practices was defined as a farmer employing zero tillage (ZT) and crop residue retention during several years in at least one growing season. The study focused mainly on the irrigated season where the start of sowing and the tillage operations for the non-CA plots are more uniform and easier to detect. The detection of crop residue retention was found to be too complicated to be captured by remote sensing, as the retention is too transient because decomposition sets in rapidly. A method based on radar imagery from Sentinel 1A, developed in Belgium for tillage recognition (Chome, Baret, & Defourny, 2016) was chosen for the ZT detection as it can detect the different soil moisture regimes resulting from the two land preparation methods. This study aimed at assessing the accuracy of the ZT identification using an extensive ground-truthing campaign. The results showed a 94% accuracy of ZT detection. This is a promising first step. It is recognized that extensive data on field boundaries would need to be available to extend this technique to entire regions but the prospects of these becoming available in the future in Mexico appear good.

The same methodology was used across the Indo-Gangetic plain reaching from the Punjab to Bihar. In those areas where the field size was sufficient for ground-truthing to train the satellite (Punjab and Haryana) reasonable conversion between the household survey data and the remote sensing (RS) data was achieved. However, the use of the algorithms developed for those states could not be transferred to Bihar without creating a large over-estimation of the areas under ZT. Thus, the RS technology shows promise in tracking diffusion of ZT in some contexts if the necessary investments are made to develop regional algorithms based on extensive ground-truthing. The detection of full-fledged CA adoption will require similar efforts in the detection of crop residues and legumes in the cropping system. A pre-requisite for the successful application of RS technology for ZT or CA detection is the proper identification of field boundaries. The use of GPS in household surveys managed by the World Bank LSMS-ISA program (Carletto, Gourlay, Murray, & Zezza, 2016) offers the prospect of these data being collected, but confidentiality concerns limit their wider sharing or publication online – GPS coordinates of individual households or plots collected through research cannot be in the public domain.

Remote sensing technology was used to assess the extent of AWD practices in the Mekong Delta of Vietnam. The Synthetic Aperture Radar (SAR) data retrieved from the European Space Agency's (ESA) Sentinel 1 satellite with an average return date for the two satellites of six days and a 10x10m resolution was used to calculate a wetness index, with the intention of reflecting AWD adoption. Remote sensing was capable of detecting a drying trend in areas where AWD adoption was common according to the household survey, but it did the same in areas where adoption estimates from the household survey showed it not to be very prevalent. Estimating AWD adoption using remotely sensed data is complex;. the return frequency of the Sentinel satellites are marginal for AWD detection (data every six days may simply be too infrequent to build up the drying and wetting trends with sufficient confidence) and SAR data are difficult to interpret. In addition, remote sensing cannot differentiate between natural AWD cycles, purposeful draining of fields to avoid metal toxicity in rice, and the delay in flooding to save water and methane emissions, this last objective being the major motivation for promoting the AWD practice. The question to ask is whether further investments in this technology are worth it given the problems in differentiating the origin or motivation behind the drying cycle.

Identifying fertilizer trees on farms poses a similar set of challenges. Landsat 8 imagery was combined with 400 biophysical field observations and 550 household surveys to arrive at signatures for the presence/absence of *Faidherbia albida*, the predominant fertilizer tree in the eastern and southern provinces of Zambia according to a 2015 Rural Agricultural Livelihood Survey (RALS). The biophysical survey showed that 6% of the sampled region had *F. albida*. For cultivated plots this was 15% with an average density of 15 trees per ha. The HH survey reported trees on all farms in the sampled region with a density ranging from 12 to 19. The RS technology applied and algorithms developed for the purpose of mapping *F. albida* were 60% accurate in predicting the presence of *F. albida* and 93% accurate in predicting its absence. It is recognized that selective clearcutting, whereby *F. albida* is often traditionally spared in the clearcutting process, is common in these regions as its beneficial properties are known in the communities. However, active planting of seedlings is also reported and RS cannot readily distinguish between the two practices. In all, the RS technology shows promise and might be further developed to assess the geographic extent of fertilizer trees or other agroforestry practices. However, the causal roots of the presence of trees on farms will need elucidation with the help of detailed household surveys.

The data collection technologies pioneered in the current studies have shown mixed results. The use of remote sensing in detecting signals associated with the implementation of a novel NRM technology is promising, particularly given the fact that ever better and more versatile remote sensing platforms will become available. The signals that are detected are not always a true reflection of the practice being promoted (e.g. in AWD) or may reflect only a part of the promoted package (e.g. CA). However, in combination with traditional household surveys, remote sensing may help assess the geographic extent of adoption, provided calibration of the signal has been done throughout the region of concern. Once this is accomplished, the remote sensing technology would provide an excellent tool for tracking the diffusion of the technology over time.

In the case of surveying farmers on ISFM adoption in remote regions with the use of mobile phones and text messages, there is both a clear age bias in the respondents and insufficient clarity in soliciting responses from farmers which yields some illogical answers that are difficult to reconcile without being face-to-face with the subject. An unrepresentative population of farmers select into the SMS survey, and the data obtained from those that do participate are of limited validity. However, it would be inappropriate to draw conclusions for cell phone surveys in general from this limited experience – much more promising examples are being published (Arthi et al., 2018; Dabalen et al., 2016).

7 CONCLUSIONS

Given the efforts expended in learning more about the diffusion of NRM practices considered successful at a given point in time by CGIAR proponents, it seems prudent to draw some lessons from the results. First, it is clear that there are serious discrepancies between the claimed successes and the reality on the ground. There can be a host of reasons for this lack of adoption. In order to adopt a technology, farmers first have to know that it exists. The data from these studies do not allow us to make a sharp distinction between those who know about the technology but don't adopt, and those who are ignorant of the existence of the technology. However, given that these empirical cases were motivated by a prior claim of widespread adoption, and that CGIAR centers and partners have invested in promoting them, it seems unlikely that these efforts will have completely failed to reach farmers.

Some of the possible reasons for non-adoption, low adoption or dis-adoption are that the technology does not pay for itself, does not fit the agricultural system, or is too complex for farmers to see the anticipated benefit. Table 4 summarizes the insights gained through these studies, as well as the discussions held in workshops in Rome (December 2015) and Washington DC (February 2018 – summarized in ISPC, 2018) on how attributes of NRM practices influence the rate at which they are adopted. Within a given community, any of these reasons may prevent a farmer from adoption and one might question whether some of the barriers to adoption could have been anticipated before the technology was introduced. Given the prime importance of private benefits accruing to adopters, for driving adoption along, it would seem unwise to look too far beyond a problem of low or negative short-term profitability as being the major constraint to adoption.

Indeed, it may be efficient for extension projects focused on a certain technology to invest, *ex ante*, in analyzing the recommendation domain in terms of the agro-ecology suitable for the technology, its extent as well as contiguousness and the socio-economic context that favors adoption. Such analysis could provide a realistic expectation of the fraction of the farmers' population that is likely to benefit and adopt. Experimental studies to reveal behavior are even better and there is a growing literature in agriculture for examining agricultural technologies using RCTs. Such use of RCTs should not take as their starting point an assumption that the specific technology under study is "privately beneficial" and that behavioral or market failures explain low adoption. Rather the experimental approach to revealing farmers' response to the technology should be included earlier in the piloting / testing phase of new NRM practices.

Of course, the recommendation domain for any NRM practice is dynamic. Though the eco logical conditions are generally rather stable, desertification, climate change, and pests and diseases may disrupt this stability and change the farmer's assessment of the technology on offer. Shifts in context due to socio-economic developments likely change faster than ecological conditions, as farming communities become better connected to markets, farmers are better educated and the prospects of career options outside agriculture improve. Thus, practices that do not work today may work tomorrow or *vice-versa*.

To some extent, government policies can be designed to change the context and stimulate the uptake of a technology. If the private economic returns are the prior constraint, governments may offer incentives such as subsidies or payment for ecosystem services, particularly if the public benefits of adoption can justify such an investment. Research on how recommendation domains can be expanded will help development agencies and governments in creating an enabling adoption environment. The Holy Grail in NRM innovation would be an invention that has a degree of scale and context neutrality and thus has a recommendation domain that encompasses a range of ecologies and socio-economic contexts. The results presented here suggest that there is a dearth of broad-based NRM practices that can address some of the production and sustainability issues with which farmers are struggling. This poses a true research challenge to CGIAR but it is an urgent research agenda given the myriad ecological challenges facing agriculture over the coming decades.

In the meantime, development agencies should be encouraged to promote NRM management principles that will conserve the natural resource base on which agriculture relies such as soils, water and biological resources. One of these simple ideas gaining popularity in the context of the Paris Agreement is the build-up of soil organic matter, as it serves as the substrate for soil life and health. As a technology with benefits that are deferred into the future, it is often difficult to convince farmers to retain or return organic residues. If payments for the adoption such practices – so that farmers benefit in the short-term – can give it the necessary momentum in the quest for carbon-sequestration to mitigate climate change, farmers will benefit in the long-term. The single mindedness of such an objective (increase soil organic matter) combined with an agnosticism about means for achieving it, may lead to a range of simple practices that are made economically attractive due to external incentives, are simple to transfer and relatively easy to fit into existing production systems. Such a shift towards promoting, incentivizing and monitoring the adoption of widely-applicable principles, rather than specific practices that may only fit in relatively small agro-ecological niches, represents a potentially significant change and one that is worthy of reflection among the NRM research community.

REFERENCES

Andersson, J. A., & D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems and Environment, 187*(November), 116–132. https://doi.org/10.1016/j.agee.2013.08.008

Arthi, V., Beegle, K., De Weerdt, J., & Palacios-López, A. (2018). Not your average job: Measuring farm labor in Tanzania. *Journal of Development Economics, 130*(October 2016), 160–172. https://doi.org/10.1016/j.jdeveco.2017.10.005

Barrett, C. B., Moser, C. M., Mchugh, O. V, & Barison, J. (2004). Better Technology , Better Plots , or Better Farmers ? Identifying Changes in Productivity and Risk among Malagasy Rice Farmers. *American Journal of Agricultural Economics, 86*(4), 869–888.

Beaman, L., Benyishay, A., William, C., Magruder, J., Beaman, L., Benyishay, A., & Magruder, J. (2016). Can Network Theory-based Targeting Increase Technology Adoption ?

Benyishay, A., Parks, B., Runfola, D., Tanner, J., Trichler, R., Heuser, S., … Anand, A. (2017). *A primer on geospatial impact evaluation methods, tools, and applications*.

Breza, E. (2016). Field experiments, social networks, and development. In *The Oxford Handbook on the Economics of Networks*.

Burke, M., & Lobell, D. B. (2017). Satellite-based assessment of yield variation and its determinants in smallholder African systems. *Proceedings of the National Academy of Sciences, 114*(9), 2189–2194. https://doi.org/10.1073/pnas.1616919114

Carletto, C., Gourlay, S., Murray, S., & Zezza, A. (2016). *Land Area Measurement in Household Surveys: Empirical evidence & practical guidance for effective data collection*. Washington D.C.

Caswell, M., Fuglie, K., Ingram, C., Jans, S., & Kascak, C. (2001). *Adoption of agricultural production practices: lessons learned from the US Department of Agricultural Area Studies Project* (No. Agricultural Economic Report No. 792). Washington D.C.

Chome, G., Baret, P., & Defourny, P. (2016). Mapping farming practices in Belgian intensive cropping systems from Sentinel-1 SAR times-series. In *Living Planet Symposium*. Prague, Czech Republic.

Dabalen, A., Etang, A., Hoogeveen, J., Mushi, E., Schipper, Y., & Engelhardt, J. von. (2016). *Mobile Phone Panel Surveys in Developing Countries: a practical guide for microdata collection*. http://dx.doi.org/10.1596/978-1-4648-0904-0

de Janvry, A., Dustan, A., & Sadoulet, E. (2011). *Recent Advances in Impact Analysis Methods for Ex-post Impact Assessments of Agricultural Technology : Options for the CGIAR*. Rome.

Doss, C. R. (2006). Analyzing technology adoption using microstudies: Limitations, challenges, and opportunities for improvement. *Agricultural Economics, 34*(3), 207–219. https://doi.org/10.1111/

j.1574-0864.2006.00119.x

Emerick, K. (2017). The cost of favoritism in network-based markets. IED Discussion Paper Series - Institute for Economic Development, Boston University, (288), 1–65. http://www.bu.edu/econ/files/2017/03/Emerick_The_Cost_of_Favoritism.pdf%0A

Evenson, R. E., & Gollin, D. (2003). Assessing the impact of the Green Revolution, 1960 to 2000. *Science, 300*(5620), 758–762. https://doi.org/10.1126/science.1078710

Floro, V. O., Labarta, R. A., Becerra López-Lavalle, L. A., Martinez, J. M., & Ovalle, T. M. (2017). Household Determinants of the Adoption of Improved Cassava Varieties using DNA Fingerprinting to Identify Varieties in Farmer Fields: A Case Study in Colombia. J*ournal of Agricultural Economics*. https://doi.org/10.1111/1477-9552.12247

Fuglie, K. O., & Kascak, C. A. (2002). Adoption and diffusion of natural-resource conserving agricultural technology. *Review of Agricultural Economics, 23*(2), 386–403. https://doi.org/10.1111/1467-9353.00068

Griliches, Z. (1957). Hybrid Corn : An Exploration in the Economics of Technological Change. *Econometrica*, 25(4), 501–522.

Griliches, Z. (1958). Research Costs and Social Returns : Hybrid Corn and Related Innovations. *Journal of Political Economy*, 66(5), 419–431.

Hopper, D. (1965). Allocative efficiency in traditional Indian agriculture. *Journal of Farm Economics*, 47(3), 611–624.

ISPC. (2018). Managing Natural Resources for Sustainable Production Systems: A Research Agenda at the Crossroads?, Brief N. 68. Rome: Independent Science and Partnership Council.

Jack, B. K., Kousky, C., & Sims, K. R. E. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences, 105*(28), 9465–9470. https://doi.org/10.1073/pnas.0705503104

Kaizzi, C. K., Ssali, H., & Vlek, P. L. G. (2004). The potential of Velvet bean (Mucuna pruriens) and N fertilizers in maize production on contrasting soils and agro-ecological zones of East Uganda. *Nutrient Cycling in Agroecosystems, 68*, 59–72.

Kelley, T., Ryan, J., & Gregersen, H. (2008). Enhancing *ex post* impact assessment of agricultural research: the CGIAR experience. *Research Evaluation, 17*(3), 201–212. https://doi.org/10.3152/095820208x331711

Kosmowski, F., Aragaw, A., Kilian, A., Ambel, A., Ilukor, J., Yigezu, B., & Stevenson, J. (2018). Varietal Identification in Household Surveys: Results From Three Household-Based Methods Against the Benchmark of DNA Fingerprinting in Southern Ethiopia. *Experimental Agriculture*, 1–15. https://doi.org/10.1017/S0014479718000030

Maredia et al. (2016). Testing Alternative Methods of Varietal Identification Using Dna Fingerprinting: Results of Pilot Studies in Ghana and Zambia. *MSU International Development Working Paper, 149*(149), 1–36. https://doi.org/10.13140/RG.2.2.11573.27361

Nkonya, E., Johnson, T., Kwon, H. Y., & Kato, E. (2016). *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development*. https://doi.org/10.1007/978-3-319-19168-3

Nyamangara, J., Mashingaidze, N., Masvaya, E. N., Nyengerai, K., Kunzekweguta, M., Tirivavi, R., & Mazvimavi, K. (2014). Weed growth and labor demand under hand-hoe based reduced tillage in smallholder farmers' fields in Zimbabwe. *Agriculture, Ecosystems & Environment, 187*, 146–154. https://doi.org/10.1016/J.AGEE.2013.10.005

Ofori, F., & Stern, W. R. (1987). Cereal–Legume Intercropping Systems. *Advances in Agronomy*, 41, 41–90. https://doi.org/10.1016/S0065-

2113(08)60802-0

Pannell, D. J., Llewellyn, R. S., & Corbeels, M. (2014). The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems & Environment, 187*, 52–64. https://doi.org/10.1016/J.AGEE.2013.10.014

Pattanayak, S. K., Wunder, S., & Ferraro, P. J. (2010). Show me the money: Do payments supply environmental services in developing countries? *Review of Environmental Economics and Policy, 4*(2), 254–274. https://doi.org/10.1093/reep/req006

Rao, J. N. K. (2015). *Small-Area Estimation*. John Wiley & Sons.

Reicosky, D. C. (2015). Conservation tillage is not conservation agriculture. *Journal of Soil and Water Conservation, 70*(5), 103A–108A. https://doi.org/10.2489/jswc.70.5.103A

Rogers, E. M. (1962). *Diffusion of innovations*. Simon and Schuster.

Ruttan, V. W. (1996). What happened to technology adoption-diffusion research? *Sociologia Ruralis, 36*, 51–73.

Stevenson, J. R., Macours, K., & Gollin, D. (2018). *The rigor revolution in impact assessment: Implications for the CGIAR* (Standing Panel on Impact Assessment synthesis reports). Rome.

Suri, T. (2011). Selection and Comparative Advantage in Technology Adoption. *Econometrica, 79*(1), 159–209. https://doi.org/10.3982/ECTA7749

Valbuena, D., Erenstein, O., Homann-Kee Tui, S., Abdoulaye, T., Claessens, L., Duncan, A. J., … van Wijk, M. T. (2012). Conservation Agriculture in mixed crop–livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research, 132*, 175–184. https://doi.org/10.1016/j.fcr.2012.02.022

Vanlauwe, B., AbdelGadir, A. H., Adewopo, J., Adjei-Nsiah, S., Ampadu-Boakye, T., Asare, R., … Mutsaers, H. J. W. (2017). Looking back and moving forward: 50 years of soil and soil fertility management research in sub-Saharan Africa. *International Journal of Agricultural Sustainability, 15*(6), 613–631. https://doi.org/10.1080/14735903.2017.1393038

Vanlauwe, B., Descheemaeker, K., Giller, K. E., Huising, J., Merckx, R., Nziguheba, G., … Zingore, S. (2015). Integrated soil fertility management in sub-Saharan Africa: Unravelling local adaptation. *Soil, 1*(1), 491–508. https://doi.org/10.5194/soil-1-491-2015

Waibel, H., & Zilberman, D. (2007). *International research on natural resource management advances in impact assessment*. Retrieved from http://www.cabi.org/cabebooks/FullTextPDF/2008/20083095706.pdf

Walker, T. S., & Alwang, J. (2015a). *Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa*. Wallingford, UK: CGIAR Consortium of International Agricultural Research Centers; CAB International.

Walker, T. S., & Alwang, J. (2015b). *Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa*. https://doi.org/10.1079/9781780644011.0000

Wright, B. D., & Shih, T. (2010). Agricultural Innovation, 47. Retrieved from http://papers.ssrn.com/abstract=1565895

ANNEXES

A1. DOCUMENTING ADOPTION OF CONSERVATION AGRICULTURE ACROSS THE INDO-GANGETIC PLAINS

Bhargava A, Boudot C, Butler A, Chomé G, Gupta K, Singh R and U Schulthess

Overview

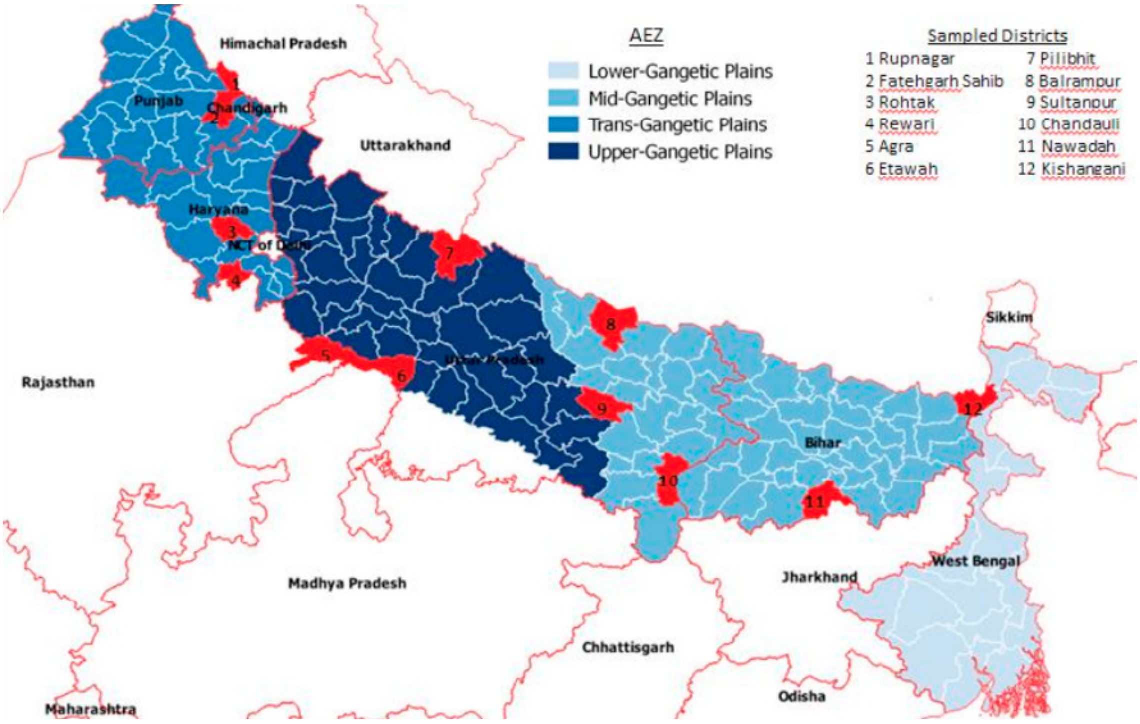
Conservation Agriculture (CA) includes continuous minimal soil disturbance (zero tillage [ZT]) and permanent organic soil cover (mulching), combined with diversification of crops grown in sequence and association preferably including at least one legume. In the 1970's local researchers in India began to explore ZT agriculture for rice-wheat cropping systems. Despite the potential benefits of CA, lack of access to affordable sowing technology prevented the practice from gaining popularity with farmers. In 1994, the launch of the CGIAR Rice Wheat Consortium reignited efforts to develop and promote ZT agriculture across the Indo-Gangetic Plains (IGP). Unfortunately, rigorous monitoring of adoption rates has not accompanied CA promotion in India. Widely-used estimates relied primarily on rough calculations by experts at the state level using a range of indicators, such as the sale and rental of ZT drills and the average area coverage per drill (Gupta et al. 2002; Erenstein et al. 2007).

This study aims to compile the first robust and regionally representative estimates of IGP CA adoption. The researchers conducted a large-scale household survey across four states (Punjab, Haryana, Uttar Pradesh [UP], and Bihar) covering 3,600 households from 240 villages across 12 districts and complemented findings with area estimates newly developed remote sensing methods.

Background

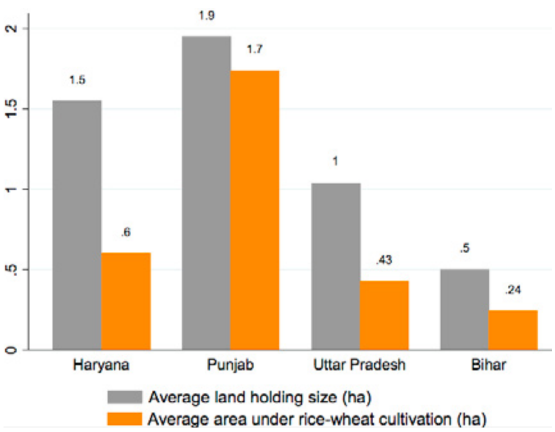
The IGP has four agro-ecological zones (Figure A1.1) varying in soil type, rainfall, temperature, and water availability, which likely influence the type of crops grown and agricultural practices adopted. Rice-Wheat is the predominant cropping sequence in the IGP. Farmers plant rice at the onset of the monsoon (Kharif season) and wheat in the winter (Rabi season). The research team confined the study to the most prominent wheat producing zones, covering the states of Punjab, Haryana, UP, and Bihar.

Figure A1.1: Agro ecological sub-regions of Indo-Gangetic plains and selected districts.

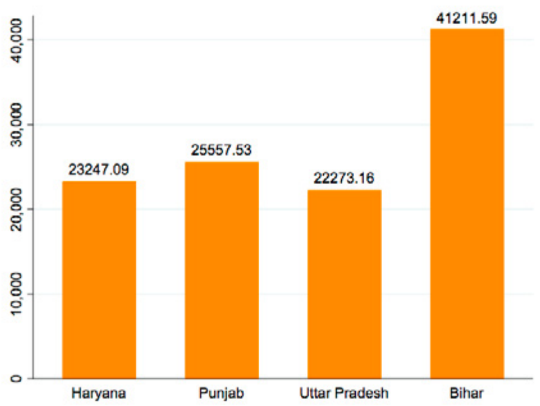


The researchers selected the sample to be representative at the regional and administrative levels and used a stratified three-stage cluster sampling design. In the first stage, they randomly selected four districts from the each AEZ district list of the 2011 Indian census leading to a total of 12 selected districts across the study area (Figure A1.1). During the second stage, the researchers chose a random sample of 20 villages from each selected district from the 2011 Indian census list. Within each selected village, they conducted complete listing surveys eliciting information on identification features for all households. In the third stage, the research team randomly selected households from this sampling framework for the main survey using a proportional sampling methodology, based on village population). The main survey covered, on average, 15 households per village, across 20 villages in each of the selected 12 districts, giving a final sample population of 3,607 households across 240 villages. Farmers often select the specific aspects of CA (as defined by FAO) which are most beneficial to them. Due to this flexibility and interdependence of practices, it would be unreasonable to simply define adoption by the strict FAO definition. As a result, the researchers measure adoption according to three definitions varying in degrees of completeness.

Graph A1.1: Average land holding and area under rice-wheat cultivation (ha)



Graph A1.2: Average agricultural input expenditure (Kharif 2016)



Remote sensing has great potential for shedding light on technology adoption, particularly CA as satellite imagery and machine learning may be able to observe soil quality, mulching, cropping patterns, and tillage. Initial ground truthing of remote sensing data is essential to obtain robust estimates and was conducted in regions of Punjab, Haryana, and Bihar. These were sampled because the International Maize and Wheat Improvement Center (CIMMYT) was actively conducting demonstration and other experiments in relation to CA in these regions, and they were known to have little adoption. This selection ensured that a sampling of enough ZT and non-ZT sites in order to train the classifier.

Results

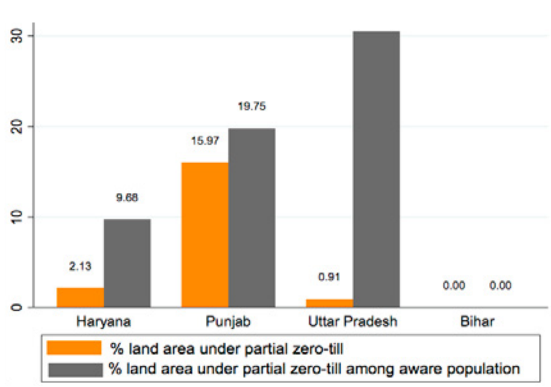
Household survey

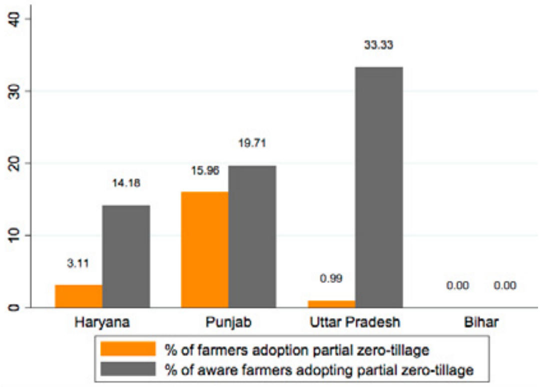
Researchers found large variation in the land holding size across the four states, with Punjab reporting the highest average land holding of 1.9 hectares per farmer as opposed to 0.5 hectares reported by farmers in Bihar (Graph A1.1). On average, Punjab also has the highest percentage of land under rice-wheat cropping system (89%) compared to 40% in Haryana, 43% in UP, and 48% in Bihar. On average, 91% of the agricultural land area is irrigated for the entire sample, with only slight variation across states. Although the farmers in Bihar have the lowest land holding, they spend the most on agricultural inputs (Graph A1.2). The average per hectare expenditure on agricultural inputs is during Kharif (monsoon) season. Awareness is a natural precursor to adoption of a technology. Across the entire sample, there were low levels of awareness of CA, with on average less than 19% of participants responding positively to knowing of these practices. Of the subset of those aware of the technology, the vast majority area in Punjab, with much smaller shares in Haryana, Uttar Pradesh and Bihar.

The researchers found low levels of adoption, even by the broadest definition of partial ZT with less than 4% of the complete sample practicing ZT in at least one agricultural season. Adoption of complete ZT or complete CA was only observed in Punjab and was limited to less than 1% of land area.

Due to the low percentages, the discussion focuses only on the case of partial ZT. Graph A1.3 and A1.4 explore the percent of total land area and farmers under partial ZT, respectively, across the four states. Adoption was concentrated in Punjab where almost 16% of the farmers as well as the cultivated land area is under partial ZT. In the remaining states, less than 3% of the total cultivated land area is under partial ZT and similar for the percent of farmers. This variation is also likely the result of continuous targeting and promotion, as well as the higher financial status of farmers in Punjab relative to UP or Bihar. ZT requires the use of specific machines for sowing, which may not be available to poorer farmers. Adoption rates among the population that is aware of CA (see Graph A1.3 and A1.4) is about one-fifth for the total sample. This suggests that while awareness is clearly a precursor to adopting, it is not the sole constraint. In Punjab adoption rates are similar among the aware and total population suggesting that information is no longer a constraint. In contrast, adoption rates in Haryana and UP are significantly higher among the aware population which indicates that promotion efforts in these regions could still boost adoption.

Graph 1.4: Percent of farmers adopting partial zero-till





Remote Sensing

The researchers relied on a methodology that was developed for ZT estimation in Belgium (Chomé, 2016). The distribution of the percentage of ZT fields by administrative sub-district level is shown in Figure A1.2 and A1.3. Overall, they estimated an area of 0.59 million ha that are under ZT within an area of 3.24 million ha of cropland in Punjab and Haryana. This results in a ZT proportion of 18% which matches well to the estimates established through household surveys. The reliability of the measure for Bihar and Eastern UP is questionable mainly due to the small size of the fields, the small size of the training and validation sample (ground truthing sample), and diversity in agricultural practices across and within districts in a given state.

Discussion

The household survey estimated an adoption rate ranging from 15.96% of total cultivated area under partial ZT in Punjab to 0% on Bihar. When scaling these estimates to the four states, on average only 3.37% of the cultivated land area is under partial ZT practice. This corresponds to approx 0.86 million ha of cultivated land.

The remote sensing analysis, aimed at complementing the household survey with an objective measure of adoption of ZT, reports an average adoption measure of approximately 18% (corresponding to 0.59 million ha of cropland) in Punjab and Haryana and 28% (corresponding to 0.44 million ha of cropland) in Bihar and Eastern UP. Importantly, both measures of adoption report very high rates of heterogeneity in CA adoption. Large differences across states ares shown in the household survey, however, notably, the remote sensing evidence suggests that this variance can take place within a much smaller geographical coverage as represented in Figure A1.2 and A1.3. This variation is important for interpreting any figures scaled up at the state or agro-ecological zone, since the granularity of the data is limited in comparison to the area covered. While only a small region overlaps between the household survey and the remote sensing, both methods find similar rates of ZT adoption for this area. This shows that both these methods are capable of detecting ZT practices in the IGP and help in validating each other. However, the remote sensing methodology assumes that the environmental conditions and farming practices are identical in the entire region that is being classified. The results from this study seem to show that this assumption was not met, as unreasonably high ZT adoption rates were observed for regions outside of the ground truth data collection areas. Thus, more efforts for ground truth data are required if this approach is to be applied to larger areas.

Figure A1.2: Percent of zero till fields per administrative sub-district in the winter of 2016/17 in Punjab and Haryana

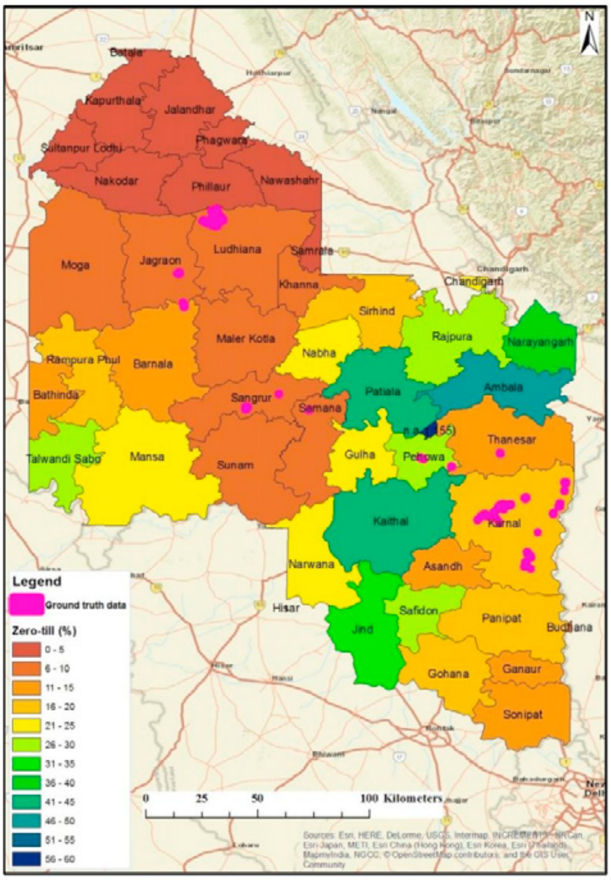
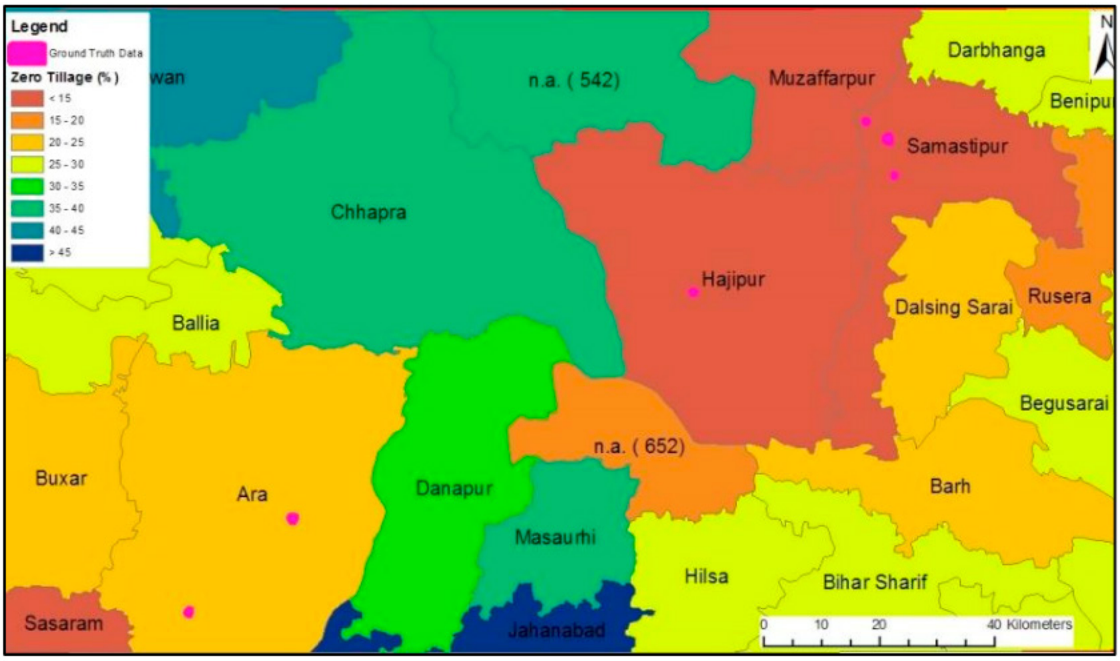


Figure A1.3: Percent of zero till fields per administrative sub-district in the winter of 2016/17 in Bihar and Uttar Pradesh



A2. ESTIMATING CONSERVATION AGRICULTURE ADOPTION IN NORTH AND CENTRAL MEXICO

Sonder K, Schulthess U and G Chomé

In parallel work recently completed in Mexico as an innovative collaboration between the Université Catholique de Louvain and CIMMYT, researchers acquired and analyzed images from the European Space Agency for areas in the Northern Mexican states of Sonora and Sinaloa as well as Guanajuato in central Mexico. Results for Sinaloa show an average accuracy of 94% for predicting tillage type. Limitations of widespread utilization of the technology include the need for availability of spatial data delineating field boundaries to clearly identify cropped and non-cropped areas as well as the association of crop management data such as irrigation timings and crop types. Researchers expect some of these issues to improve in the near future with "big data" and crowd-sourcing applications for field boundary detection.

A3. ADOPTION OF CONSERVATION AGRICULTURE IN MOZAMBIQUE AND ZAMBIA

Mutenje M, Marenya P, Fantaye K T and K Mazvimavi

Overview

This research team evaluated CA adoption in Mozambique and Zambia, analysing which components were adopted in different combinations and how this varies by types of farmer.

Background

The research team employed a mixed method approach complemented with sequential triangulation. This included an initial semi-structured questionnaire for CA project managers and researchers in Zambia and Mozambique, and subsequent expert interviews to develop an inclusive and specific definition of CA adoption. In the meta-analysis, the authors examined whether the likelihood of reporting a positive or a statistically significant coefficient varies by the research design or the measurement approach. To complement and verify the results extracted from the meta- analysis, researchers analysed two waves of panel data (2010 & 2016) from the Sustainable Intensification of Maize legumes in Eastern and Southern Africa (SIMLESA) program in central Mozambique, and the national agricultural household survey partial panel survey (2008-2012). In Zambia, the research team used two waves of panel data (2011 & 2015) from the Sustainable Intensification of Maize legumes in Eastern Zambia (SIMLEZA), rural agricultural livelihood survey (RALS, 2012 & 2015), and longitudinal data from crop forecasts (2010-2015) to complement the meta-analysis. The team analysed adoption patterns and dynamics across time and space for the two countries using descriptive statistics and a trivariate probit model.

Results

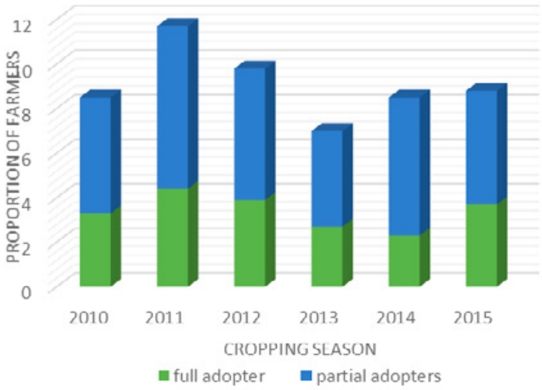
Inconsistent measurement of CA adoption

CA experts from Mozambique and Zambia expressed complete knowledge of the FAO CA definition though in practice they have adapted the definition to the agro-ecological contexts and diverse farming and cropping systems. The research team considers a farmer to be a full CA adopter if they practice all the three principles for a minimum of three cropping seasons consecutively on at least 0.4 hectare. The experts cited that implicitly CA adoption is often defined as a farmer who practices any one of the three components of CA on some part of his or her land in a given season. This flexibility is a major driver of uncertainty in adoption estimates. The researchers also attribute large variation in adoption estimates to the current CA development agenda characterized by scaling-up strategies without adaptive research, and focusing on accountability to donors. For example, in Mozambique, the researchers observed that 75% of the monitoring and impact assessment tools focused on outputs not outcomes. Hence insufficient investment in impact monitoring and evaluation during project design contributed to the CA adoption estimates discrepancies. About 75% of the development organization in the two countries rely on figures they obtain from lead farmers, resident extension officers, or coordinators. These data are accepted without validation. The meta-analysis results revealed pooled cross-sectional data and panel surveys produce consistent estimates after controlling for sampling strategy and sample size.

Influence of climate variability and high-quality extension

The trivariate probit estimates highlight the importance of climate variability and quality extension in increasing adoption of the three CA principles. For example, increased variability of the onset of rain increases a farmer's propensity to adopt all CA technology components. High-quality extension increases the probability of applying each of the CA principles as well. Proponents of CA have argued that successful scaling-out requires continued technical support over a period of at least 10 years until the system is solidly established (Derpsch et al., 2015). However, most development and research projects rarely last more than five years in Zambia and Mozambique.

Figure A2.1: CA adoption dynamics in Zambia (pooled crop forecasting data)



Discussion

In light of the diverse farming systems and agro-ecological settings, there is a need to develop a regional functional definition of CA and reporting criteria that provide clarity on three dimensions of adoption, methodological, and contextual detail. Adoption studies are important to supply data for return-on-investment and impact analysis, which underscore the need to develop high-frequency panel datasets and use of pooled cross-sectional data from large random samples of farmers. To overcome large variation in adoption estimates in the same country or region over the same period, suitable spatial and temporal measurement approaches are an absolute necessity, as well as a balance between on-farm physical observations and survey recall data.

A4. ADOPTION OF CONSERVATION AGRICULTURE IN MALAWI

Holden S, Katengetza S, Fisher M, and C Thierfelder

Background

CA is promoted in Malawi using a "lead farmer" approach, with the assumption that adoption of CA by these leaders will induce their "followers" to adopt in turn. The research team studied the adoption of CA component practices among 182 lead farmers, a sample of 546 their followers (three per leader), and compared these cross-sectional survey results to those for 317 households that have been the subject of panel data in three previous waves starting in 2006.

Results

The authors first establish that a strict definition of CA results in very low adoption rates in Malawi, even among well-informed lead farmers. Low short-term returns and high initial costs of controlling weeds appear to be the main constraints. Of 205 lead farmers, only five (2%) had fully adopted CA and a further 12 (6%) had partially adopted, with comparable adoption rates among their followers (1% full adoption; 6% partial adoption). Rates are even lower in the random sample of 338 households with less than 1% for full adoption and less than 2% for partial adoption.

The authors examine the adoption of a broader range of soil fertility management practices, particularly maize-legume intercropping and organic manure. The authors use the panel data survey collected by the Norwegian University of Life Sciences (NMBU) in four waves in six districts in Malawi over a period of nine years, and the data are analyzed using a correlated random effects model with a control function approach. Results show an increase in adoption rates from 33% in 2006 to 76% in 2015 for maize-legume intercropping, and from 30% (2006) to 53% (2015) for organic manure application. Regression results reveal that exposure to early and late dry spells increases the likelihood of adoption.

Discussion

The authors conclude that CA components needs to be combined with Soil Fertility Management (SFM) to bring more nutrients into the farming systems with depleted soils with low soil organic matter (SOM) to increase short-term returns and reduce leakages. A temporary subsidy and orchestrated conversion to minimum tillage may be necessary to cross the hurdle towards adoption on larger areas, and herbicides and spraying equipment may be necessary in such a transition. Costs and health hazards related to use of herbicides may be reduced through an orchestration approach. After such a transition the weed problem should be reduced and so also the need for subsidies while higher SOM should enhance the returns to other inputs.

A5. DOCUMENTING THE ADOPTION OF CONSERVATION AGRICULTURE IN MALAWI AND ZAMBIA

Arslan A, Alfani F, Scognamillo A, Ignaciuk I , Asfaw S, Conti V, Grewer U, Kokwe M, Kozlowska K, McCarthy N, Phiri G and A Spairani

Overview

Conservation Agriculture (CA) is promoted as a combination of practices contributing to sustainable production intensification. The ultimate goals are to improve the utilization of agricultural resources through the integrated management of available soil, water, and biological resources as well as increase yields, reduce labor requirements, improve soil fertility, and reduce erosion while contributing to higher output and improving food and nutrition security. This study provides a comprehensive cross-country understanding of the determinants of CA adoption in Malawi and Zambia, as well as empirical evidence on their impacts on productivity in the two countries.

CA promotion is a high priority in agricultural policy documents and climate adaptation plans in Malawi and Zambia. Despite significant efforts to promote CA, adoption rates remain low. In Malawi, the National Conservation Agriculture Task Force, the National Smallholder Farmer's Association of Malawi, CGIAR, and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) have taken action to promote CA, however adoption rates are much lower than expected: approximately 1-2%. The growth of sustainable agriculture in Malawi remains precarious. Smallholder farmers face many barriers constraining the adoption of CA, including economic constraints, information constraints, and cultural norms. Since the 1980s, groups such as Ministry of Agriculture and Cooperatives, Swedish Government (SIDA), FAO, the World Bank, World Food Programme (WFP), and the European Union (EU) have promoted CA in Zambia. Similar to Malawi, adoption is still relatively limited and unstable. Zambian households face key constraints to CA adoption such as increased labor and input costs, higher economic risk combined with limited increase in short-term net gain, and limited access to quality legume seeds.

Background

The research team analyzed two nationally representative panel datasets together with high resolution climatic data from both Malawi and Zambia in order to update previous evidence on the topic (Arslan et al. 2014, 2015 and Asfaw et al., 2016). The study also draws upon the similarities and the differences between the two countries to derive lessons for further promotion of agricultural technologies that have the potential to improve productivity and food security.

First, the researchers combined geo-referenced household panel data with long-term climatic data on rainfall and temperature to create a unique data set. For Malawi, the panel data was from the World Bank Integrated Household Panel Survey (IHPS) within the Living Standards Measurement Study (LSMS). The EPIC researchers focused on households that lived in rural areas and cultivated at least a plot in both periods, creating a panel of 1,715 households.

For Zambia, the research team used the Rural Agricultural Livelihoods Survey (RALS), which was collected by the Central Statistics Office (CSO) in collaboration with Michigan State University and the Indaba Agricultural Policy Research Institute. In 2015, a sample of 7,934 households were interviewed, out of which 7,254 had been interviewed in 2012 and 680 new households were added from different clusters in three provinces namely Lusaka, Eastern and Muchinga. When combined with the long-term climatic data, this enhanced dataset allowed for modeling of technology adoption decisions taking into account different measures of locally relevant climate risk as possible determinants (Figures A5.1 and A5.2).

Second, the team model farmers' adoption decisions regarding different practices to capture the complementarities and/or substitutabilities among them, controlling both for climatic risk factors and household-specific time-invariant unobserved heterogeneity.

Last, the team assessed the empirical association between technology adoption and household farm productivity controlling for climate shocks, household characteristics, soil characteristics, agro-ecological heterogeneity, and government programs and institutions relevant for smallholder farmer production.

Results

Malawi

In Malawi, the researchers found that climate risk is associated with a higher probability to adopt at least one of the CA practices. In particular, the results highlight that the more the farmers are exposed to rainfall variability the more they are likely to adopt all the practices considered. Similarly, the more they are exposed to a false start to the rainy season, the greater is their likelihood of adopting legume intercropping. Socio-demographic characteristics do not seem to be significant drivers of CA adoption in Malawi, except for gender of the household head, as they find that a female household head reduces the probability of crop residue being retained on the soil.

Zambia

The study found comparable estimates on adoption of CA practices in Zambia. Correlations between CA adoption and climate risk are highly heterogeneous across the practices considered. Farmers are more likely to adopt legume intercropping and crop rotation in wards that have a higher probability of experiencing a late onset to the rainy season. Overall the results support the idea that CA practices are adopted as adaptation strategies to the changing climate conditions and to the related risk of market and crop failure. Socio-demographic characteristics, such as higher education level and higher age of the household head are both associated with a higher probability of adoption. Older farmers may have a comparative advantage in terms of capital accumulated, contacts to extension services and credit worthiness leading to higher probabilities of technology adoption (Langyintuo and Mekuria, 2005). More educated households may be able to gather and analyze relevant information for decisions (Huffman, 2001) and may be more likely to adopt complex practices.

Similar results between the two countries

Determining similarities and differences between the two countries is important to derive lessons for further promotion of agricultural technologies that have the potential to improve productivity and food security. For both countries, the study reveals that climate, agro-ecological and bio-physical soil characteristics matter. The historical rainfall patterns as well as the agro-ecological and the nutrient availability constraints do influence the decisions of technology adoption at the household level. The findings provide evidence that the CA adoption is more likely in areas characterized by high variability, low moisture or low soil nutrient retention capacities. The higher probabilities of adoption are indirect evidence that farmers may be motivated by expected contributions of CA practices in improving soil structure and fertility. The results also indicate that CA adoption may be also a risk-mitigating strategy allowing households to lower the risk of crop and market failures.

Figure A5.1: Adoption of CA practices in Malawi (authors' elaboration based on IHPS 2013 data)

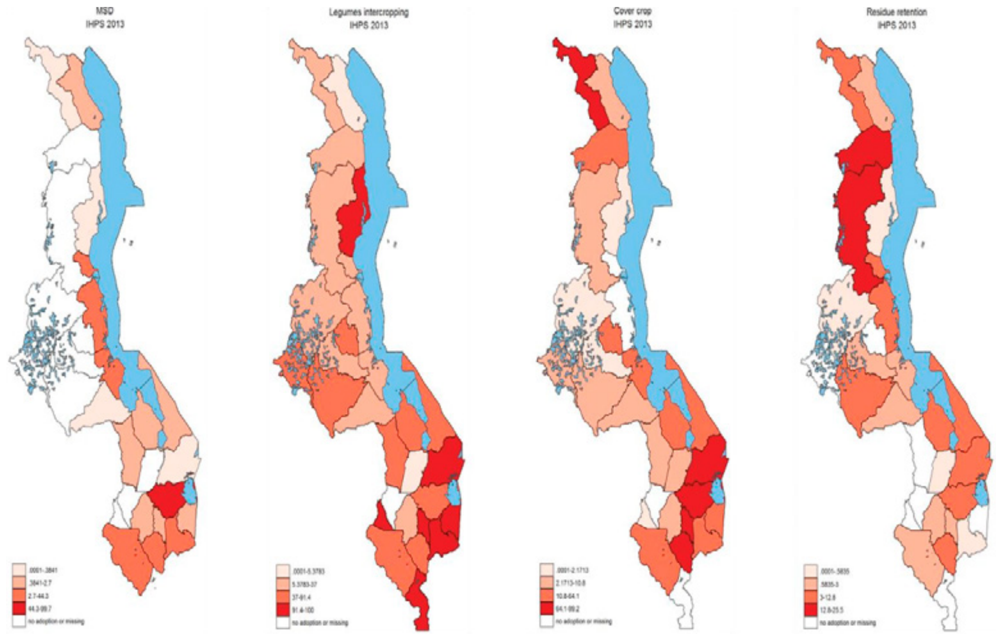
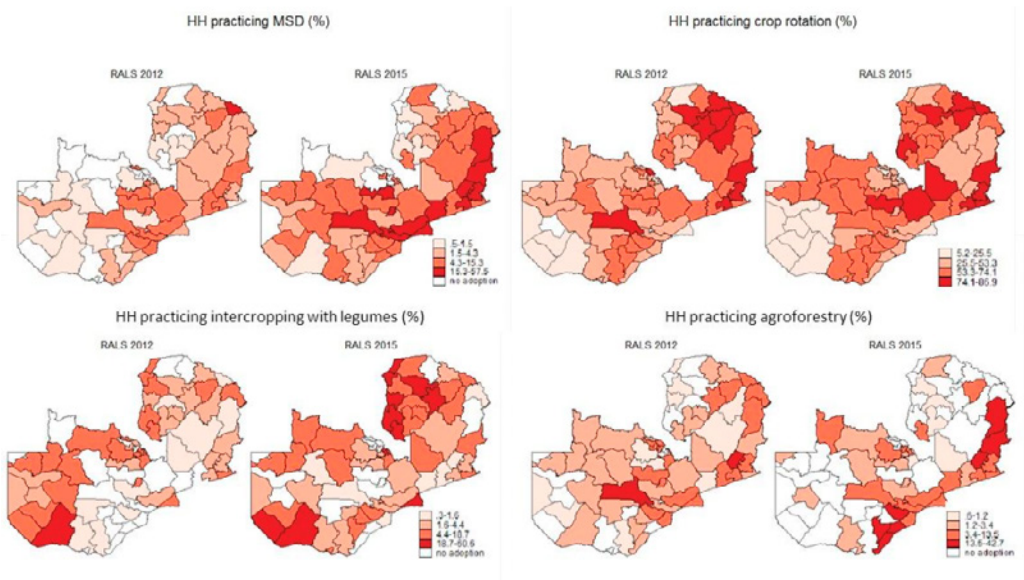


Figure A5.2: Adoption of CA practices in Zambia (authors' elaboration based on RALS 2012 and 2015 data)



In addition, land fragmentation is likely to be a constraint to the adoption of certain practices. In Zambia, land size is positively associated with the probabilities of adoption of all the practices analyzed. In Malawi, the results suggest a similar pattern for the retention of crop residues and crop rotation. This is probably due to the fact that certain practices are suitable and profitable only on relatively larger plots. Since the land endowment is a proxy for wealth, these results may be associated with farmers' opportunity costs and their discount rates. Larger landholders face lower opportunity and risk costs of adopting new land management practices. On the other hand, since smallholders are likely to be characterized by a higher intertemporal discount rate and the benefits of CA can be seen after a certain amount of time and/or under particular conditions, interventions should provide incentives and assistance for the implementation of these practices. Combined, these findings indicate that CA may not be suitable for many smallholders in the absence of supportive credit or other risk management strategies. However, the negative association between land size as well as the positive effect on value of total crop produced of legume intercropping in Malawi provide some evidence that the existence of well-functioning output markets increases profitability of adoption and helps to overcome the barriers related to the fragmentation of the land.

The institutional environment also affects CA adoption. The development of well-functioning input and output markets should go together with promotion to lower opportunity and risk costs related to adoption. Policy interventions aimed at removing barriers to CA adoption and developing flexible technology packages that suit context-specific needs of households are essential for future policies to improve productivity, profitability, and eventually the food security of smallholder farmers.

A6. ADOPTION OF CONSERVATION AGRICULTURE IN ZIMBABWE, AND FERTILIZER MICRO-DOSING IN NIGER AND ZIMBABWE

Michler J, Mazvimavi K, Kairezi G, Liverpool-Tasie L, and A Sano

6A. CONSERVATION AGRICULTURE IN ZIMBABWE

Overview

Beginning in 2003, NGOs and other development stakeholders implemented significant CA interventions with smallholder farmers. NGOs led the promotion of CA as a hand-hoe based technology with which farmers prepared planting basins during the dry season, retained at least 30% soil cover, and rotated cereal-legume crops. Despite benefits that researchers claim to be associated with CA, the area of arable land under CA remained low. As of 2011, farmers only cultivated 5% of the area allocated to maize with CA principles. Furthermore, adoption of mulching and crop rotation practices remained low due to competing uses for crop residues and preferences for growing staple cereals over legumes. Since this initial flurry of CA promotion and research, there has been little work to measure current CA adoption in Zimbabwe.

Background

This study attempts to assess the current trends of CA adoption relying on three different data sets regarding CA practices in Zimbabwe. All three data sets oversampled farmers who were practicing CA, thus limiting the usefulness of the data in calculating adoption rates at the national level. They are:

- **ICRISAT's five-year panel data** set is most complete data set on adoption and impacts of CA in Zimbabwe. Researchers collected the data to help monitor and evaluate the impact of CA promotion as part of the Protracted Relief Program (PRP). They selected surveyed households through multi-stage sampling to be representative of the smallholder farming community in Zimbabwe. This analysis uses unbalanced panel data consisting of 730 households covering the 2007/08 to 2010/11 seasons.

- In 2015, the **Food and Agriculture Organization of the United Nations (FAO)** funded a study to measure the impacts of CA on crop productivity, food security, and household income in Southern Africa. ICRISAT carried out a household survey during 2015 in Malawi, Zambia, and Zimbabwe. In Zimbabwe, researchers used a three-stage stratified random sampling technique to select and interview 308 smallholder farmers. 190 were CA adopters and 118 were non-adopters.
- The most recent data on CA comes from a 2016 study in Zambia and Zimbabwe funded by the **Vuna Climate Smart Agriculture Programme**. The study aimed to evaluate the contributions of CA practices in improving crop resilience to drought. Researchers drew data from a cross-sectional survey covering a total of 680 smallholder farmers evenly split between the two countries. In Zimbabwe, they interviewed 340 smallholder farmers across six districts. Of the interviewed farmers, 202 were CA adopters and 138 were non-adopters.

Results

Adoption estimates for each data set are based on different adoption levels. If CA adoption is defined as the implementation of all three CA practices, CA adoption is extremely low. Over the final two years of the PRP study period, less than 10% of farmers applied all three CA practices to at least one of their plots. The findings from the 2014/15 study are consistent with panel study findings. The results also show that only about 8% of the plots received all three CA practices. Competing uses of crop residues limits the use of crop residues as mulching material. Application of practices such as crop rotation is undermined by preference given to production of maize.

Adoption levels in 2015/16, by crop and overall, are similar to those reported from the ICRISAT three-country survey conducted the previous year. Farmers implemented all three CA practices on around 8% of their plots. Similarities between adoption rates across different studies provide evidence of partial adoption.

Over the study period, there is strong evidence of dis-adoption of minimum tillage, regardless of crop type. In the 2008 harvest year, when over 80% of households received input support from the PRP, 44% of all plots were “CA plots.” As input subsidies declined over time, so did the use of minimum tillage. By the 2011 harvest year, only 17% of all plots were “CA plots.”

While CA is a plot-level technology, technology adoption is often measured at the household-level. Using the plot-level data, researchers can calculate various household level measures of farmer adoption. When CA adopter is defined as a farmer who practices minimum tillage on at least one plot, adoption rates appear very high. Over the four-year study period 85% of farmers practiced minimum tillage on at least one plot in at least one year. Adoption, as defined by “applying at least minimum tillage”, was very high during the PRP period but by 2010/11 less than half of the households were practicing minimum tillage on at least one plot. When a CA adopter is defined as a farmer who practices minimum tillage on all his or her plots, over the four year period fewer than 20% of households can be considered CA adopters.

Discussion

Lack of recent data. While CA has been vigorously promoted in Zimbabwe for the past decade, there is a lack of recent, nationally representative data available regarding CA adoption practices. The most recent data that exists for calculating nationally representative adoption is ICRISAT’s panel data study, which concluded in 2011. More recent data collection efforts focus on the impact of CA adoption, not adoption itself, and thus tend to survey adopter and non-adopter farmers in fixed proportion. This type of data is of limited usefulness to calculate representative farm-level adoption, but can still be useful in determining what specific practices are adopted.

Prevalence of partial adoption. All three surveys findings agree that farmers rarely apply all three CA practices in one plot. Farmers implemented all three CA practices on less than 10% of farmed plots. This study reveals the evidence of partial adoption. This study also finds that farmers who adopt minimum tillage do not implement the practice on all their plots. However, using the available data, it is difficult to come up with accurate national levels of adoption.

Need for more studies on CA adoption. There is need to conduct a more vigorous national representative study to cover this gap in literature on CA adoption. Future researchers who attempt to calculate CA adoption rates in Zimbabwe will need to ensure that the sampling frame is nationally representative of smallholder agriculture and will need to be more precise in how they define CA adoption.

6B. ADOPTION OF FERTILIZER MICRODOSING IN ZIMBABWE

Background

Crop yields in the fragile semi-arid areas of Zimbabwe have decreased over time due to decline in soil fertility from mono-cropping, lack of fertilizer, and other factors. Problems of declining soil fertility are particularly acute in dry areas characterized by low intrinsic soil fertility, inadequate use of soil amendments, and unreliable rainfall. Surveys during the mid- to late-1990s and early 2000s in southern Zimbabwe indicate that less than 5% of farmers commonly used fertilizer. To address these issues, the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) and partner organizations developed fertilizer microdosing (MD), a natural resource management (NRM) practice that allows farmers to apply small quantities of nitrogen fertilizer while maintaining or increasing yields. MD is the targeted application of small, affordable quantities of fertilizer using between one fifth and one third of the normally recommended application rate. Due to its affordability, MD is a strategy that enables resource-poor farmers in low-rainfall regions to unlock the power of chemical fertilizers. However, previous studies have been unable to separate the impact of MD from other methods of fertilizer use. Using newly collected panel data on fertilizer use in Zimbabwe, this study analyzes factors influencing MD adoption and how adoption decision impacts the amount of fertilizer that farmers use. The study also assesses MD's impact on yield compared to other application methods.

Overview

This report is based on panel data collected by ICRISAT in January 2013 and in December 2016. Each survey collected information on plot management practices and cereal output for two cropping seasons, 2010/11 and 2011/12 for the 2013 survey along with 2014/15 and 2015/2016 for the 2016 survey. The surveys provide plot-level data for 3,819 plots from 458 households across four cropping seasons. The study sample covered eight semi-arid districts where farmers had been trained in MD. The research team randomly drew households from registries compiled during the collection of ICRISAT's five-year panel survey on conservation agriculture (CA) that indicated which households had received MD training. The surveyors also interviewed households that were not exposed to MD. They had difficulty identifying wards that had not been exposed to MD trainings given that input distribution was often accompanied by some form of MD training and was frequently embedded with CA methods. Of a total sample of 458 households, 377 (82%) were categorized as exposed to MD, while 81 households (18%) were categorized as not having received any form of training in MD technology.

Results

Farmers across Zimbabwe use different methods to apply their fertilizer. These include broadcasting and line spreading, spot application at the plant base, and spot application within a planting basin. In this study, the research team categorized spot application at the plant base and within the planting basin as MD techniques, given that they are both designed to use low quantities of fertilizer. Farmers in Zimbabwe primarily use two different types of fertilizer: ammonium nitrate or AN (NPK 34-0-0) and compound D (NPK 10-20-10+6.5%S).

Some farmers will use only one type while many farmers use the two types of fertilizer in combination. Farmers are considered as full MD adopters when they apply all fertilizer using only MD techniques. Likewise, farmers who combine MD and other application method are considered as partial adopters.

Across the surveyed regions in Zimbabwe, 40% of households use fertilizer and of those 88% apply some fertilizer by MD (35% of all farmers). Of only full MD adopters, fertilizer use drops to 78% (30% of all farmers). The ratio of farmers who use fertilizer, who use some MD, and who only use MD is fairly stable over the four years of the survey. This result is encouraging since fertilizer subsidies, as well as MD promotion, was mostly curtailed after the 2011/12 season. The continued application of fertilizer through MD represents a commitment to practice by farmers who initially adopted the technique.

The research team finds strong differences in plot and yield characteristics when they compare plots on which only MD is used to other fertilized plots. Non-MD plots are significantly larger while MD plots have significantly higher yields. The higher yields from MD come despite significantly lower amounts of fertilizer used on the plots. Most striking, application rates of compound D are higher on MD plots than on no-MD plots. The results show that the quantity of fertilizer used has increased over time, regardless of application method. These results present an unexpected scenario that in Zimbabwe farmers have adopted the NRM practice of fertilizer MD but have failed to reduce fertilizer application rates. Thus the spatial pattern of fertilizer application is consistent with MD but not the quantity applied.

Econometric results suggest that being trained on MD techniques significantly increases the probability of choosing to use fertilizer and that applying more fertilizer per hectare is associated with significant yield increases. However, MD training has no significant influence on the amount of fertilizer applied per hectare. Larger plots also increase the probability of using fertilizer while decreasing the application rate. A large asset base consistently increases the probability of using fertilizer as well as the rate of fertilizer application. These two results indicate that fertilizer cost is a constraint for households in Zimbabwe. Female-headed households are less likely to adopt fertilizer but tend to apply it at a higher rate than male-headed households. These findings provide evidence that MD training seems to convince farmers that chemical fertilizers in low-rainfall areas of Zimbabwe are a good idea, but that this has not translated into lower rates of application, as MD was designed to achieve.

Implications for stakeholders

These outcomes reveal that conditional on having adopted MD, applying fertilizer at higher rates tends to have a positive and significant effect on yields. Findings further suggest that MD trainers have successfully communicated to farmers the value of chemical fertilizers for increasing yields. However, what seems to have been lost is that farmers can increase yields by applying small, targeted amounts of fertilizer. Instead, the results suggest that the message farmers received is that more fertilizer is better, even when using spot application. As a result, MD farmers apply fertilizer at a higher rate than non-MD farmers. This over-application of fertilizer means that the two primary benefits of MD (cost reduction and reduction of groundwater contamination from fertilizer runoff) are likely not associated with the use of MD in Zimbabwe.

6C. ADOPTION OF FERTILIZER MICRO-DOSING IN NIGER

Overview

Two modes of micro-dosing fertilizer are practiced in Niger – the first is to use approximately 30 kg ha-1 applied at different times accompanied by a specific process for spot-application; the second involves mixing fertilizer and seed at planting. There is a quantitative difference in terms of the amount of fertilizer used – typically much less when mixed with seed (2 – 8 kg ha-1) which likely has different impacts on productivity.

Background

Data come from a 2013-14 survey administered to approximately 800 households from 40 villages in four regions in Niger in proximity to areas where MD had been promoted. Nationally representative data from the LSMS in 2011/12 suggest 13% of households using fertilizer where the average in the team's sample is 43% but with large variation across regions.

Results

Adoption of any kind of MD (with spot-placement taking place using amounts less than broader coverage) in the sample is 18% but for "pure" MD (following the recommended process of three people working together to apply fertilizer – one person to dig the hole, the next to put in the fertilizer and a third to put in the seed and close the hole). The sample total for this method is only 3%. By contrast, 29% of farmers mix fertilizer with seeds. These patterns suggest that fertilizer use has increased while the use of MD has remained low.

A7. FERTILIZER TREES AND FODDER SHRUBS IN ZAMBIA: UPTAKE ASSESSMENT AND VALIDATION USING GEOSPATIAL METHODS

Vågen T-G, Masikati P, Chiputwa B, Parmutai M, Franzel S, Hughes K, Jacobson M, Kuntashula E, Nhlane R, Alfani F, and A Arslan

Overview

The research team explored the potential of innovative geospatial methods, in particular remote sensing, for mapping the distribution of the *Faidherbia albida* fertilizer tree species in Zambia. Conventional survey methods to assess the uptake of agroforestry, such as structured household surveys, are costly and sample sizes are often low. Alternative approaches for data collection are needed to conduct large-scale assessments of adoption. The study is motivated by the fact that the World Agroforestry Centre (ICRAF) were promoting agroforestry in Zambia – and fertilizer trees in particular – for many years (Ajayi et al, 2011).

Background

In late 2016 and from March-May 2017, field surveyors identified high levels of tree species diversification in many farming systems in Zambia, with over 200 species of trees and almost 90 different tree species in agricultural fields alone. Using geospatial methods, researchers found that farmers in Zambia tend to leave trees in their fields, or in some cases allow seedlings to naturally regenerate, generally favoring nitrogen-fixing trees such as *Faidherbia albida* or Miombo species such as *Brachystegia spp* or *Combretum molle*.

Results

In terms of presence across field sites in the sample area, *Faidherbia albida* occurred in about 6% of the sampled field plots. In cultivated areas, *Faidherbia albida* is often retained and managed by farmers after clearing of woodlands for cultivation. Approximately 15% of the sampled plots in cultivated areas had *Faidherbia albida*. In the croplands that had *Faidherbia albida*, the average tree density was 15 trees ha^{-1}.

Discussion

Strength of geospatial methods for sensing and mapping the distribution of *Faidherbia albida*

Results suggest that geospatial Landsat 8 satellite imagery and field data on the presence or absence of the *Faidherbia albida* fertilizer tree species are highly accurate. Researchers validated these models against on-farm household survey date and fertilizer tree inventories, and results showed that they could separate fields with high prevalence of *Faidherbia albida* from those with very few or no trees with reasonable accuracy. Geospatial methods have high potential for mapping of key agroforestry species, and for assessing uptake of fertilizer trees across larger areas. Researchers can apply these approaches to other agroforestry species across developing countries, including fodder trees and shrubs. Due to these species' limited occurrence in Zambia, researchers focused on *Faidherbia albida* in the current study.

Source of *Faidherbia albida* seedlings and agroforestry training

The research team established that farmers' main sources of *Faidherbia albida* seedlings were Zambian government extension and projects, as well as through non-governmental organizations such as Conservation Farming Unit (CFU), Conservation Agriculture Scaling Up (CASU) and World Vision. Other important sources are private nurseries, and friends and neighbors. Farmers also reported to have received agroforestry training primarily from projects and/or non-governmental organizations, followed by extension officers, government agencies, and farmer-to-farmer programs. These findings resulted from on-farm surveys in three districts within Lusaka and Eastern provinces, covering a total of 550 households, of which 288 were sampled from Eastern province and the remaining 262 from Lusaka province. They correspond well with findings from the 2015 Rural Agricultural Livelihoods Survey carried out by FAO and national partners (see study number 5 for other uses of this survey), and the findings also confirm the importance of *Faidherbia albida* as a fertilizer tree species for farmers in Zambia.

Diversification and uptake of natural resource management (NRM) practices in Lusaka versus the Eastern Province

The on-farm survey showed a greater number and more diverse trees in Lusaka farming households, which had significantly larger farm sizes than the Eastern province. While household adoption or uptake of other NRM practices such as crop rotations, mixed cropping, and zero tillage was also highest in Lusaka, the proportion of land under NRM practices and the number of *Faidherbia albida* trees per hectare were both higher in the Eastern province. Farmers who maintained more *Faidherbia albida* trees in their fields maintained more trees in general and had higher levels of tree diversity than non-adopters in both districts.

Decline of fertilizer tree promotion since ICRAF's departure in 2006

The research team surveyed the literature and found that from 1986-2006, there was significant agroforestry promotion activity in Zambia, particularly by ICRAF. ICRAF's departure in 2006 created a void of agroforestry activities in the country, although results reveal that the earlier projects laid the foundation for fertilizer tree activity and the uptake of agroforestry, specifically *Faidherbia albida*. The last decade's absence of fertilizer tree promotion in Zambia is in part attributed to heavy promotion of conservation agriculture that views fertilizer tree promotion as only an add-on to conservation farming practices. Fertilizer trees, for the most part, are seen as minor and not widely adopted in conservation agriculture projects. Even the widely-recognized non-governmental organization CFU carries out activities with *Faidherbia albida* only, which explains at least in part why this particular species is more prevalent in the farms surveyed as part of this study.

A8. DOCUMENTING ADOPTION OF ALTERNATE WETTING AND DRYING TECHNIQUE IN VIETNAM

Lovell R, Thuy N and N Phong

Overview

Alternate Wetting and Drying (AWD) is a water-saving practice in rice production in the Vietnamese Mekong River Delta (MRD). The Vietnamese government is promoting AWD through their "1 Must Do, 5 Reductions" (1M5R) campaign, but adoption is uneven. This research used an interdisciplinary approach to understand the extent and degree of AWD adoption across the delta. First, the research uses series of focus groups, key informant interviews, and household surveys in Dong Thap, An Giang, Soc Trang, and Bac Lieu Provinces to understand the variance of farmer approaches to AWD and the likelihood of adoption in each province. Second, it uses European Space Agency Sentinel-1a and 1b radar data, combined with in-situ moisture readings, to determine AWD adoption through change detection of a time series wetness index. The approach measures "drydown" between each time step.

Background

Since the late 1980s, Vietnam has emerged as a significant player in international rice production, producing three rice crops per year in many irrigated areas of the MRD. However, the triple rice crop requires nutrient and water inputs far beyond the soil and precipitation limits of the environment. Over many years, the prolonged soil wetness required for triple rice production can harm the soil and lead to aluminium toxicity.

The Ministry of Agriculture and Rural Development (MARD) extended the Agricultural Competitiveness Program (ACP), a World Bank program, to the Mekong River Delta in November 2012. The program promotes the 1M5R slogan, a catchy and easy way for farmers to adopt more sustainable practices. The "1 Must" promotes use of certified seeds; while the "5 Reductions" means reducing water by adopting AWD, as well as fertilizer, pesticides, post-harvest loss, and seed inputs. The ACP was rolled out in 2013 and adoption data indicates that 70% of farmers in the MRD are users of 1M5R. However, adoption is uneven across the delta, especially AWD adoption.

Results

Farmer Organization (water distribution institution) membership influences adoption

In provinces in which a Farmer Organization (FO) controls water use and distribution, AWD adoption is tied to the FO fee structure. Each farm that falls within an FO is systematically linked to neighboring farmer's watering regimes, meaning that a farmer must water if the FO decides it is watering time. This can have differential impacts on AWD adoption. For example, in An Giang Province, farmers pay a lump sum per season for irrigation water. There is no incentive to reduce watering throughout the season. However, in Bac Lieu, FOs can choose to reduce the number of waterings per season and offer between 600,000 and 700,000 VND savings to their users.

Farmers do not generally use a perforated pipe to measure water levels in the field

Farmers are not using the AWD perforated pipe to determine when to water their crop, despite the pipe being offered for free by MARD agricultural extension departments. The International Rice Research Institute (IRRI) have promoted use of the pipe as a means to ensuring the water level does not retreat too far below the surface of the soil. Instead, farmers use the "bird crack" method in which they look for soil cracking that resembles the length and width of a bird foot. However, this method can only be used in soil that does not contain Aluminum or too much sand. This is an interesting result consistent across all provinces because it makes "presence of the pipe" no longer a necessary (and observable) condition for determining adoption.

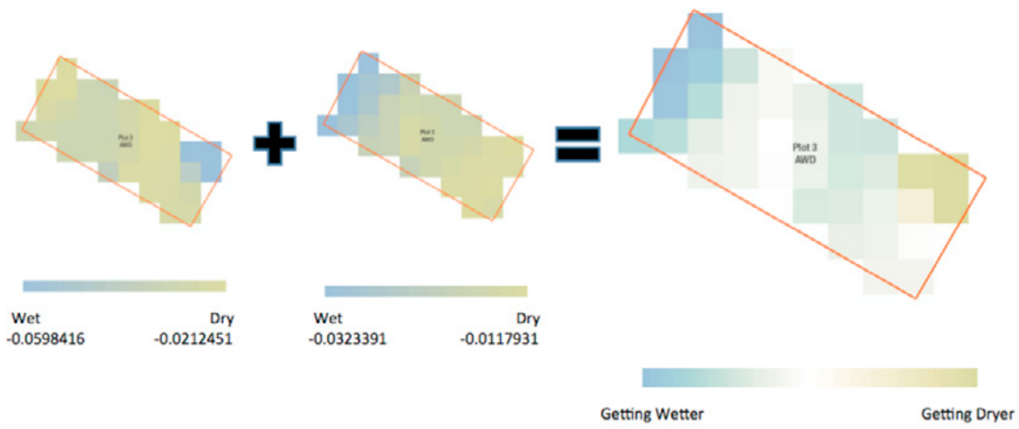
Coastal and inland provinces show different habits of AWD adoption

First, there is a distinct difference between coastal and inland province knowledge of AWD. For example, Soc Trang has knowledge gap compared to Dong Thap and An Giang, which have upwards of 60% AWD knowledge in household interview respondents. Second, the scoring system applied to household surveys indicates a stark contrast of AWD adoption between coastal and inland provinces. Results also indicate that seasonality can influence AWD adoption. The coastal province of Soc Trang is unable to adopt the practice during the Autumn-winter season because they do not produce rice during this time. Similarly, Bac Lieu produces a very small amount of rice during this season. However, An Giang and Dong Thap see steady rates of AWD scores throughout all three seasons.

Change detection is a viable remote sensing application to document adoption

The use of Synthetic Aperture Radar (SAR) data to understand shifts in moisture over large areas is a burgeoning method in remote sensing. Figure 1, below is a simple representation of the process of using wetness index data from each individual cell to understand change over time. The model assumes that areas of the delta that show consistent change (i.e. patterns of flooding and "drydown") throughout the growing season are AWD adopters.

Figure A8.1: Wetness index calculated from Synthetic Aperture Radar (SAR) data



Recommendations for Further Research

Research and development to use remotely sensed data for documenting AWD adoption.

- Use a power spectral density test to understand the complex periodicity of the SAR data across the delta over time. The change detection approach used for the SAR data analysis illustrates the average change over time for each cell in the tile that covers the MRD. However, a more nuanced approach would be to use a power spectral density analysis to understand the periodicity of the "drydown" signal and the power of that signal. In other words, cells with increased likelihood of exhibiting an oscillating habit (which is presumed to be the AWD signal), would score higher on the power spectral density analysis.
- Repeat the same analysis for all three seasons of rice to increase the accuracy of the power spectral density test. While the approach was able to detect patterns of "drydown" across the delta, conclusions would create a more robust signal analysis with longer sets of continuous data. If each growing season in a year could be analyzed continuously, especially over a series of years, this would enable detection of a more conclusive and reliable AWD signal.

A9. MAPPING ADOPTION OF INTEGRATED SOIL FERTILITY MANAGEMENT (ISFM) PRACTICES: THE CASE OF KENYA, RWANDA AND ZAMBIA

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Background

ISFM is defined as a set of soil fertility management practices that include the use of improved germplasm, mineral fertilizers, and organic inputs adapting these practices to local conditions. ISFM is not a single technology but a set of technology components that are co-applied in the same plot, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al 2015). The concept of ISFM was developed at the Tropical Soil Biology and Fertility (TSBF) Institute of CIAT (TSBF-CIAT), and research started in 1970-80s under the TBSF. The ISFM development included both on-station and on-farm soil fertility trials. It has been tested in sub-Saharan Africa, both in CGIAR and non-CGIAR institutes; particularly in the Democratic Republic of Congo (DRC), Kenya, Rwanda, and Zambia jointly with mapping of soil diversity with the need to determine soil fertility constraints.

Studies have shown that the uptake of ISFM remains low – largely because it is a new paradigm and its promotion by extension service providers is limited. Nkonya et al (2016) observed that only 6% of farmers use ISFM compared to 19% and 25% users of inorganic fertilizer and organic inputs, respectively. Using both primary and secondary data collected to document adoption of ISFM, three case study countries were studied: Kenya, Rwanda and Zambia. To test and validate new tools for documenting adoption of agricultural practices, a mobile phone survey was conducted - only in Rwanda due to budget constraints. The results were then compared with data collected using traditional data collection methods – i.e., in-person household survey. Secondary data have been used to document adoption and assess the impact of ISFM as well as the drivers of its adoption in Kenya and Zambia. The specific objectives of this study were to:

- Determine adoption rate of ISFM in Kenya, Rwanda and Zambia
- Design methodological approaches for determining adoption rates of innovations
- Analyze drivers of adoption of ISFM in the case study countries
- Analyze impact of ISFM on income and sustainable land management practices

Kenya and Zambia: Analysis of secondary data

The authors estimated adoption based on household survey data collected in other surveys – the Ag Sector Household Baseline in Kenya from 2013, and the Rural Agricultural Livelihoods Survey in Zambia from 2012. In Kenya, the adoption for ISFM as a package is between 24 and 29% depending on the crop, with potato (a commercial crop in Kenya) the highest. In Zambia, ISFM adoption is at 6% for maize and less than 1% for other crops.

Rwanda: Mobile phone survey approach

The authors conducted two waves of data collection from 1000 households in Rwanda using the services of SMS survey company GeoPoll. The first wave covered all farm operations from planting to crop maturity and the second phase covered harvesting, marketing and other post-harvest activities. The second wave covered activities ranging from harvesting to marketing. Socio-economic characteristics were also collected to help study the drivers of ISFM adoption. To help reduce non-response bias, respondents were given a US$ 0.50 air time coupon at completion of the survey. Studies have shown that the non-response is particularly high among older people. The authors conducted two waves of data collection in which the first wave covered all farm operations from planting to crop maturity and the second phase covered harvesting, marketing and other post-harvest activities.

When comparing the sample respondents to the demographics of the country as a whole (established through the seasonal agricultural survey), the authors find major over-representation of younger people (<35 years old) and under-representation of middle-aged (35 – 54) and elderly farmers (>54). Younger people represent 93 % of all the respondents to the SMS survey, despite only representing 40% of the population. The over 54 years-old age range were virtually absent (0.3% of respondents) despite representing 20% of rural households.

Furthermore, measurement error for those that do respond appears to be very high – average yields are reported that are a tiny fraction of average yields in the population with little recourse for checking or follow-up with the respondents. Therefore no new adoption estimates could be generated for Rwanda.

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