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Obstacles to Widespread Diffusion of IPM in Developing Countries: Lessons From the Field

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Abstract

Integrated pest management (IPM) is a way of managing agricultural pests using ecological principles and with minimum damage to the environment and human health. In developing countries, numerous IPM programs have been developed with the intent of increasing yields, reducing costs, and minimizing adverse impacts of pest management. Despite its promise and many millions of dollars being spent on training and diffusion, IPM has not been widely adopted in developing countries. This paper provides evidence about what is known about global adoption, what factors have been identified as obstacles to more widespread adoption, and ways of overcoming these factors. Behavioral economics provides insights that help explain lagging IPM adoption and promises potential for relatively simple solutions. Means of evaluating and implementing behavioral economics approaches are described and some lessons are gleaned from a single study employing these approaches in Ecuador. Implications for broader diffusion are discussed.

Key words: integrated pest management, adoption, behavioral economics, Ecuador

Introduction

Integrated pest management (IPM) is a crop protection strategy that grew out of concerns about high dependency of agricultural production on toxic pesticides (Morse and Buhler 1997). Early IPM programs involved monitoring pest populations in the field and use of pesticides only when economic thresholds are crossed (Stern et al. 1959). IPM techniques gradually evolved to include practices such as host plant resistance, biological control, and altered agronomic management (Pretty and Bharucha 2015, Norton et al. 2019). The newest thinking about IPM reflects a further evolution toward managing host stress rather than killing pests, increased focus on breeding for tolerance to pest injury, and emphasizing proper use of pest management tactics (Peterson et al. 2018). The evolution reflects the maturation of a philosophy of IPM, which integrates multiple disciplines and focuses on *managing* a pest population rather than *controlling* it. In practice, IPM involves selecting from a menu of options, all of which are environmental and human health friendly compared to traditional practices.

A typical IPM regime in developed countries follows a stepwise approach from pest identification, prevention and exclusion, monitoring, and use of multiple practices (Penn State Extension 2018). These practices range from simple, such as manual removal of diseased plants or harmful insects, to complex, such as using biological controls or grafting plants onto resistant rootstock. Despite the existence of a continuum of practices from simple to complex, developed-country IPM programs usually describe a relatively rigorous process for producers interested in adopting an IPM approach. For example, the Penn State Extension website describes multiple steps a typical IPM producer must take. These include proper identification, the need to learn pest and host life cycle and biology, use of traps and record-keeping for monitoring insect pests, establishment of an 'action threshold' above which the pest population will likely create economically meaningful damage, and, finally, choice of the appropriate combination of management techniques (Penn State Extension 2018). Because of the complexity of IPM as practiced in the developed world, extension agencies frequently include units dedicated to teaching and diffusing IPM to clients.

In developing countries, IPM packages are now widely available to farms of different sizes and types. As with their developed-country counterparts, developing-country IPM practices range from simple to quite complex (Pretty and Bharucha 2015, Muniappan and Heinrich 2016). Pretty and Bharucha (2015) note that except for very rare cases, such as classic biological control through release of an antagonistic pest, IPM is implemented with farmer engagement and must be locally relevant. Because IPM represents a departure from typical farm management practices, multiple methods have been utilized to promote its diffusion in developing countries (Harris et al. 2013). These include mass media dissemination, extension visits, field days, and farmer field schools (FFS). Evaluation of the effectiveness of alternative diffusion methods has been hampered by loose definitions of IPM adoption and inability to identify a causal link between exposure to the method and adoption. Evidence, however, generally shows that low-cost methods such as farmer field days and mass media are sufficient to stimulate adoption of relatively simple IPM practices, while high-cost, intensive diffusion practices such as FFS may be needed for practices requiring detailed knowledge of pest life cycles or biological principles (Mauceri et al. 2007, Ricker-Gilbert et al. 2008, Harris et al. 2013). Recent innovations in behavioral economics (DellaVigna 2009, Thaler 2016) may help inform decision makers about how to overcome common behavior-related obstacles to IPM adoption.

While good information is easily found on global pesticide use (Pretty and Bharucha 2015), evidence about diffusion of IPM is spotty. Part of the problem is definition: there is no global consensus on what constitutes farm-level adoption of IPM and how to measure it. Without such a consensus, what is considered IPM adoption, such as use of a resistant variety, in one study might not be considered as such in another. Since IPM is a continuum, small measures such as scouting prior to spraying or moving from a highly toxic to a less-toxic pesticide might be considered IPM adoption. The varying realizations of IPM make farm surveying, the building block of aggregate adoption estimates, more difficult. Nationally representative surveys of agriculture such as the Living Standards Measurement Study-Integrated Survey of Agriculture (LSMS-ISA), supported by the World Bank, do not contain questions necessary to precisely identify IPM adoption at the farm level. These surveys are widely used to measure adoption of improved crop varieties (Kinuthia and Mabaya 2017) and other technologies, but without a clear consensus on what constitutes IPM, which may vary by crop, they cannot provide information about aggregate diffusion. For example, the Tanzania ISA asks about organic fertilizer and pesticide/herbicide use and why the farmer uses each input, but does not contain further information on management practices, use of less-toxic alternatives, etc. Instead of nationally representative surveys, estimates of aggregate IPM diffusion from developing countries usually depend on project-related data (e.g., Pretty and Bharucha 2015) or expert opinions, but these estimates are clouded by inconsistent understanding about what constitutes IPM, lack of representative surveys, and possible bias on the part of experts or project managers and beneficiaries.

Objectives

The objectives of this paper are to: 1) provide evidence related to IPM adoption in developing countries; 2) identify obstacles to more widespread adoption; 3) describe and discuss insights about overcoming obstacles to adoption from behavioral economics; and 4) discuss how behavioral considerations might be used to overcome obstacles to adoption.

Review of Evidence

Evidence on Aggregate Diffusion and Factors Affecting Adoption

Estimates of aggregate adoption of IPM in the developing world are hampered by lack of agreement about what IPM adoption is and how to measure it. However, overall evidence suggests that IPM technologies are not widely adopted in lower-income countries (Morse and Buhler 1997, Orr 2003, Parsa et al. 2014, Jørs et al. 2017). Parsa et al. (2014) attribute low adoption to outreach and training deficiencies, poorly aligned incentives (such as subsidies for pesticides), and insufficient farmer management skills, among others. Access to information about IPM and sufficient training in IPM techniques are clear obstacles to broader adoption. As a result, most IPM programs have components to overcome these barriers, but lack of information may not be the only obstacle.

Orr (2003) argues that IPM may not be sufficiently profitable in many African agro-ecologies to justify adoption, especially considering the corresponding risk and uncertainty associated with adoption. Morse and Buhler (1997) note that factors such as the complexity of IPM recommendations, the tendency of scientists to work in silos, and the sometimes geo-specificity of IPM recommendations preclude widespread promotion and use of IPM in low-income countries. They conclude that heterogeneous ecological conditions make it difficult to find a one-size-fits-all IPM package. So, even though there is compelling evidence of impact of IPM on farm incomes, on reduction of pesticide use, and on producer and consumer well-being in places where it has been adopted (Pretty and Bharucha 2015, Norton et al. 2019), broad diffusion may be constrained by weak economic viability in heterogeneous agro-ecologies or under different policy regimes. Norton et al. (2019) focus mainly on estimates of economic impacts; Pretty and Bharucha (2015) summarize evidence with respect to pesticide use and yields. Both of these studies show high returns to IPM in the cases (projects) studied.

Like many complex technologies, developing-country farmers adopt IPM in a piecewise fashion (Norton et al. 2019). Experimentation with components of a technology package allows farmers to learn about the technology and its risks (Feder et al. 1985; Feder and Umali 1993, Ersado et al. 2004). Certain components of IPM packages may only be appropriate under specific conditions. Pest pressure is not uniform, pests may emerge at different phases of the crop cycle, they evolve over time, some IPM technologies are divisible and rarely do complete 'packages' exist for an entire crop or ecosystem (Muniappan and Heinrichs 2016). All these factors contribute to experimentation with IPM components and there is very little evidence from developing countries of adoption of complete packages (Norton et al. 2019).

Statistical analyses of determinants of IPM adoption in developing countries generally use a standard utility- or profit-maximization framework (e.g., Feder et al. 1985) and farm-household data gathered for the specific purpose of adoption evaluation. Studies regress a measure of farm- or plot-level adoption on variables reflecting conditions in the household (e.g., age, education, number of workers), conditions on the farm and factors affecting productivity (e.g. farm size, slopes, access to water), access to information, risk factors, and other things. Measures of IPM adoption depend on how the research defines the concept and are either a binary variable (adopts/does not adopt), counts of practices adopted, or measures of adoption intensity. Results from these studies are mixed and few generalizations can be made; small sample sizes tend to lead to imprecisely estimated parameters, but some patterns emerge. In general, variables reflecting farmer education and information about IPM, when significant, have positive impacts on IPM adoption (Maumbe and Swinton 2000, Mauceri et al. 2007, Carrión et al. 2016). As a result, access to training or programs promoting IPM are generally strong predictors of IPM adoption (Mauceri et al. 2007, Ricker-Gilbert et al. 2008). Few studies show farm size to be a significant determinant of IPM adoption, and those that do (e.g., Maumbe and Swinton (2000) find the size effect to be rather small. One explanation for low spread may be that IPM is not profitable for large-scale innovating farmers who tend to lead others in their adoption of new technologies (Feder et al. 1985).

Consensus has formed that when commercial applications of IPM technologies exist, adoption is more widespread. This is because private sector actors have incentives to advertise and promote their wares and because the private sector would rarely promote a technology that does not work or is not profitable to farmers (Kyriacou et al. 2017, Guerci et al. 2018). Examples of commercially applicable IPM technologies include fruits and vegetables grafted onto resistant rootstock. Examples of grafting as a successful IPM strategy include eggplant in Bangladesh (Mian et al. 2016) and naranjilla in Ecuador (Clements et al. 2016). In Ecuador, the Autonomous National Agricultural Research Institute (INIAP for its Spanish acronym) developed, tested, and validated naranjilla grafted onto fusarium-resistant (*Fusarium oxysporum* f. sp. *quitoense*) rootstock (*Solanum hirtum* Vahl (Solanaceae)). When released, the new variety (*INIAP Quitoense*) was not widely diffused because training was needed to stimulating grafting at the farm level. Instead, grafting was undertaken by a private enterprise who sold grafted plants at approximately seven times the cost ($1.10 vs. $0.15) of a non-grafted seedling. Despite the price differential, the variety is being promoted by the private company PILVICSA and adoption has accelerated in recent years (Clements et al. 2016). Other IPM technologies with commercial potential include pheromone traps and biological control agents, such as trichoderma in India (Naakkeeran et al. 2016).

Markets for IPM technologies and markets that reward producers who use IPM (such as a price premia which exist for organic production) have been slow to emerge in developing countries. As such, commercial farmers, who tend to adopt technologies early and, through demonstration to their neighbors, promote technology spread, have not broadly entered the IPM realm. IPM branding has not been widespread in the developing world, partly due to imprecise definitions, and partly due to difficulty monitoring. Lack of branding possibilities has also slowed IPM diffusion.

Economic Explanations for Slow Adoption in Developing Countries

The consensus of the literature supports the finding that IPM adoption in developing countries is spotty at best (Orr 2003, Parsa et al. 2014, Norton et al. 2019). Three main factors contribute to slow adoption from the demand side: farmer awareness and knowledge, perceptions of low profitability of IPM technologies, and risk and uncertainty. Lack of awareness and knowledge about IPM reflect well-known problems with agricultural extension in many developing countries, where funding has been cut and commodity programs compete for scarce funds (Larochelle et al. 2017). Given the potential complexity of IPM, farmer knowledge can be a fundamental constraint (Jørs et al. 2017). Exposure to a technology is a key determinant of overall adoption (Diagne and Demont 2007) and farmers experiment incrementally (Ersado et al. 2004).

Compared to conventional agricultural technologies, IPM has relatively low potential for private sector involvement because many of the practices involve altered management rather than commercializable technologies such as new seeds or fertilizers. Some exceptions to this statement exist. Pest resistant seeds, for example, have high potential for private sector involvement. Biopesticides and other biological control agents are also an exception. In these cases, there is potential for the private sector to produce and market these agents. Private sector promotion can help solve the generic problem that farmers may be unaware of IPM solutions (Norton et al. 2019). In other cases, the private sector can hinder wider adoption of IPM. In Indonesia, for example, government support for rice IPM led to widespread adoption between 1989 and 1999. As government support waned, pesticide producers and traders quickly entered with aggressive advertising programs, effectively replacing IPM with chemical controls (Thorburn 2015).

Complexity of some IPM practices increases the knowledge burden on the potential adopter. For example, applications of most biopesticides must be carefully timed to be effective, some pheromones only attract male insects and only suppress pest populations if applied area-wide, and grafting requires relatively precise control of humidity for the grafted seedlings. Successful adoption requires knowledge on how to implement the practice not just on the practice itself. Peterson et al. (2018) argue that IPM advocates have missed the boat by focusing too closely on practices or tactics and not adequately empowering (teaching) farmers to use them. Information and communications technology (ICT) has the potential for overcoming some information constraints to IPM adoption. For example, the Scientific Animations Without Borders (SAWBO) platform has made low-cost animated videos that provide information about pest control using IPM. These videos can be downloaded to smart phones and used and shared among farmer-recipients (Bello-Bravo and Pittendrigh 2018). Evidence shows that learning gains from these animations are greater compared to traditional extension approaches (Bello-Bravo et al. 2017). It is clear that a new frontier in delivering IPM messages is being created by innovations in ICT.

Low profitability of IPM technologies is acknowledged to be a constraint to widespread diffusion in some cases (Morse and Buhler 1997, Orr 2003, Jørs et al. 2017) even though many assessments of IPM in developing countries show relatively high returns in controlled trials (Pretty and Bharucha 2015, Norton et al. 2019). While controlled experiments show evidence of profitability, a large yield gap exists between experimental results and returns when the technology is taken to the farmer field. The complexity of the technology or failure to adequately train farmers in implementation may contribute to disappointing results on individual fields. Alternatively, profitability of IPM may be low due to policies such as subsidies to pesticides which lower the cost of conventional production to the relative detriment of IPM (Pingali and Rola 1995, Pingali and Gerpacio 1997, Parsa et al. 2014).

Risk and uncertainty can affect IPM adoption decision making, but the effect depends on the nature of the risk and of the practice in question. IPM, because it involves pest management rather than pest control, reflects a form of informal risk management (Alwang et al. 2001, Peterson et al. 2018) and by controlling pests, risks of infestation fall. When IPM practices replace purchased inputs, such as pesticides, market risk, such as fluctuating input and output prices, can make adoption more attractive. Use of a non-purchased IPM input instead of a purchased input lowers exposure to market-related risks. Additional risks—to human and animal health, for example—also fall when less-toxic inputs are used. When IPM involves purchases of more expensive substitutes, however, adoption implies additional exposure to market risk. Labor-intensive IPM practices can also insulate adopters from market risks. So, IPM can raise or lower exposure to market risks and risks' effect on adoption depends on many factors.

Uncertainty is perhaps more pernicious than risk. Uncertainty refers to an inability to know all the information necessary to evaluate risk. In the context of IPM adoption, a principal concern is whether particular practices will be effective. Such uncertainty will lead to less adoption and this uncertainty grows over time as pests and diseases evolve (Peterson et al. 2018). On the other hand, IPM practices may be attractive under uncertainty about outbreaks of pests and diseases. A traditional approach would be a prophylactic spray to avoid an uncertain outbreak, while a scouting-based IPM system would wait until the pest or its damage is present in the field.

A further cause of low returns of IPM adoption, well-recognized in the developing-country literature, is that some of the benefits are external to the producer. For example, costs of inappropriate pesticide use include adverse health outcomes (Pingali and Roger 1995, Antle et al. 1998) and off-farm damage to water quality and non-target species (Antle et al. 1998, Norton et al. 2019). These damages tend to be less highly weighted among farmers compared to yield and profitability. Farmers often perceive that they face lower risks of crop failures when using chemical controls of pests (Jørs et al. 2017). Decades of indoctrination by chemical vendors have led to suspicions that non-chemical controls may not be effective. By and large, farmers in low-income countries are risk averse and they will not adopt a technology until there is substantial evidence of its benefits relative to current practices.

Behavioral Economic Explanations

In recent years, behavioral economists, merging economic theory with concepts associated with human psychology, have uncovered numerous factors associated with perceived anomalies in decision making (Thaler 2016). Using a behavioral perspective, decisions that may seem odd, such as failure to adopt IPM, have compelling psychological explanations. Behavioralists point out that deviations from standard economic models of decision making include non-standard preferences, non-standard beliefs about the state of nature, and non-standard decision making (DellaVigna 2009, Larochelle et al. 2017). Each of these deviations can emerge due to the realities of IPM and can affect rates of IPM adoption. There are few research efforts to date that have applied a distinctly behavioralist perspective to explain the phenomenon of low IPM adoption.

Non-standard preferences are associated with outcomes such as present bias, procrastination, loss aversion, and endowment effects. In the context of IPM, present bias means the decision maker prefers immediate results and, for example, pesticides might be preferred because their action leads to immediate insect deaths. Partly due to present bias, decision makers use conventional technologies due to the lure of dead insects. Procrastination is associated with the tendency to delay actions until damage is evident and may be inconsistent with the IPM philosophy of managing rather than controlling insects (Norton et al. 2019). Procrastination may work for scouting and only spraying beyond a threshold, but many other IPM practices require proactive management. For example, use of resistant varieties requires the farmer to purchase a seed input, and if these purchases are delayed until right before the crop is planted, money may be tight (Duflo et al. 2008). The uncertainty associated with IPM makes it less attractive than conventional practices due to loss aversion—small-scale developing-country farmers place more weight on losses than gains and they know with certainty whether conventional practices work. Thus, farmers tend to over-apply pesticides as an insurance against crop failure (Waibel 1986).

Finally, studies of economic phenomena almost universally show endowment effects (Thaler 2016)—while economists would say that sunk costs should not be considered in decision making, they almost always are. Thus, investments in sprayers and other tools needed for conventional pest management lead farmers to make decisions to continue using them. Present bias would also lead them to not invest in capital to undertake long-term strategies (such as trap costs), so non-standard preferences reinforce themselves.

One form of non-standard beliefs is overconfidence—decision makers tend to think they are better than others at managing complex processes. In the context of pest management, farmers overestimate their ability to manage toxic pesticides and avoid damage from pesticide over-use. This overconfidence leads to mixing of toxic chemical cocktails, greater off-farm damage due to pesticide runoff (Pingali and Gerpacio 1997), and, when combined with non-standard preferences described above, over application of pesticides (Waibel 1986, Pretty and Bharucha 2015).

Another behavioral phenomenon is non-standard decision making. In contrast to the economic model of a rational decision maker with complete information, research shows that decisions are fraught with difficulty due to limited attention and menu effects. Limited attention is a well-documented phenomenon whereby decisions are made without fully considering their ramifications. Decision making with limited attention is particularly prominent among the poor who, because of other pressing concerns, find their 'decision bandwidth' to be taxed (Mullianathan and Shafir 2013, Schilbach et al. 2016). Examples of limited attention are decisions made without consideration of external costs (e.g., off-farm damage from pesticide runoff affecting others) or longer-term health costs (Pingali and Roger 1995, Crissman et al. 1998).

Menu effects refer to the phenomenon that when faced with several complex choices, decision makers may become overwhelmed by the options and adopt a default position. In contrast to the standard (well-known) economic model where more options are always thought to be good, menu effects can be associated with sub-optimal decision making. In developing countries, it is well documented that simple IPM practices are more likely to be adopted and simple messages are the preferred means of transmitting information to farmers (Huan et al. 1999, Ricker-Gilbert et al. 2008). In general, when decision makers are faced with numerous, complex choices, they show preference for the familiar (e.g., do as they have always done), show preference for the salient (e.g., chemicals stand out as a pest management option), avoid choices, and select the default option (DellaVigna 2009 contains numerous references).

As IPM typically involves complex choices since producers face numerous pests, manage them before or after they appear, and use input-intensive control mechanisms (Norton et al. 2019), reflection on recent findings in behavioral economics would lead to the conclusion that IPM adoption is likely to be attenuated. Complexity leads to perverse choices and when combined with other behavior-related phenomena, it is no surprise that there is a tendency to stick with what is known and most visible and continue with business as usual.

Traditional Remedies to Low Adoption

Recognition of the problem of complexity does not require a behavioral economics approach. In fact, IPM professionals have known for years that IPM complexity requires intensive training of farmers. In fact, the FFS solution—involving intensive training of a small number (usually around 25) for an entire cropping cycle—is a well-recognized attempt at solving the complexity issue (Luther et al. 2005). As is well known in the psychology literature, distributed practice, or breaking the study of the same material and principles into separate episodes, is associated with more effective learning (Cepeda et al. 2006). By performing repeated tasks over a growing cycle, FFS can effectively conduct distributed practice. FFS have been successful at training farmers in IPM principles and most evaluations of FFS show that they are effective at promoting IPM adoption (Feder et al. 2004, Mauceri et al. 2007, Davis et al. 2011). FFS, however, tend to be expensive per person trained (Feder et al. 2004) and have not been shown to lead to spillovers among non-participating farmers. The FFS approach assumes that because participants are selected for being entrepreneurial (leading farmers), much of the impact of the FFS will be through spread to non-participants (Feder et al. 2004). Because these spillovers have not been observed, the FFS have limited impacts beyond those directly trained, and are less effective when brought to scale (Norton et al. 2019). As a result, the cost and scale of FFS limit their effectiveness as an option to promote wide diffusion. In Ecuador, however, Carrión Yaguana et al. (2016) found some spillovers, but they were not as large as expected.

A Behavioral Option: Cheap Messaging

IPM adoption in the developing world is lagging behind its potential and training and promotion are viewed by many as a possible solution. Developing-country extension systems are stretched thin and the most successful conventional means of promoting IPM adoption—FFS—is costly and time-consuming. Behavioral insights provide a potential solution: IPM programs or messages can be targeted to address some of the more pernicious adoption-limiting factors, such as procrastination or menu effects. Through such targeting, cost-effective means to promote diffusion can be found. For example, text messages, and ICT alternatives such as animation videos, sent to farmers represent an easy and inexpensive way of delivering information (Bello-Bravo et al. 2017, Larochelle et al. 2017). If the text message can be targeted to overcome a specific behavioral constraint, they promote IPM adoption (Fig. 1). As shown in Fig. 1, the text reminders provide an additional stimulus compared to traditional training and this stimulus should increase adoption of the practices.

An additional advantage of the behavioral approach is that many of the concepts are easily adaptable to field experimentation. A recent study from Ecuador (Larochelle et al. 2017) examined the impacts of text messaging on behavioral obstacles to adoption of IPM. The authors noted that cell phones are becoming ubiquitous, even in remote areas of developing countries, that text messages are inexpensive to deliver, and that text messages designed to reinforce messages delivered through alternative, more extensive training might be effective at promoting IPM. They explicitly test the ability of text messaging to overcome procrastination (a reminder effect) or

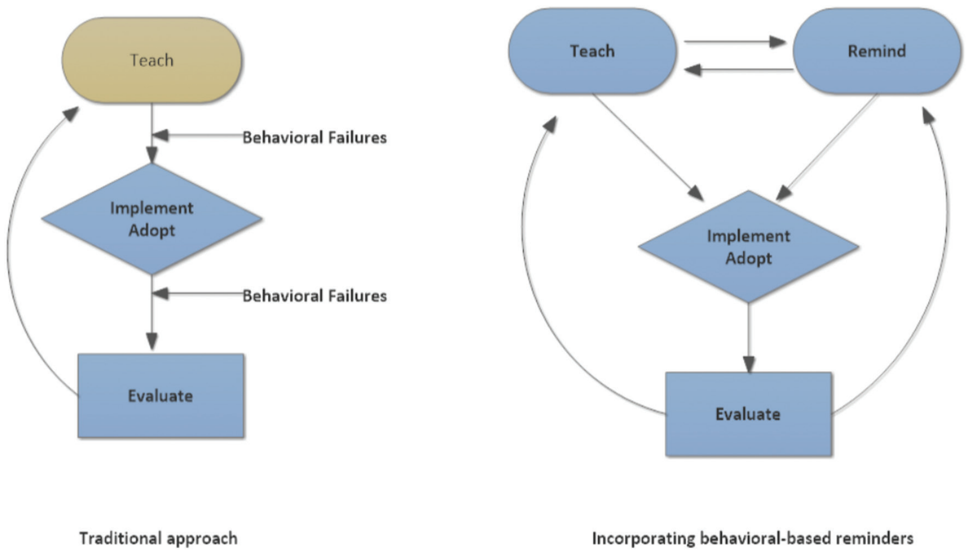

Fig. 1. Teaching and reminders: a behavioral approach to promoting adoption of IPM.

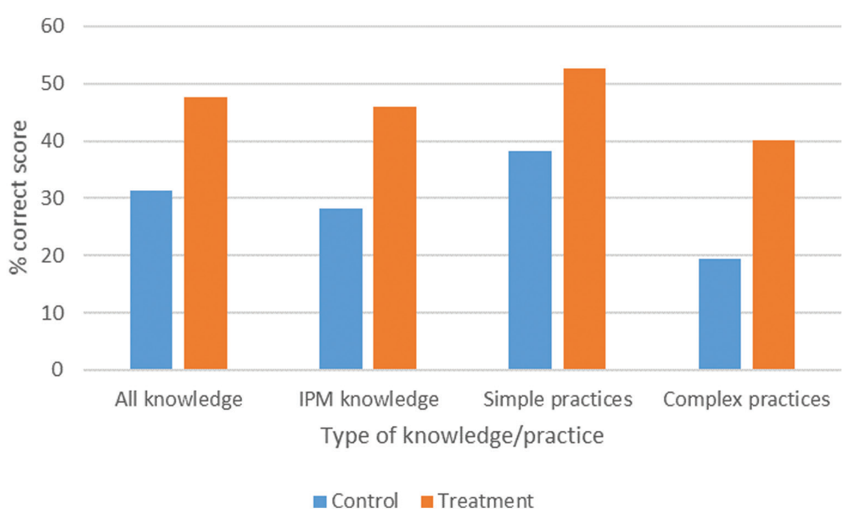

Fig. 2. Knowledge scores for different forms of IPM (percent of participants correctly identifying each practice) by exposure to treatment. All differences are statistically significant. Source: Larochelle et al. (2017).

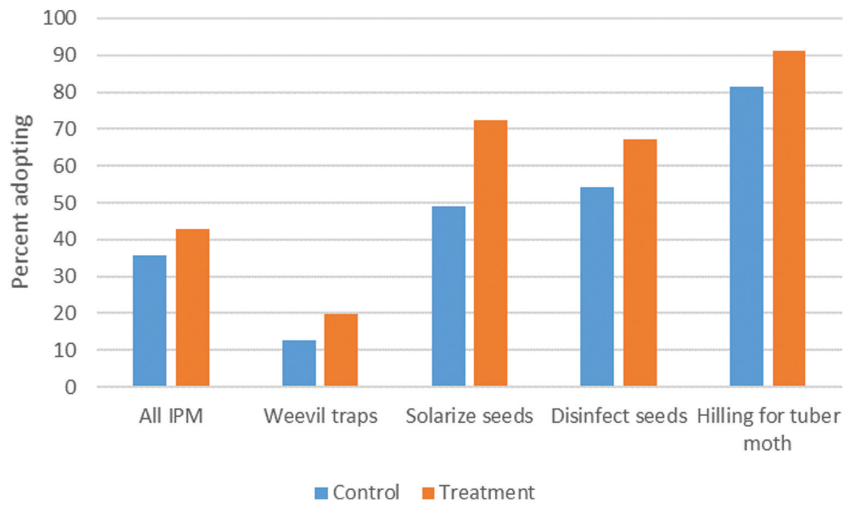

Fig. 3. Adoption of IPM practices (percent of participants adopting each practice) by exposure to treatment, selected practices. All differences are statistically significant. Source: Larochelle et al. (2017).

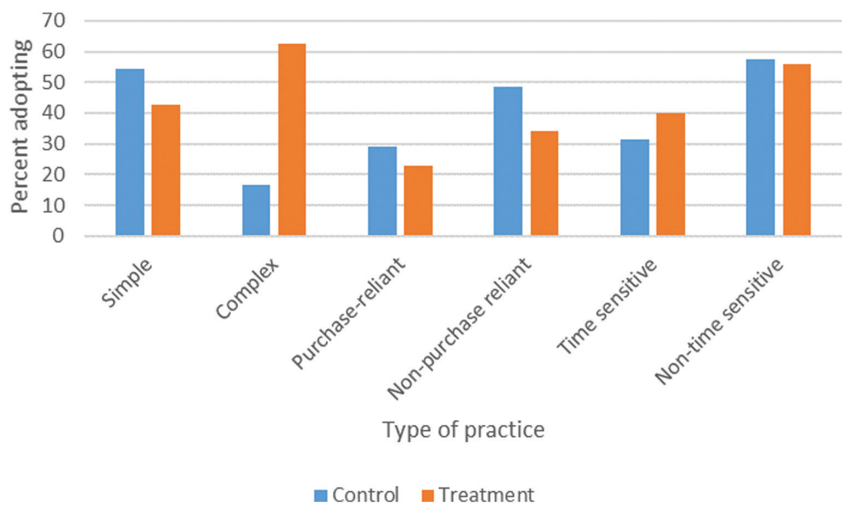

Fig. 4. Adoption of IPM practices by exposure to text message reminders, by practice type. All differences except non-time sensitive are statistically significant. Source: Larochelle et al. (2017).

build farmer knowledge. They also examine these effects according to the complexity of the IPM practices and provide insights into ways of overcoming menu effects described above.

The experiment involved randomly assigning farmers who participated at an IPM field day which contained three demonstration stations into two groups: the control group received nothing, while the treatment group received two or three text messages each week over 10 wk spanning the potato-growing season. Participation in the program was voluntary and participants provided informed consent. Following harvest, farm-household surveys were administered to participants (control and treatment). The purpose of the survey was to understand farmer knowledge and use of IPM practices during the prior growing season. Findings from the study showed: 1) receipt of text messages had a statistically significant positive impact on farmer knowledge (Fig. 2); 2) receipt of text messages was positively associated with uptake of IPM practices (Fig. 3); 3) the impact of receipt of text messages was most pronounced for complex processes, providing evidence that the text messages can be used to overcome menu effects (Fig. 4); and 4) receipt of messages had a larger positive effect on adoption of time-sensitive practices compared to practices that could be conducted at any time during the growing season (Fig. 4). The third finding is also evidence of the effectiveness of distributed practice in overcoming obstacles to learning complex processes. The last finding provides evidence that text messages help overcome the tendency to procrastinate.

The effectiveness of text messages in changing farmer behavior is likely to depend on the context. The study area in Larochelle et al. (2017) had been covered by intensive IPM training over many years, and farmers were receptive to the possibility of IPM use. However, this and other studies (e.g., Carrión Yaguana 2016, Cole and Fernando 2016, Global System for Mobile Association (GSMA) 2017, Jack and Tobias 2017) provide evidence that text messages can be used to complement other training methods. Whether used as a reminder to reinforce prior messages, or to help build knowledge based on training or other experience, the text message is an attractive alternative as a low-cost way to overcome behavioral constraints to IPM adoption.

Conclusions

Despite its potential and evidence of impact in project-affected areas, IPM adoption is limited in most developing countries. Without widespread adoption, the substantial resources spent for IPM research and outreach will not achieve their intended impacts. Broader impacts are required to continue to justify these expenditures and the main vehicle for intensive education of farmers, the FFS, is expensive to undertake and of questionable impact when brought to scale. The constraints to IPM adoption are now well known and, even where there is evidence of profitability of the IPM practices, adoption can lag. Behavioral constraints, which are important parts of the entire constraint set, can often be overcome by small changes—for example, by providing information at key decision points, or complementing other training to better enable farmer decision making.

Use of ICT such as text or video messaging to promote IPM technology adoption in the developing world lags behind its potential. IPM, because of its complexity and 'newness' in many settings, has some attributes making text messaging especially appropriate for overcoming behavioral obstacles. Adoption may be slowed by behavioral factors, such as present bias, procrastination, loss aversion, menu effects, and others. The study from Ecuador represents an experiment designed to test the relative importance of a couple of these factors and shows that text messages can be used to overcome them. The study's findings are also consistent with the psychology literature showing that distributed practice increases learning of complex tasks.

It is important to recognize that text messages are not a panacea. To be effective, they should be delivered in a structured way. Timing, message content, farmer ability, and the complexity of the IPM practice all help determine whether a text message solution is likely to be effective. The environment in Ecuador is unique in that intensive IPM interventions had already occurred and the field day participants were well versed in the concept. In other less saturated areas, a messaging program would probably begin with very simple messages and reinforce concepts and practices that are familiar. As the use of text messages proliferates, the effectiveness of individual messages or message programs will likely wane. Menu effects can emerge as decision makers are bombarded by competing messages.

The same entities, whether governmental or project-based, that promote IPM can implement a text messaging program at reasonable costs. The messaging program should complement existing extension methods and, depending on experience, could substitute for ineffective methods. Targeting could be made on the same basis as is eligibility/participation in the regular program. The marginal cost of messaging can be near zero, but, as noted, it is important that the message structure and content be carefully designed. Small-scale piloting of message programs could be used to inform the design of such programs. But, evidence shows that technology-based solutions can have a large impact.

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References Cited

Alwang, J., P. B. Siegel, and S. L. Jorgensen. 2001. Vulnerability: a view from different disciplines. Social Protection Discussion Series no. 0115. The World Bank, Washington, DC.

Antle, J. M., D. C. Cole, and C. Crissman. 1998. Further evidence on pesticides, productivity and farmer health: potato production in Ecuador. Agric. Econ. 18: 199–207.

Bello-Bravo, J., and B. R. Pittendrigh. 2018. Scientific Animations Without Borders (SAWBO): animating IPM information and education everywhere. Outlooks Pest Manag. 29: 58–61.

Bello-Bravo, J., M. Tamò, E. A. Dannon, and B. R. Pittendrigh 2017. An assessment of learning gains from educational animated videos versus traditional extension presentations among farmers in Benin. Info. Tech. Develop. 24: 224–244.

Carrión Yaguana, V. R. 2016. Agricultural technologies and economic development: three essays on technology adoption and inequality. Ph.D. dissertation, Virginia Tech, Blacksburg, VA.

Carrión Yaguana, V., J. Alwang, G. W. Norton, and V. Barrera. 2016. Does IPM have staying power? Revisiting a potato-producing area years after formal training ended. J. Agric. Econ. 67: 308–323.

Cepeda, N. J., H. Pashler, E. Vul, J. T. Wixted, and D. Rohrer. 2006. Distributed practice in verbal recall tasks: a review and quantitative synthesis. Psychol. Bull. 132: 354–380.

Clements, C., J. Alwang, V. Barrera, and J. M. Dominguez. 2016. Graft is good: the economic and environmental benefits of grafted naranjilla in the Andean Region. Renew. Agric. Food Sys. 32: 306–318.

Cole, S., and N. Fernando. 2016. Mobile'izing agricultural advice: technology adoption, diffusion and sustainability. Working Paper 13-047, Harvard Business School, Cambridge, MA.

Crissman, C. C., J. M. Antle, and S. M. Capalbo. 1998. Economic, environmental, and health tradeoffs in agriculture: pesticides and the sustainability of Andean potato production. Kluwer Academic Publishers, Boston, MA.

Davis, K., E. Nkonya, E. Kato, D. Mekonnen, M. Odendo, R. Miiro, and J. Nkuba. 2011. Impact of farmer field schools on productivity and poverty in East Africa. World Dev. 40: 402–413.

DellaVigna, S. 2009. Psychology and economics: evidence from the field. J. Econ. Lit. 47: 315–372.

Diagne, A., and M. Demont. 2007. Taking a new look at empirical models of adoption: average treatment effect estimation of adoption rates and their determinants. Agric. Econ. 37: 201–210.

Duflo, E., M. Kremer, and J. Robinson. 2008. How high are rates of return to fertilizer? Evidence from field experiments in Kenya. Am. Econ. Rev. 98: 482–488.

Ersado, L., G. Amacher, and J. Alwang. 2004. Productivity and land enhancing technologies in Northern Ethiopia: health, public investments, and sequential adoption. Am. J. Agric. Econ. 86: 321–331.

Feder, G., and D. L. Umali. 1993. The adoption of agricultural innovations: a review. Technol. Forecast. Soc. Change 43: 215–239.

Feder, G., R. Just, and D. Zilberman. 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cult. Change 33: 255–298.

Feder, G., R. Murgai, and J. B. Quizon. 2004. Sending farmers back to school: the impact of farmer field schools in Indonesia. Rev. Agric. Econ. 26: 45–62.

Global System for Mobile Association (**GSMA**). 2017. Creating scalable, engaging mobile solutions for agriculture: a study of six content services in the mNutrition initiative portfolio. (https://www.gsma.com/mobilefordevelopment/wp-content/themes/theme_mobilefordevelopment/magri-repo/Creating-engaging-scalable-solutions-for-agriculture.pdf). Accessed on February 21, 2019.

Guerci, M., G. W. Norton, M. N. Ba, I. Baoua, J. Alwang, L. Amadou, O. Moumouni, L. Karimoune, and R. Muniappan. 2018 Economic feasibility of an augmentative biological control industry in Niger. Crop Prot. 110: 34–40.

Harris, L., G. W. Norton, A. N. M. Rezaul Karim, J. Alwang, and D. B. Taylor. 2013. Bridging the information gap with cost-effective dissemination strategies: the case of integrated pest management in Bangladesh. J. Agric. Appl. Econ. 45: 639–654.

Huan, N. H., V. Mai, M. M. Escalada, and K. L. Heong. 1999. Changes in rice farmers' pest management in the Mekong Delta, Vietnam. Crop Prot. 18: 557–563.

Jack, K., and J. Tobias. 2017. Seeding success: increasing agricultural technology adoption through information. IGC Growth Brief Series 012. International Growth Centre, London, United Kingdom.

Jørs, E., A. Aramayo, O. Huici, F. Konradsen, and G. Gulis. 2017. Obstacles and opportunities for diffusion of integrated pest management strategies reported by Bolivian small-scale farmers and agronomists. Environ. Health Insights 11: 1178630217703390.

Kinuthia, B. K., and E. Mabaya. 2017. The adoption and dis-adoption of improved maize varieties in Tanzania, Mimeo. Cornell University, Ithaca, NY. (http://barrett.dyson.cornell.edu/staars/fellows/files/Kinuthia_Mabaya%2015%20Feb%202017%20abstract.pdf). Accessed on February 21, 2019.

Kyriacou, M. C., Y. Rouphael, G. Colla, R. Zrenner, and D. Schwarz. 2017. Vegetable grafting: the implications of a growing agronomic imperative for vegetable fruit quality and nutritive value. Front. Plant Sci. 8: 1–23.

Larochelle, C., J. Alwang, E. Travis, V. H. Barrera, and J. M. Dominguez. 2017. Did you really get the message? Using text reminders to stimulate adoption of agricultural technologies. J. Dev. Stud. 55: 548–564.

Luther, G. C., C. Harris, S. Sherwood, K. Gallagher, J. Mangan, and K. T. Gamby. 2005. Developments and innovations in farmer field schools and the training of trainers, pp. 159–190. *In* G. W. Norton, E. A. Heinrichs, G. C. Luther, and M. E. Irwin (eds.), Globalizing IPM: a participatory research process, Ch. 9. Blackwell Publishing, Ames, IA.

Mauceri, M., J. Alwang, G. W. Norton, and V. H. Barrera. 2007. Adoption of integrated pest management technologies: a case study of potato farmers in Carchi, Ecuador. J. Agric. Appl. Econ. 30: 765–780.

Maumbe, B. M., and S. M. Swinton. 2000. Why do smallholder cotton growers in Zimbabwe adopt IPM? The role of pesticide-related health risks and technology awareness. Paper presented at the American Agricultural Economics Association, 30 July – 2 August 2000, Tampa, FL.

Mian, Y., S. Hossain, and R. Karim. 2016. Integrated pest management of vegetables in Bangladesh, pp. 235–250. *In* R. Muniappan and **E. A.** Heinrichs (eds.), Integrated pest management of tropical vegetable crops, Ch. 11. Springer, Dordrecht, the Netherlands.

Morse, M., and W. Buhler. 1997. Integrated pest management in developing countries. Lynne Rienner, Boulder, CO.

Mullianathan, S., and E. Shafir. 2013. Scarcity: why having too little means so much. Henry Holt & Company, New York.

Muniappan, R., **and** E. A. Heinrichs (eds.) 2016. Integrated pest management of tropical vegetable crops. Springer, Dordrecht, the Netherlands.

Naakkeeran, S., P. Renukadevi, and **K. E. A. Aiyanathan.** 2016. Exploring the potential of *Trichoderma* for the management of seed and soil-borne diseases of crops. *In* R. Muniappan **and** E. A. Heinrichs (eds.), Integrated pest management of tropical vegetable crops, Ch. 4. Springer, Dordrecht, the Netherlands.

Norton, G. W., J. Alwang, M. Kassie, and R. Muniappan. 2019. Economic impacts of IPM practices in developing countries. *In* D.W. Onstad and P.R. Crane (eds.), The economics of integrated pest management of insects. CABI Publishing, Oxfordshire, United Kingdom.

Orr, A. 2003. Integrated pest management for resource-poor African farmers: is the emperor naked? World Dev. 31: 831–845.

Parsa, S., S. Morse, A. Bonifacio, T. C. B. Chancellor, B. Condori, V. Crespo-Pérez, S. L. A. Hobbs, J. Kroschel, M. N. Ba, F. Rebaudo, et al. 2014. Obstacles to integrated pest management adoption in developing countries. Proc. Natl. Acad. Sci. USA 111: 3889–3894.

Penn State Extension. 2018. What is integrated pest management. https://extension.psu.edu/what-is-integrated-pest-management. Accessed on February 21, 2019.

Peterson, R. K. D., L. G. Higley, and L. P. Pedigo. 2018. Whatever happened to IPM? Am. Entomol. 64: 146–150.

Pingali, P. L., and R. V. Gerpacio. 1997. Towards reduced pesticide use for cereal crops in Asia. CIMMYT Economics Working Paper 97-04, CIMMYT, Mexico, D.F., Mexico.

Pingali, P. L., **and** P. A. Roger (eds.) 1995. Impact of pesticides on farmer health and the rice environment. Kluwer Academic Publishers and International Rice Research Institute (IRRI), Norwell, MA and Los Baños, Laguna, Philippines.

Pingali, P. L., and A. C. Rola. 1995. Public regulatory roles in developing markets: the case of pesticides. *In* P. L. Pingali and P. A. Roger (eds.), Impact of pesticides on farmer health and the rice environment. Kluwer Academic Publishers and International Rice Research Institute (IRRI), Norwell, MA and Los Baños, Laguna, Philippines.

Pretty, J., and Z. P. Bharucha. 2015. Integrated pest management for sustainable intensification of agriculture in Asia and Africa. Insects 6: 152–182.

Ricker-Gilbert, J., G. W. Norton, J. Alwang, M. Miah, and G. Feder. 2008. Cost effectiveness of alternative IPM extension methods: an example from Bangladesh. Rev. Agric. Econ. 30: 252–269.

Schilbach, F., H. Schofield, and S. Mullainathan. 2016. The psychological lives of the poor. Am. Econ. Rev. 106: 435–440.

Stern, V., R. Smith, E. Van den Bosch, and K. Hagen. 1959. The integrated control concept. Hilagardia. 29: 81–101.

Thaler, R. 2016. Misbehaving: the making of behavioral economics. Norton, New York.

Thorburn, C. 2015. The rise and demise of integrated pest management in rice in Indonesia. Insects 6: 381–408.

Waibel, H. 1986. The economics of integrated pest control in irrigated rice: a case study from the Philippines. Crop Protection Monographs. Springer-Verlag, Berlin, Germany.