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How do stakeholder interactions in Cambodian rice farming villages contribute to a pesticide lock-in?

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ABSTRACT

This paper addresses the conditions and mechanisms that sustain pesticide use by Cambodian rice farmers and constrain a transition to more sustainable pest control practices. We analyzed data from a survey of individual farmers (N = 320), focus group discussions with farmer groups, and interviews with input sellers, rat hunters and local extension agents.

Our findings show that farmers mix different types (e.g. herbicides and insecticides) and brands of pesticides in one application. Other chemicals, in particular 'growth activators' are often added to these mixes. The interaction patterns and financial arrangements among farmers, pesticide sellers, and laborers promote or sustain these practices. Increasing returns to information and recursive social interaction at the community level thus create a lock-in situation for pesticide use.

These findings have direct implications on targeting interventions, which are often aimed at providing knowledge to government extension agents and farmers. Our results suggest that farmers' knowledge on pest management is not the only driver for their decisions and practices. A broader scope of intervention in communication and feedback loops between stakeholders directly interacting with farmers can help to diversify the suite of recommendations while providing a balance in the information that reaches farmers. Changes in these social arrangements and informal rules may be required to affect positive changes in rice pest management.

1. Introduction

One of the development goals is to achieve food security through forms of sustainable agriculture. The challenge, captured by the notion 'sustainable intensification,' is to increase productivity levels with the use of fewer or less costly alternative resources (FAO, 2009; Garnett et al., 2013; Struik and Kuyper, 2017). The rice-growing regions of Asia face a particular challenge in this respect. Besides high water use and emission of methane, a major greenhouse gas, wetland rice cultivation is also characterized by the use of high levels of agro-chemicals (Ketelaar and Abubakar, 2012; Carvalho, 2017). Working towards sustainable intensification thus requires profound changes in the current routines of rice cultivation. For pest control there are alternatives to an exclusive reliance on chemical pesticides. Integrated Pest Management (IPM) has been introduced as a more sustainable pest management strategy. It involves agronomic practices that limit pest populations, promoting the impact of natural enemies, use of biological control agents (BCA), and as a last resort, targeted use of pesticides (Zehnder et al., 2006; Heinrichs et al., 2017; Heinrichs and Muniappan, 2017). This paper addresses the constraints and opportunities for sustainable rice crop protection in Cambodia.

Cambodia's recent history of war and international isolation resulted in a late introduction of rice improvement strategies by international development agencies and agribusiness. This late introduction created an opportunity to apply lessons learned in other Asian rice production areas concerning Integrated Pest Management. Overall, the national government supports initiatives for sustainable food production. IPM was ratified as the national crop production strategy in 1998. In addition, there is an established National IPM Programme with a network that includes researchers at national level and extension staff all the way

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to farmer trainers in the villages (Ngin, 2002). Nevertheless, pesticide use in Cambodia is exponentially increasing (MAFF, 2012; Matsukawa et al., 2016). This increase is evidenced most prominently by the trend in pesticide import values, which had multiplied 285 times between 2006 and 2010 (FAO, 2012), and continues to rise. In 2011, the amount of imported pesticides was documented at 5,598 tonnes, but by 2016 it had increased to 41,648 tonnes (MAFF, 2012, 2017). At the same time, IPM was introduced to Cambodian farmers with proven benefits to those who tried the technology (Ngin et al., 2017). However, there remains limited adoption of IPM practices (Jackson et al., in this issue), and evident reliance on pesticides by Cambodian rice farmers (Matsukawa et al., 2015, 2016). This study focuses on the village-level dynamics that shape the use of pesticides in Cambodia.

This paper addresses key socio-technical dynamics that affect pesticide use by rice farmers in different Cambodian villages. The question why farmers continue to use pesticides even when alternatives are available has been addressed in various studies. Some of the provided answers for Cambodia highlight the ineffective implementation of pesticide regulations (Taylor, 2014), the limited knowledge of farmers regarding IPM (Kimkhuy and Ngin, 2002), the proliferation of available pesticides (Ngin et al., 2017), or agronomic conditions such as field size and varieties used (Matsukawa et al., 2016). Studies on pesticide use in other countries highlight beliefs and cultural norms (Palis et al., 2006), as well as uncertainties about the products and difficulty to coordinate networks for use of alternative technologies (Wagner et al., 2016). These explanations each have their validity and, taken together, testify that multiple factors are at stake. Agronomists are familiar with multiple factors affecting pest control and therefore opt for a systems approach (Barzman et al., 2015, Heinrichs et al., 2017). As implied by the cited studies, there are social factors interacting with agronomic factors. Combining social and technical (including agronomic) factors in a single conceptual framework is common in the field of Science and Technology Studies (for an overview see Sovacool and Hess, 2017). One relevant concept from this field is technological lock-in. Technological lock-in refers to accumulated economic, legal and social advantages connected to a particular technology that favour its use over alternatives, even when alternatives are technically more advanced or socially desirable. The main underlying mechanism that creates a technological lock-in is a repeated preference for one technology and uncertainty over alternatives emerging from interaction dynamics between various stakeholders (Arthur, 1989; Perkins, 2003). A lock-in situation does not exclude or choke innovation, but causes innovations to follow a particular trajectory, copying operational models and mechanisms of existing technologies. Lock-in emerges in the production of pesticides as the chemical industry continues to develop new pesticide products. This is because they have the technical capacity and are familiar with organizing the logistics, legal arrangements, and marketing of such products (Joly and Lemarie, 2002). At the user side, interactions between farmers, input suppliers and extension agencies create a similar lock-in situation as pesticides are applied repeatedly (Spangenberg et al., 2015). Lock-in mechanism are also prevalent in international networks of research institutes, as potential industrial applications and co-funding by commercial partners can direct a research agenda away from less financially rewarding topics such as IPM (Van Loqueren and Baret, 2009).

While previous studies in Cambodia have alluded to this pesticide lock-in (e.g. Ngin, 2017; Matsukawa et al., 2016; Taylor, 2014; Flor et al., 2018), there is a gap in knowledge about how interaction dynamics at the community level makes farmers apply pesticides and hesitant to use available alternatives. Understanding the socio-technical dynamics of pest management in farming communities can provide insights on where to target interventions to ease the pesticide lock-in. The objective of this paper is to provide insight on the interaction dynamics of pest control and arrangements that lock-in specific pest control technologies in Cambodian rice farming communities.

2. Conceptual framework

The concept of technological lock-in originates from economic theories about innovation and distribution of technologies (Perkins, 2003). As an overall notion, it explains why certain technologies are widespread and continue to be used despite the existence of alternatives that are arguably better on the basis of specific features and emerging new insights. Technological lock-in suggests a straightforward binary, where one technological option prevails and alternatives are locked out. However, alternative technological options are rarely excluded entirely, as is the case with IPM in Cambodia. Lock-in is about dominance of one technology over another resulting from general mechanisms, primarily economies of scale, organizational learning, reduction of uncertainty, and embeddedness in larger networks (Arthur, 1989; Perkins, 2003). Each of these mechanisms is applicable to the use of pesticides in agriculture (Joly and Lemarie, 2002). However, in practice these mechanisms have little to say about the role of users and other social actors in the choice between one technological option and another.

Klitkou et al. (2015) refined the general mechanisms by listing nine processes underlying technology lock-in, in the energy sector. These partially overlap with those previously mentioned, and equally focus on the development and distribution stages of technologies. A situation of lock-in happens as costs of producing a technology go down over time and the benefits for using them increase. Klitkou et al. (2015), following the work of Arthur (1989), and Katz and Shapiro (1986), specified lock-in mechanisms at the industry level discussing how incremental innovations become cheaper. More specifically, the lock-in of pesticides and the consequential 'lock-out' of IPM as an alternative had been described as an effect of these broader mechanisms (Cowan and Gunby, 1996). Van Loqueren and Baret (2008) further examined lock-in factors affected by market, public extension services and research, regulations and policies applied in the past, but also included the user context or those relating to farmers. In a study on small scale agriculture, factors such as gender, access to advice from agrochemical technician, size of cultivated land, and choice of main crop contributed to lock-in (Wagner et al., 2016). These studies point out that aside from broader mechanisms at the industry level there are also user context mechanisms that affect lock-in.

As our interest is in the user end of pesticide lock-in, we highlight three of the processes mentioned by Klitkou et al. (2015) that concern the user context. A first mechanism is 'technological interrelatedness'. This explains the benefits of one technical option due to connections with other technologies. In another paper we addressed this mechanism by showing how factors such as crop establishment practices, water management, and fertilizer application tie in with pesticide use (Flor et al., 2019). Another process Klitkou et al. (2015: 25) identify is 'informational increasing returns', referring to a cumulative repetition and confirmation of information about the technology as it gains dominance among users. In short, as information sharing about a technology accrues, further use is favored. A third user-related process Klitkou et al. (2015) identified is 'collective action', which is about shared values and behavioral patterns that assert the use of a particular technology. This refers to an emerging belief that the use of a particular technology is not merely effective but seen as the (only) right way to act. Using the technology (and not another one) leads to approval and appreciation by community members. These two processes provide the framework for investigating the interaction dynamics for pesticide use in Cambodian rice communities. It raises important questions about key actors in the recurrent spread of information, how farmers apply pesticides and how its use is valued by different actors.

3. Methods

We employed a mix of methods to understand mechanisms that could lock-in a specific technology at the user context. For this, we first examined the practices and the technologies being used, taking a quantitative view of pest management in rice farming across different ecological zones in Cambodia. We also gauged the sources of information that farmers obtained. Furthermore, to understand the social interactions underlying such practices, we implemented focus group discussions and interviews of different stakeholders involved in pest management.

We obtained data on pest management practices of farmers via a 2016 survey of rice production practices. The surveyed farmers (n = 320) were geographically spread across Cambodia in the provinces of Battambang, Kampong Thom, Prey Veng and Takeo. These provinces represent varied agro-ecological conditions for rice farming. In each, two villages from separate districts were selected because they had intensive rice production (at least two cropping seasons per year), access to irrigation, short distance to a government station that can provide extension services, and road access. The farmers surveyed (40 per village) were randomly selected from a list of farmers living in two villages within each province. The interview instrument was pre-tested, and consent of all respondents was obtained prior to the survey. All interviews were conducted face-to-face in Khmer. The survey covered rice production practices, farming characteristics, as well as the sources of information, with attention to different aspects of pest management and pesticide use.

Data regarding pest management, and specifically pesticide use, were summarized and descriptive statistics were obtained. Furthermore, analysis of variance followed by Tukey HSD post-hoc test was performed separately on the number of pesticide applications, the number of pesticides types mixed, and the number of products (trade names) mixed, with province and season as the independent variables.

Subsequent to the survey, the same eight villages were revisited for a qualitative study. Focus group discussions (FGDs, 89 farmers, average of 11 farmers per FGD) and semi-structured interviews were implemented to find out about who is involved in interactions over pesticide use, how such interactions take place, and how pest management is carried out and perceived at the community level. The stakeholder groups and the linkages mentioned during the FGDs and interviews were coded into a database to create a visual picture of the network and interactions using UCINet 6 and NetDraw. Furthermore, we explored if and how the socio-technical arrangements surrounding pest management at the community level influenced the pesticide use of farmers.

Data from the survey and FGDs were analyzed in complement with interview data from the various stakeholders that farmers mentioned were involved in pest management. A specific interview guide was used for each stakeholder group including 9 village input retailers, 4 rat hunters and sellers, 2 laborers, 17 government and company extension agents, 5 irrigation service providers, and 3 dealers or distributors of pesticide at the nearest town. These participants were purposively sampled based on whom farmers and other stakeholders said were relevant to pest management in their area.

The interviews focused on activities for pest management. This included the topics, technologies and products they promote, linkages with other stakeholders, their observations and actions regarding the practices and preferences of farmers, decisions during their interactions for pest management, and resources and financial arrangements involved. Informed consent was obtained prior to all FGDs and interviews. Open coding of the data was done through Atlas.ti. Qualitative data analysis was iterative starting from the data collection phase, with further thematic analysis done through Atlas.ti (Smit, 2002). The themes that emerged from the qualitative study were analyzed following the framework described in Section 2 which focuses on user context of technological lock-in.

4. Results

We first detail the pest management practices of farmers, specifically to check whether farmers rely on pesticides or use alternative technologies. To examine the user context behind this, we then show the stakeholder network, discussing the role of non-farmer stakeholders in pest management. Lastly, we discuss the interaction patterns within this network relating to information as well as other social norms or arrangements for pest management.

4.1. Practices on pesticide use

The main pest management activity of farmers in the four provinces was application of pesticides. Of the total number of times pest management was implemented in 2015–16 by surveyed farmers, only 1% entailed non-pesticide methods such as manual picking of snails, hand weeding, or rat hunting. The rest of the pest management activities were implemented using a form of chemical pesticide. There were differences in the number of pesticide applications and products (trade names) mixed across provinces; and the number of applications differed across seasons (Table 1).

Farmers surveyed had an average of two to four pesticide applications in one rice-cropping season (Table 2). There were farmers however, who applied pesticides as many as 16 times. Farmers applied different types of pesticides, but according to pesticide sellers, *'insecticides and herbicides were the most in demand'*. Further examination into pesticide use shows not only a high number of applications, but also use of more than one pesticide type in a single application (Table 2).

Between 33 and 71% of farmers in each province mixed pesticides of different trade name or brand in each application (Table 2). Furthermore, between 8 and 33% mixed different types of pesticides, usually herbicide and insecticide, or insecticide and fungicide, in one application. Mixing of the various pesticide groups and brands was not done in every application; hence there were still many applications in which only one product and type of pesticide were used. Rodenticides were never mixed with other pesticides.

The main pesticides used covered several classes (active ingredients were classified based on list from www.weedscience.org). The classes of insecticides used included organophosphate, pyrethroid, ryanoid, neonicotinoid, pyrrole, macrocyclic lactone, pyridine azomethine and phenylpyrazole. The herbicides included pyrimidinyl(thio)benzoate, chloroacetamide, glycine, quinoline carboxylic acid, phenoxy-carboxylic-acid, aryloxyphenoxy-propionate and sulfonylurea. Some farmers used brands of herbicide that had active ingredients from two to three classes. The fungicides included dioxolane and triazole, a mix with AI from these two classes, or a mix with sulfur. The molluscicides included clonitralid-olamine, and aldehyde molluscicide. Lastly, the rodenticides were inorganic rodenticides.

Between 19 and 58% of farmers in the wet season and then 31 and 79% in the dry season mixed growth activators–substances that enhance plant activity, with pesticides or sprayed these at the same time as pesticides (Table 2). Growth activators are a mix of NPK and minerals such as calcium or gypsum (according to interviews with pesticide sellers). These were often sold in small packets to be mixed with pesticides. There were 'specific growth-activators suited for the different

Table 1
ANOVA of number of pesticide applications, types of pesticide mixed, and products (trade names) mixed across province and season.

Dependent variable	Independent variables	F	p-value
Number of pesticide applications	Province	10.444	0.000
	Season	47.550	0.000
	Province*Season	2.477	0.610
Number of pesticide types mixed	Province	2.412	0.066
	Season	1.030	0.311
	Province*Season	0.028	0.994
Number of products (trade names) mixed	Province	28.919	0.000
	Season	0.011	0.917
	Province*Season	0.488	0.719

Table 2
Farmers' pesticide use (a total of herbicide, insecticide, molluscicide, rodenticide and fungicide) shown in average applications per season, percentage of farmers who mixed different types of pesticide in an application, mean number of pesticide types mixed; percentage of farmers who mixed pesticides of different trade names in an application, mean number of products mixed; and percentage of farmers who mixed growth activators. Data are grouped by province, and wet and dry season 2015–16; N = 320; with minimum and maximum values; S.E. Mean in brackets.

	Mean pesticide applications* (S.E. Mean)	Min, Max	Mixing different types of pesticides (e.g. herbicide and insecticide)			Mixing different trade names or brands of pesticide			% of farmers who applied growth activator
			% of farmers	Mean number of pesticide types mixed* (S.E. Mean)	Min, Max	% of farmer	Mean number of products mixed* (S.E. Mean)	Min, Max	
Wet season									
Battambang (N = 80)	2.4^{c} (0.159)	1,7	22.5	1.52^{a} (0.073)	1,2	71.3	2.03^{a} (0.082)	(1,5)	39.2
Kampong Thom (N = 80)	3.3^{ab} (0.331)	1,16	7.5	1.32^{a} (0.095)	1,2	32.5	1.36^{c} (0.048)	(1,3)	37.7
Takeo (N = 80)	2.6^{bc} (0.199)	1,8	11.3	1.36^{a} (00.92)	1,2	45.0	1.76^{b} (0.079)	(1,4)	18.8
Prey Veng (N = 80)	3.6^{a} (0.205)	1,7	20.0	1.39^{a} (0.020)	1,3	62.5	1.90^{ab} (0.080)	(1,6)	57.9
Dry season									
Battambang (N = 80)	3.0^{c} (0.197)	1,9	22.5	1.45^{a} (0.069)	1,2	66.3	1.98^{a} (0.077)	(1,5)	44.1
Kampong Thom (N = 80)	4.3^{ab} (0.340)	1,14	7.5	1.29^{a} (0.087)	1,2	38.8	1.36^{c} (0.049)	(1,3)	47.6
Takeo (N = 80)	3.8^{bc} (0.303)	1,11	21.3	1.31^{a} (0.058)	1,2	56.3	1.73^{b} (0.065)	(1,5)	30.7
Prey Veng (N = 80)	4.3^{a} (0.230)	1,10	32.5	1.31^{a} (0.046)	1,3	66.3	2.00^{ab} (0.065)	(1,6)	78.9

*Means within a column followed by the same letter in superscript are not significantly different ($p < 0.05$).

stages of the rice crop' (according to a pesticide seller).

Notably, farmers observed different key pests across the four provinces (Fig. 1). Farmers noted stemborer, brown planthopper and leaffolders as key pest insects, and brown leaf spot and blast as the key diseases. These pests were perceived to have caused the most damage at the same seasons farmers applied the pesticides shown in Table 2. In the

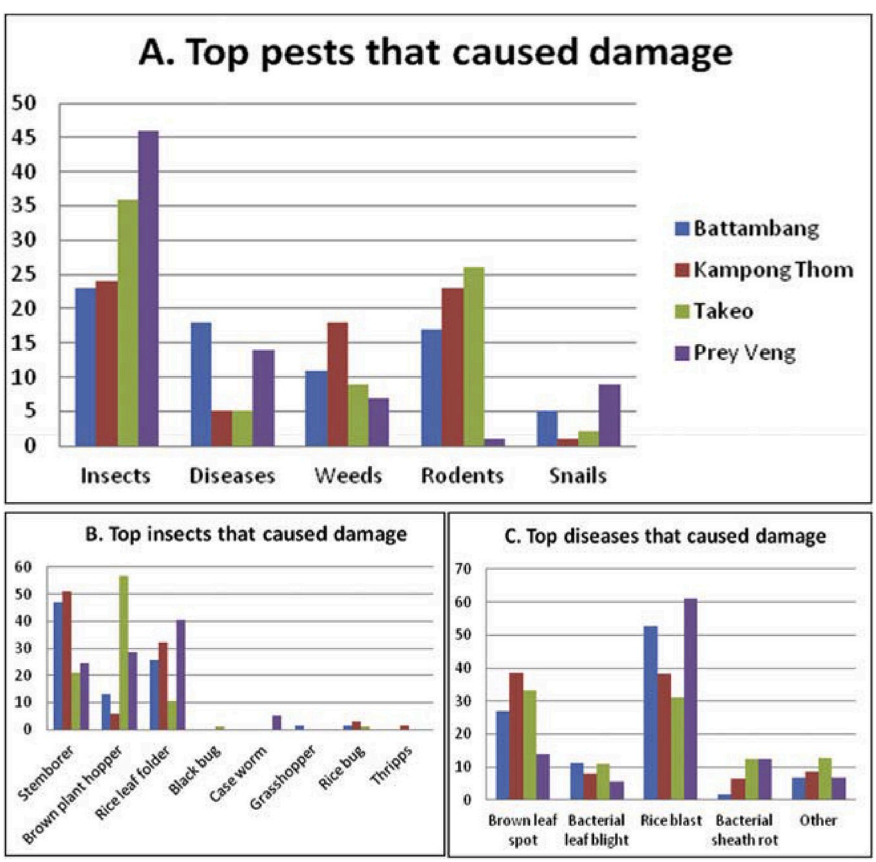

Fig. 1. Pests identified by farmers (%) as the main problems (A), with details on the insects (B) and diseases (C) that caused damage, in 2015–16 from four provinces in Cambodia, N = 320.

survey however, the data on pesticide use were asked separately from data on observed pests. Hence, the pesticide applications could not be characterized as corresponding precisely to a specific pest or incidence.

4.2. Stakeholders and their interactions for pest management

There were different stakeholders involved in pest management; and they each had different roles (in text boxes, Fig. 2). Government extension agents had the most diverse roles, entailing different types of interactions with farmers and other stakeholders. They work at village, commune, and district levels, but all were coordinated through the Provincial Department of Agriculture Forestry and Fisheries. Government extension agents were also the only group that provided formal training on pest management to farmers. Of the four provinces, only Prey Veng had reported on-going field schools, season-long learning activities usually about pest identification and management, in select villages in early 2018.

To address immediate pest problems however, it is not extension agents but pesticide sellers whom farmers interacted with the most for pest management recommendations (Fig. 2). Sellers especially those living within the villages were the most accessible to farmers for direct consultation regarding pest management. Some sellers interviewed formerly worked at a government office, and one was currently also an extension staff.

Extension agents from pesticide companies helped the pesticide sellers when they could not identify the pest problems. They also '*scoped out areas where [the company's] products are not being sold*' and then established technology demonstrations with 'demo farmers'. Demo farmers test the product and share the knowledge about it to other farmers.

According to one seller, '*when there are pest problems, we call them (the private extension agents)*'. Another said, '*they come to see the field and talk with farmers … they inform us what to recommend.*'

Furthermore, sales agents from pesticide companies supported the pesticide seller through promotional activities at the shops, but they had minimal interaction with farmers. Farmers either implemented the pest management activities themselves or hired laborers. In many cases, the laborers were also farmers, but some were landless residents who provide services for spraying and other farm work. Laborers may provide the sprayers as part of the service, but they do not buy the pesticides.

Irrigation service providers, particularly those in gravity irrigation or larger pump irrigation systems, played a role in coordinating farmers for cropping synchrony, but they were not actively involved in pest management. Other stakeholders such as rat hunters were not perceived to be involved in pest management because collecting rats for sale or consumption is limited in scope and not timed well enough to control the pest. For example, '*they collect only when they see combine harvesters in the fields*'. Rat hunters and sellers coming from within the villages were present in Takeo and Kampong Thom, but not in the other provinces.

4.3. Influential interactions for pest management

The pest management decisions of farmers were influenced by the interactions with different stakeholders. These interactions included information or knowledge sharing. Additionally, interactions were organized around resources and financial arrangements. Lastly, there were linkages and coordination mechanisms that collectively bound the decisions of farmers. All these constituted patterns of interaction for pest management at the community level.

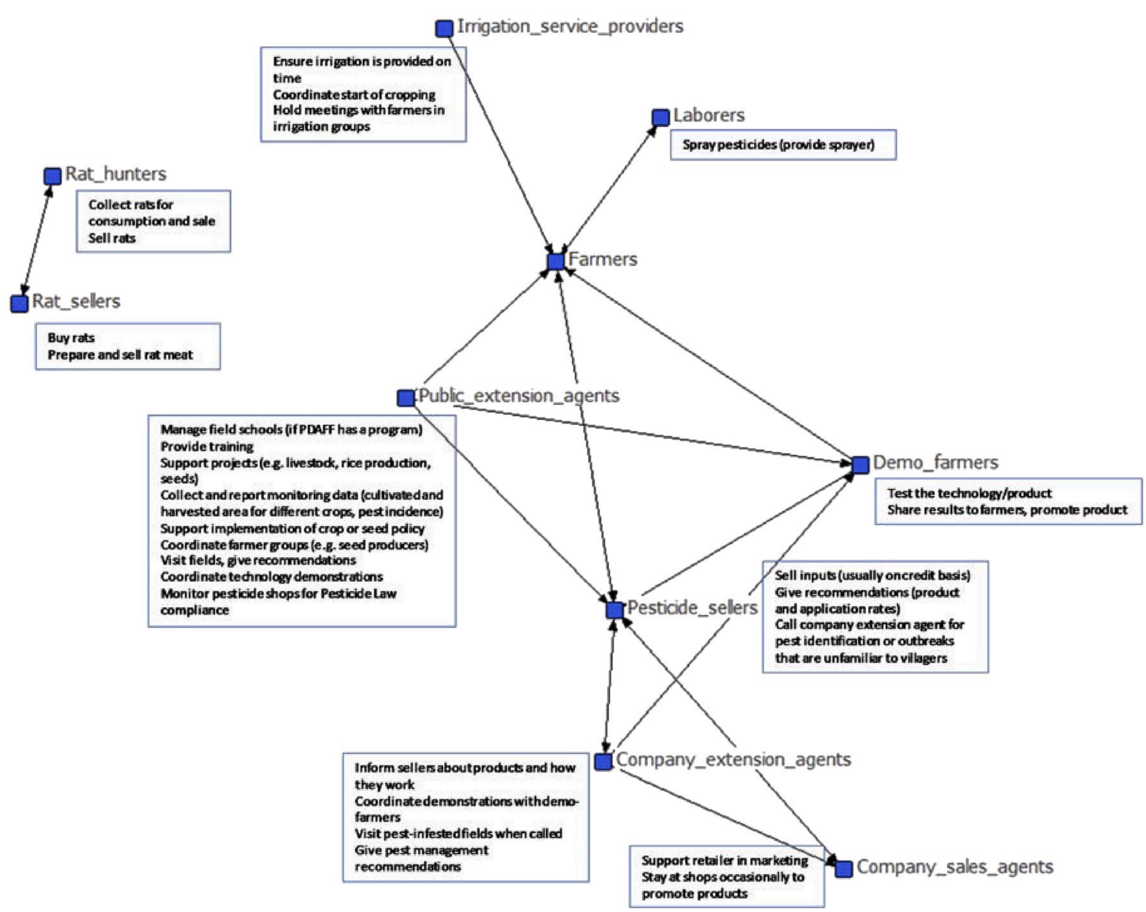

Fig. 2. Key stakeholders involved in pest management in the surveyed sites, and their roles*PDAFF = Provincial Department of Agriculture, Forestry and Fisheries.

4.3.1. Interactions for knowledge and information

Farmers interacted with different stakeholders, but the influential interactions for information were specific to a few groups. The main sources of information were extension agents (both public and company extension staff) and pesticide sellers; however, regarding decisions for selecting or applying pesticides, the sellers were more prominent (Table 3). Although farmers surveyed mentioned media as source of information, they also qualified that information from the media was not specific to their pest management issues, in contrast with the information from sellers.

According to farmers and sellers, farmers do not decide about pesticides at the start of the season. They did so when they saw symptoms of pest injury in the fields (also evident in the decisions regarding timing of application, Table 3). Farmers then went to the shops, some bringing samples of the damaged crop, and requested advice. Sellers do not recommend calendar application, but provided recommendations according to the pest problems described by the farmer. Sellers said they worked on the basis of trust:

> One seller said, '*if it doesn't work they [farmers] won't come again*'. According to another, '*they trust me because I don't lie to them.*'

The sellers had discussions with the farmers, and '*gave recommendations on products … although some farmers knew what they wanted to buy*'. Sellers also provided additional information such as mixtures of products and growth activators suited to the crop stage that farmers described:

> One seller said,' *farmers preferred to buy from me* [because] *I am skilful in giving recommendations on how to mix and when to apply … suited for each crop stage*.' Another seller said 'the *company's [pesticide] products are effective because they are mixed with NPK for specific crop stages … nitrogen rate is different.*' A farmer also said *'they don't know whether it [growth activator] helps with pest management',* but they can see it *'helps plants flower at the same time'* or make *'grains more yellow … and there are no spots on the grains.*'

When probed, the seller described growth activators for three different crop stages targeting roots, stem, and flower. She recommended a different packet with different mix of NPK for each growth stage that targets these parts of the plants. Each stage also corresponds to a recommended insecticide. She matched growth activators with pesticides for 3 different insects. Worm, leaf folder and then stem borer, were perceived to affect each stage subsequently. It is possible that the active ingredients of the insecticides do not change, but the mixture with growth activator is different for each crop stage. As the other seller quoted above shows, a key difference in the recommendation is the composition of the growth activator that is included in the recommended mixture of pesticide.

Farmers depended on the seller for this information since growth activators were not in the common fertilizer recommendations such as those provided by government extension agents. Lastly, based on the field size that farmers specify, the seller provided the application rate. Hence, advice from sellers is the main factor for decisions regarding pesticide rates (Table 3). Although some farmers (44%) said they also checked the label, there were farmers who said they have to '*overdose a little, because the pesticide might not work [if using the correct rate].*'

Laborers were involved in applying pesticides but there was limited sharing of knowledge. They also did not typically make the decisions on the pesticide selection, but did make decisions on the number of sprayer loads to apply. Laborers and farmers mentioned that discussions between them on what to apply occasionally occur. Farmers were noted to provide instructions to laborers, although other farmers stated '*the laborers are farmers themselves and know what to do.*' Most laborers thus depended on their own knowledge and skills in applying the pesticides provided by farmers.

The village-level retailers of pesticides do not get formal training, but dealers (two of the sellers interviewed) from the surrounding town said they '*joined a government-organized training on pesticides*'. This training was required for their business operations. Most retailers therefore relied on the advice from company technicians or utilized their own background (some were farmers or former government staff). Retailers also depended on the private extension agents to update them on results from technology demonstrations. The private extension agent would find a key farmer who was willing to apply the product and set up the demonstration usually on 1 ha or bigger plots. The demo-farmer was responsible for all on-farm activities, with some technical guidance from the technician. These private extension agents do not directly sell or promote the products to farmers but they communicate the results of demonstrations to pesticide sellers, who then describe to the farmers how these products work. There were sellers who noted that

> He *'would not sell a new product unless a demonstration on it had been done'*.

> Another seller said, '*the company staff contracts the [demo] farmers, then invites them to a workshop. They give the product to the farmer. The costs are to be paid after the crop is harvested. This is for the demonstration. They [sellers] will then distribute the product and farmers use it.*'

Also shown in Table 3, neighbors in the farming community are important sources of information. To an extent, farmers also obtained agricultural information from farmer leaders and farmer groups. Although government extension staff may be consulted for some pest management concerns, their proximity to the village made them less connected to farmers, compared with resident pesticide sellers. They also have varied concerns to advice farmers on and thus, are not focused on pest management topics only (Fig. 2). For example, a commune-based public extension worker who is a trained member of an IPM

Table 3
Percentage of farmers and their information sources, with factors (% of farmers who identified these) affecting their decisions about timing of application, product selection, and application rates; N = 320.

Where farmers get information		How farmers decide on timing		How farmers decide on products		How farmers decide on application rates	
Source	%	Factor	%	Factor	%	Factor	%
Extension agents	32.2	Visible damage	50.6	Effectiveness of product	84.9	Advice from sellers	80.2
Input sellers	31.3	Advice from sellers	39.5	Advice from sellers	22.5	Label	44.1
TV	28.4	Label	21.3	Advertising	3.1	Advice from relative/neighbor	15.4
Neighbors	23.8	Pest presence	10.8	Advice from extension	2.2	Advice from extension	5.2
Relatives	20.3	Advice from relative/neighbor	8.0	Cost	0.6	Other	1.5
Radio	17.5	Growth stage	2.2	Other	2.2		
NGO	13.8	Spray at regular intervals	2.5				
Farmer group	5.6	Extension	1.5				
Farmer leader	2.8	Other	1.2				
Farmer field school	2.5						
Mobile	0.3						
Field day	0.3						
None	24.1						

group is at the same time involved in organizing farmers for livestock raising, giving trainings on other aspects of rice production, and helping farmer groups to do accounting or manage a small business.

4.3.2. Resource and financial arrangements

Some interactions for pest management are intertwined with specific resources or financial arrangements. The most apparent were the interactions between farmers and sellers. Some farmers noted there are shops with better options or recommendations in the nearest town, but there were many who still bought in the village. Of farmers surveyed (N = 320), 72% said they bought from the village retailer, while 19% bought from dealers or sellers in the town. An important reason was the arrangements around credit.

According to one seller '*if they pay within 20 days, I still give them the same as cash price'*; For another, *'some farmers buy with cash, others pay partially, and some after harvest … at 2% interest,'*

The pesticide sellers also had financial arrangements with dealers and companies. One seller preferred a company who comes to deliver products to him. He had to pay 50% in advance, with no interest on the products. None of them said they had sales quotas, but companies have promotions:

' … sell 10 boxes [400 packets per box], get 2 boxes free, or get a cash incentive. The cash incentive is 500 Riel/packet off of the company's *set* price. The company also gives gifts like shelf for the shop, or 1 box free.'

Furthermore, company extension agents had funding arrangements with farmers. They provided 50% off the price of the products if the farmers agree to do the demonstration on their farms. They also *'sign a contract that if the product will not work, the company will pay for the losses'*. After this, if the products work, they expected demo-farmers will share the knowledge to other farmers.

Arrangements with laborers differed between villages and entailed differences on pesticide use. In most villages the laborers were paid according to the number of sprayer loads they apply. Some for instance mentioned '*3000 Riel (0.75 USD)', *others '*5000 (1.25 USD)* per *sprayer load'*. Farmers said laborers would spray an average of *'8–10 tanks* per *hectare'*. In comparison, farmers in other villages paid a fixed amount per hectare (e.g. 35,000 Riel or 8.75 USD). Farmers preferred this because *'they use less pesticide and save money'*. With the latter financial arrangement, laborers did not have the incentive to increase sprayer loads of pesticides.

Financial arrangements with other stakeholders did not affect pest management. Irrigation service fees for example were not affected even if pest problems occur. There was also no social sanction if farmers did not follow the set schedule for starting the season. Similarly, rat hunters did not affect pest management practices. Aside from an additional food source, there was not much market incentive for rat hunters to actively collect and sell rats. There were other sources of protein that farmers also collected from the rice fields such as snails, insects or fish, and there was no mention of cultural importance of rat meat.

4.3.3. Coordination

At the village level, coordination for pest management was enacted via different stakeholders. Government extension agents for example coordinated many aspects, such as formal trainings and field schools. They provided information to farmers, monitored pesticide shops for illegal pesticides, and gathered data on pest incidence, thereby connecting policy implementation with information delivery.

Pesticide sellers provided a different coordination mechanism which connected companies with farmers. Some farmers and pesticide sellers mentioned the sellers call and '*company extension agents come within 1-2 days … to assess a field and identify the pest problem*'. Companies also connected with village pesticide sellers for new products. Company technicians reported to pesticide sellers about demonstration results. They also worked with company marketing agents, for example, as companies frequently update product packaging,

'Farmers always change brands. They prefer new ones. New is more effective. So companies also have updated products (change the color etc. on the label).'

Coordination by irrigation service providers occurred via their meetings with farmers. Notably however, this coordination to start the planting season was absent where irrigation is accessed through individual wells and pumps. Some providers obtained feedback on problems such as weeds when the irrigation is not well timed: '*farmers blame me a bit [when irrigation is delayed and weeds grow]*', but they were not actively involved in pest management.

5. Discussion

Pesticide reliance of Cambodian rice farmers has been previously recorded (e.g. Pin and Mihara, 2013; Matsukawa et al., 2016; Flor et al., 2018), and this study further supports this. Furthermore, we showed a common practice of mixing the pesticides with growth activators, which constitutes additional fertilizer application targeted at a specific stage of the crop (also in Matsukawa et al., 2016). Studies have shown that the costs of using recommended practices from IPM-Farmer Field Schools in Cambodia were lower than costs for practices that rely on pesticides, with higher net returns from IPM (Ngin, 2017; Ngin et al., 2017). IPM does not exclude pesticides but rather promote the use of alternative technologies. Our survey results and that of others (Jackson et al. in this issue) however, show the farmers still opt for pesticides even when these alternatives were available.

We then investigated the interactions of stakeholders and the arrangements between them which underlie these pest management practices. In other words, we examined the user context where pesticides are used. The reliance on pesticides and minimal use of alternative practices is notable. We found there is a bias among the influential sources to promote pesticides as opposed to alternative technologies. Public extension staff and pesticide sellers were top sources of information of farmers, but when farmers observe pests and damage, the routine interactions would predominantly involve sellers. The interactions that are directly relevant to the pest management activities of farmers however, were with pesticide sellers, laborers and to a degree, company extension agents. The sellers coordinate information, products and other linkages such as between company staff, farmers who implement product demonstrations, and other farmers. This ultimately encourages farmers to use pesticides and growth activators as the seller is motivated with incentives for the sale of pesticides. The varied sources of information including, company extension agents, laborers, demo farmers and other farmers align on the focus on pesticides, as opposed to alternatives. This alignment makes the option of pesticides as the norm because of several reasons. For one, applying pesticides is one of the farm operations nested in the routines of farming (Flor et al., 2019). Thus use of pesticides is not a new or unique practice. Seeing other farmers and laborers, getting recommendation from demonstration farmers, and then getting information from sellers further emphasize this norm. In addition, information from company extension agents promoting pesticide products as solutions for pest issues reinforces the norm on pesticides. Notably, not all pesticide sellers get formal training on pesticides or alternative technologies; and hence, also depend on information from pesticide companies and technicians. This situation is also the case in neighboring Vietnam (Van Hoi et al., 2013). In contrast to all these, stakeholders such as public extension staff or rat hunters, who could provide information or services on technological alternatives, have limited scope in giving information. Farmers would have to do more to obtain information on alternatives as the current stakeholder network around pest management does not facilitate this. The 'informational increasing returns', as Klitkou et al. (2015) have coined it, is what others have called confirmation bias (Stone, 2016). The current set-up of stakeholders, already familiar with pesticides, favors a rapid spread of information on incremental changes such as new chemical products, making such information more easily accessible and accepted.

An interesting phenomena emerging from our results is that farmers do not strictly follow recommendations and information provided on product labels. As farmers are exposed to constant change in labels and diversified products, they seem to distill a workable formula for application, partly depending on information from sellers. This is not particular to Cambodia. In Vietnam, competition among many companies also drives a condition where varied trade names and active ingredients flood the market (Van Hoi et al., 2013). In the face of dynamic environmental conditions, (sometimes incomprehensible) product labels and diversity of products, farmers do not have the time to follow guidelines meticulously nor have the opportunity to experiment about it on their fields. In other words, the rapid change in products and brands makes farmers dependent on information sources on the one hand but at the same time results in rather loose and pragmatic interpretation of the information. This is likely an effect of the collective action mechanism (Klitkou et al., 2015). The perceived normative value of using pesticide overrides imperfect information or uncertainties over correct application. Our data do not provide direct evidence of such an effect though it is likely that such prestige bias is an effect of the confirmation bias (Stone, 2016). Another study on pesticide lock-in similarly found that the information from a network linked with agro-chemical technicians far outweighed that coming from much smaller network or organic cooperatives (Wagner et al., 2016).

Such effects are not merely related to information and perceptions but also have a material aspect, as relations between farmers and sellers involved financial transactions. Besides credit and input provisioning arrangements between farmers and sellers; there were also arrangements between the farmer and laborers or 'alternate pest-managers' that generated increasing pesticide use. Current arrangements with laborers induced higher amounts of pesticides applied. When laborers were paid for every sprayer load, there was more incentive for them to apply more pesticides, even if not needed. Although farmers recognized this, and there were ways to prevent it, such as paying per-hectare rates, payment per sprayer-load remained the prevailing arrangement in many villages.

The interactions and arrangements point to supportive conditions so that farmers use more pesticides, similar to findings of Escalada et al. (2009). Currently, the network for pesticide industry reaches Cambodian farming communities through pesticide sellers. Studies in other Asian countries have also documented pesticide sellers as the key or only source of pest management information and recommendations (Jungbluth, 1996; Heong et al., 2014). The interaction between sellers, company extension agents and farmers ensures information sharing regarding pesticide products, which have over time resulted in increasing returns, compared with farmers accessing information through other means. Norton et al. (2014) have discussed complex dynamics regarding information from pesticide sellers who have no training, as well as possibilities of government staff also being pulled into providing pesticide-reliant recommendations in Asian countries. Established behavioral patterns and financial arrangements favour increasing pesticide use through informal rules and financial agreements between farmers, sellers and laborers. There is thus a social system that articulates, communicates and replicates the technological choices of farmers and other stakeholders. This implies that the farmers, although trained or equipped with knowledge on pest management, may still be influenced by the socio-technical conditions to rely on pesticides. These social arrangements at community level also contribute to the pesticide lock-in.

6. Conclusion and implications

This paper examined the pesticide use of Cambodian rice farmers and presents evidence of pesticide-reliant practices and limited use of alternatives. It shows the interaction dynamics and arrangements between farmers, pesticide sellers, company extension staff and laborers that promote or sustain this practice. Ease in access to pesticide-based recommendations and recursive social interaction at the community level contribute to the lock-in of pesticides as the dominant technology.

The high use of pesticides and lack of adoption on alternative technologies indicate the existence of social conditions, and mechanisms of collective action that keep the technological practices in place. Exploring the mechanism in the user context for Cambodia however, opens scope for further understanding the complexity of changing pesticide use at the community level.

Most interventions to change pesticide use target the knowledge of farmers, for example trainings through government extension offices. While this intervention addresses a potential problem within the farmers' community with regards to pesticide use (i.e. lack of knowledge), our results show there are other influential stakeholders involved in decisions regarding pest management who need to be reached. In other words, it would be a mistake to equate knowledge simply with access to correct information. Much more important are the interactions that lead to repeated confirmation of specific information, at the cost of other information sources. Reconfiguring such interaction dynamics implies interventions that engage a variety of stakeholders rather than farmers only. The retailers, for example, provide a strong coordination role and directly reach farmers with timely pest management information. The fact that sellers must balance between trust of farmers and their own sales objectives shows there is scope to get them interested in changing pesticide management practices. The challenge is to create change among all stakeholders regarding effective IPM products, pesticide dosage, and implications of over-dosage and over application of fertilizers. The emphasis on health effects of mixed and over-dosage of pesticides could be furthered to help farmers and laborers find workable payment arrangements that would counter pesticide over use.

What is evident from this study is that farmers' knowledge of pest management is not the only driver for their decisions and practices. Change in arrangements and informal rules may also be required as these enable increasing informational returns as well as collective norms. Regulations to ensure enough information is provided regarding growth activators could support both sellers and farmers. The need for immediate and effective recommendations could be provided through means other than the already over-committed government extension agents. This could be through mobile information services, or other pay-for-service extension pathways, for example. In targeting future interventions as simultaneous socio-technical change, the alignment of these different dimensions could help to ease out of the pesticide lock-in.

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