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The Technological Trajectory of Integrated Pest Management for Rice in Cambodia

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Abstract: For the past two decades, while the efficacy of Integrated Pest Management (IPM) has been successfully demonstrated in Cambodia, its dissemination and sustained adoption among farmers have not met similar success. This study moves away from simplistic analyses about constraints in extension methods for IPM. Instead, we take a broader look into technological systems and the trajectory for pest management, which affected the spread and uptake of IPM in the country. Through a review of the wider context in policies and programs, and a survey of farmers from five provinces in Cambodia (N = 400), we examined the connections between options for pest management at the farmer level and conditions in the technological system. Using the Cambodian case study, we show that the technological system predisposes to pesticide use and as such hinders a trajectory of IPM. Systemic conditions, including interrelated agronomic practices, ecological conditions in farming communities, governance mechanisms, structures around the spread of knowledge and the industry around the technological options, have created mutual socio-technical dependencies. Although programs targeted change through knowledge of IPM, much of the systemic conditions sustain the trajectory of pesticide reliance. Hence, promoting an innovation environment that is supportive of IPM requires extension beyond knowledge dissemination, addressing these varied elements of the technological system.

Keywords: integrated pest management; technological trajectory; Cambodia; technological systems; policy; extension

1. Introduction

Over-reliance on pesticide in rice production is seen as a threat, not only to farmers' health [1], but also to the sustainability of rice sector development and food security [2]. Various forms of agricultural extension methods on Integrated Pest Management (IPM), defined as "the deployment of a variety of methods of pest control designed to complement, reduce or replace the application of synthetic pesticides" have been used to remedy this situation [3]. In the late 1980s, the Indonesian government started large-scale implementation of IPM, against brown planthopper in rice. The search for effective extension methods prompted a shift towards a participatory learning approach in the form of Farmer Field Schools, replacing the less effective, top-down, "Training and Visit" approach [4,5]. Based on these experiences, national programs in Cambodia have promoted IPM since 1993. Extension methods and approaches developed over the years and included Training Of Trainers (TOT), Farmer Trainer Orientations (FTOC) and Farmer Field Schools (FFS) [6]. These programs have involved public, private and civil sectors, aimed at helping farmers to implement ecologically- and economically-sound practices. The results were overall positive, reducing pesticide use on the rice fields of participating farmers [3,6,7]. The diffusion of IPM within and across sites, however, was limited, and the anticipated comparative benefits, most prominently higher incomes, were lacking [8,9].

This raises the question: What has caused the lack of spread of IPM in Cambodia? The short answer to the question would be that pesticide use is apparently more attractive to farmers. Indeed, as our survey work and other studies show, the spraying of chemical pesticides is the predominant technology for pest control in Cambodia, similar to other rice-growing countries [3,10]. Simple answers are hardly satisfying when it comes to complex problems. Although there was government support for promoting IPM and the programs targeted nationwide extension, IPM is apparently still not as attractive to farmers as the use of chemical pesticides. We thus need a more thorough examination of the way technological options are connected to governance structures, markets and the kind of organizations providing support and training to farmers. Such questions are pertinent to get a better view of what, besides the extension method as such, determines the impact of programs that promote IPM.

In this paper, we argue that the lack of diffusion of IPM in Cambodia could be explained through the constraining effect of the technological system for pesticide use. We will give a background to the argument and the implications for adequate extension of IPM to farmers. The perspective is important because it moves away from a framing that considers pesticide use as an individual choice of the farmer and the limited adoption of IPM as the result of 'traditional' behavior due to a lack of knowledge about the introduced technology or its potential benefits. Instead, we emphasize the routines built into the technological system for pesticide production and distribution. We explore the hypothesis that opting for pesticides rather than IPM is induced by system routines that drive the production and marketing of pesticides. Although this paper is not a critical analysis of the extension methods, the argument developed in this paper has important consequences for the implementation and diffusion of IPM. A better understanding of the system routines around pesticide as a dominant technology will help to target change processes at the system level rather than primarily at the farm level. Changing existing system routines and 'rebuilding' the system in such a way that favors the wider distribution and support of IPM is an important complementary activity, next to the immediate promotion and implementation of IPM.

2. Framework and Methods

The notion of a technical system, as originally developed by Hughes (1987), emphasizes the mutual dependencies between social and technical components of a system [11]. The notion thus highlights that changing one or more elements in a technological system has implications for other elements, as well, which creates momentum [12]. The momentum makes change complicated, but more than that, it directs change into a particular pathway. From experiences with technologies that are successfully integrated within the technological system, the tried and trusted ('normal') pattern of innovation is repeated, resulting in a technological trajectory [13,14]. These concepts provide a powerful explanation of the functioning of the pesticide industry and why IPM as an alternative trajectory is beyond the scope of the industry [15]. Technologies are part of a system consisting of multiple, interdependent technologies and supporting technical, social and economic infrastructures. These notions thus emphasize that a transition process towards the uptake of IPM requires changes beyond the farm level.

The technological trajectory sustained in the system provides a complementary approach to understanding the diffusion of innovative pest management practices among Cambodian farmers. It provides further insight into what it takes to shift from complete reliance on chemical pesticide to IPM. Based on these notions, one can predict that training farmers in applying IPM to rice is important, but not sufficient for such a transition. Notably, while we put IPM and pesticides side by side in this paper, IPM has originated as an integrated technology that includes the use of selective pesticides as needed [16]. The IPM paradigm has evolved over time with different definitions (e.g., [17,18]), but it integrates various crop protection tactics to suppress pests in ways that are safe for farmers, economically feasible and environmentally friendly.

With these conceptual considerations, we examine relevant aspects of the technological system for pest management through a review of policies, programs, knowledge and capacity building activities, as well as industry-level influences. We use secondary materials including reports, papers, and impact assessments describing IPM in Cambodia from the 1990s. We also include policy papers up to 2015. To cover another important dimension of technological trajectories, we examined pest management conditions at the community level through the practices and sources of information of farmers. This is done through analysis of survey data collected in 2016, in the provinces of Battambang, Kampong Thom, Prey Veng, Takeo and Pursat (*N* = 400). These are intensive rice growing areas. The survey captures pest management practices, including agricultural input use, of randomly-selected farmers from provinces representing varied agro-ecological conditions. With this farm-level data, we make connections to social and ecological conditions (e.g., irrigation sources, labor availability) that affect for example the synchrony of cropping, better land levelling or other pest management practices on their farms. The survey was coordinated through the General Directorate of Agriculture and local government at the village level. Informed consent was obtained for all interviews.

3. Results

We structure the findings using various aspects of the technological system. First, we present the current pest management practices of farmers, exploring the socio-technical conditions affecting pest management at the community level. We then review the programs, policies and narratives around pest management at a broader level and probe the way IPM has been introduced and implemented vis-à-vis pesticides. We further present conditions related to the industry, access to information and markets for the technologies. We then bring these together in a discussion on competing technological trajectories and how that affects the spread of IPM in Cambodia.

3.1. Farm-Level Practices

There is documentation about the rise of pesticide imports [19–22], but only anecdotal evidence specific to increasing pesticide use among rice farmers in Cambodia. We therefore did a survey in five provinces and indeed found an increase in pesticide use compared with findings presented in the literature from the 1990s. In the 1990s, annual use was estimated at 224,000 L, and there were 22% of farmers in the wet season and 57% in the dry season found to apply pesticides ([23] p. 35). Furthermore, some 38% of farmers used insecticides, 0.7% used herbicides and 28% used rodenticides ([24] p. 229). In 2016, however, 100% of farmers surveyed (*N* = 400) applied some amount of pesticide for each season. Farmers most commonly used herbicides and insecticides (Table 1). Provinces with intensive rice cropping systems such as Prey Veng and Takeo in particular had higher insecticide use per season. Very few farmers used molluscicides. Moreover, farmers often applied a mix of pesticides in one application, assuming this is more effective. This practice of mixing other pesticides with insecticide has also been documented in surveys for vegetable farmers in Cambodia [25]. The pesticide reliance is furthermore evident in the way very few farmers (3%) surveyed in 2016 mentioned the use of non-pesticide methods for pest management.

Several crop management practices are entwined with pesticide use. One is the choice of varieties and methods for planting. Most of the farmers, due to a lack of labor or water scarcity, prefer direct seeding (Table 2). This is the case in both wet and dry seasons. Farmers apply an average seed rate of 203 kg/ha (range of 157–313, *N* = 400) across the different provinces. This results in a high planting density, making it difficult to weed by hand or mechanically. Farmers prefer high seed rates, they say, as insurance against snails and other pests. Occasional floods can wash away part of the seedlings.

Furthermore, the preferred varieties have low resistance to pests. The common dry season varieties included IR504, Sen Kra Ob and OM 4900. In the wet season, traditional aromatic varieties such as Phka Rumduol are preferred, especially for Battambang and Kampong Thom.

Table 1. Mean pesticide applications for each type of pesticide (S.E. mean), including minimum and maximum applications, per province and percentage of farmers who applied the type of pesticide (*N* = 400); wet season 2016; * some farmers could not remember the number of times they applied.

Province	Herbicide min,max	Insecticide min,max	Fungicide min,max	Molluscicide min,max	Rodenticide * min,max
Battambang	3 (0.2)	2 (0.3)	2 (0.3)		2 (0.1)
	1,9	1,11	1,4		1,3
Kampong Thom	2 (0.1)	2 (0.2)	1 (0.2)		2 (0.4)
	1,4	1,5	1,2		1,12
Prey Veng	2 (0.1)	4 (0.4)	2 (0.7)	1 (0.1)	1 (0.20
	1,6	1,15	1,16	1,2	1,3
Pursat	2 (0.1)	2 (0.3)	1 (0.2)		1 (0.2)
	1,6	1,5	1,2		1,2
Takeo	2 (0.2)	3 (0.3)	2 (0.5)	1 (0)	2 (0.3)
	1,7	1,7	1,3	1,1	1,3
All provinces	2 (0.1)	3 (0.2)	2 (0.3)	1 (0.1)	2 (0.2)
	1,9	1,15	1,16	1,2	1,12
% Farmers	70	48	13	7	20

Table 2. Percentage of farmers (*N* = 400) and their crop establishment method for the wet and dry season 2015–2016.

Province	Wet Season		Dry Season	
	Transplanted	Direct Seeded	Transplanted	Direct Seeded
Battambang	0	100	0	100
Kampong Thom	29	71	2	98
Takeo	14	86	1	99
Prey Veng	4	96	0	100
Pursat	18	82	0	100
Mean	*13*	*87*	*1*	*99*

Many of the farmers said they do not synchronize the start of their cropping season with other farmers' because 'their conditions are different'. This is brought about in part by diverse sources of irrigation. In all but one of the villages surveyed, farmers within a village have 2–3 sources of irrigation. As opposed to gravity irrigation systems where there is water scheduling, there is no means of coordinated control that could enforce synchrony in the cropping season in these villages. Only 4% of the surveyed farmers said they followed activities or rituals that signal the start of the season. The majority do not follow this, except for planning to ensure that harvesting is coordinated for better access to combine harvesters. This leads to crops growing asynchronously within the area. Asynchrony in crop growth has been found to enhance pest and disease pressure [26,27].

Furthermore, the most common fertilizer, used by 67% of the surveyed farmers, is urea (46-0-0). The average quantity is 179 kg/ha of urea per season. Few farmers (7%) use diammonium phosphate (18-46-0) at 87 kg/ha in addition to urea. Fewer still (4%) add ammonium phosphate (16-20-0) at 89 kg/ha. Some 10% of farmers also used on average 4 tons of manure per ha, although the use is limited to areas where farmers have livestock. From urea application only (excluding the added N from other chemical and organic fertilizers), farmers used at least 82 kg N per ha. Excessive N application in rice is known to attract insects and disease-causing pathogens, thereby leading to increased pest and disease incidence (e.g., [28,29]).

Other conditions at the farm level that trigger pesticide use are shortage of labor, the widely-available information about pesticides and credit arrangements around inputs. These factors will be further explored in the section explaining the interaction with the industry.

3.2. Programs and Policies for Pest Management

Since the 1990s, the Ministry of Agriculture, Forestry and Fisheries in Cambodia has recognized the potentially harmful effects of pesticides on the environment and expressed the need for alternative techniques [6]. Various programs introduced and supported IPM in Cambodia. These programs were implemented under the coordination of the national IPM program of the government. The IPM program goals were aligned with the national goals for increased crop production, food security and safety. More importantly, we can see two trends in the way these programs were implemented: one that specifically targeted farmers and field-level technical problems and another that targeted farmers and the extension officers (Table 3).

In the 1990s, in the early years of IPM introduction, pesticide reliance in Cambodia was not the norm in farming communities [10,23,30]. A survey in the 1990s [23] found that pesticides were applied mostly in the dry season by 59% of farmers, but not much in the wet season (27%). In some provinces, none of the farmers used herbicides and some 1% in other provinces. Fungicides were not used at all [23,24,30]. This is also reflected in figures about pesticide availability. In those years, there were only 30 different pesticides available in the country [31]. Pests and diseases were considered less significant concerns in Cambodia compared to neighboring Asian countries [32,33]. Thus, compared with other countries, the overall impression was that farming practices in Cambodia were 'sustainable' by default and only minimal pest management action was needed.

Due to the military regime and international isolation in the 1970s and 1980s, the Green Revolution in Asia had minimal effect on rice production practices in Cambodia. By the 1990s, when Cambodia was included in the programs of international development agencies, the primary focus of yield increase, the main target of the Green Revolution, went along with the attention to IPM. Thus, rice improvement programs in Cambodia included IPM with activities including pest monitoring and research on pest identification, quantification of damage and testing of alternative pest management techniques (e.g., [23]). Due to this 'late start', the Green Revolution for Cambodia was seen as promising for enabling practices based on ecological knowledge [33].

Extension materials from the programs in the early 1990s show a focus on training to coordinate the farmer field schools and agro-ecology assessments. These approaches support learning processes, communication of key messages and pest monitoring. However, few materials mention specific recommendations or promote concrete alternative techniques [6,8].

A common message is about building the knowledge of farmers on various components of the ecosystem, understanding the root causes of pest problems and simple experiments to evaluate new ideas and techniques (e.g., [6,24]). In contrast, in the years following, the national programs promoted stronger technical key messages: healthy crop and environment, use inputs based on ecosystem analysis, encourage biological control mechanisms and pesticide application only as a last resort. A review of the programs however found the curriculum to be too technical for end users (e.g., [8]). Moreover, few of the extension staff were trained in participatory facilitation methods and skills; instead, there was a focus on technical capacity building [6].

In the late 1990s, particular events created a critical situation with respect to pest pressure in the Cambodian rice fields. One is the rapid increase of rice production and the subsequent policy to stimulate this increase. There was an over 4.4 percent per annum (roughly 3.4 million tonnes) increase in rice production that decade achieved despite unfavorable conditions in rainfall, labor, capital and infrastructure [34]. Another important moment was the opening of the country towards pesticide importation [33,35,36]. This coincided with a series of pest outbreaks and weather disturbances in 1997–1998 [37,38]. All these events happened in the same period when support for IPM took off [10,39].

Table 3. Approach, motivation and outcomes from key rice Integrated Pest Management (IPM) programs in Cambodia that were targeted mainly at farmers (1) or extension networks (2). FFS, Farmer Field Schools; TOT, Training Of Trainers.

Approach	Program	Target	Years	Main Goals	Outcomes	Sources
Pilot IPM activities; farming systems approach; FFS	Cambodia-IRRI-Australia (CIAP) IPM Program	1	1989–1999	Develop crop protection strategies using environment-sound IPM practices; capacity development;	Developed strategies for IPM; research infrastructure; survey to understand Cambodian rice-farming households	[40]
Pilot IPM activities; farming systems research	IDRC-IRRI-FAO IPM Program	1	1993–1995	Increased production using environment-friendly practices	Increased awareness of pesticide risks	[6,41]
Coordinates the national IPM program; TOT; FFS; self-sustaining networks	National IPM Program (FAO Inter-country Program, FAO—SRI Project and PUR Project)	1,2	1993–present	Sustainable intensification; sustaining IPM in the country (e.g., organizations like Srey Khmer)	Adoption by some farmers; 24% higher yields and 54% higher incomes, 48% reduction in spray events of pesticides and 59% reduction in use of WHO Class1 pesticides; institutionalized IPM	[42,43]
FFS for students, teachers and out of school youth	World Education-IPM in Schools Project	2	1996–2002	Integrating agriculture in the national curriculum		[36]
TOT, FFS, refresher courses, exchange visits, farmer congress	IPM/APIP Subcomponent	1	2000–2005	Consolidate IPM farmer training in Kandal, Takeo, Kampot, Kampong Speu, Kampong Cham, Pursat and Siem Reap		[6]
TOT, FFS, refresher courses, exchange visits, farmer congress; Local organizations to support IPM	DANIDA IPM Project	1,2	2000–2005; 2007–present	Consolidate IPM farmer training in Banteay Mean Chey, Otdor Mean Chey, Kampong Thorn, Kampong Chhnang, Svay Rieng and Prey Veng	A local organization to sustain IPM activities	[6,33]
Cross-country collaboration for: BPH monitoring; FFS	AFACI-IPM Project	2	Since 2010	Sustainable multinational collaboration network for migratory planthoppers		[44]
Establishing Plant clinics and training of plant doctors	CABI—Plantwise	1,2	Since 2012	Provide advisory services for diagnosing pest and diseases	30 plant clinics established and 58 plant doctors trained	[45]

Acronyms: IRRI = International Rice Research Institute, FAO=Food and Agriculture Organization, IDRC = International Development Research Centre, SRI = System of Rice Intensification, PUR = Pesticide Use Reduction Project, APIP = Agricultural Productivity Improvement Project, DANIDA = Danish Development Cooperation Section, AFACI = Asian Food and Agriculture Cooperation Initiative, CABI = Centre for Agriculture and Bioscience International.

The government emphasized that the IPM program was a promising means to increase productivity while also improving farmers' agroecological knowledge and skills [6,33]. In an official declaration in 1998, the Royal Government of Cambodia made the Integrated Crop and Pest Management Program the national crop production strategy [6]. The government recognized the risk of shifting towards pesticide use given the development of high-input intensive production. Thus, side by side with the drive to promote higher rice production, entailing increased use of inputs, there was a policy that supported IPM. An aspect that creates confusion in this institutionalization at the policy level is where a policy would tend to be implemented as a top-down strategy, but IPM builds upon the knowledge developed at the farm level in a participatory way [33]. For example, between 2006 and 2010, in the period of widespread infestation of Brown Planthopper (BPH), the Ministry of Agriculture Forestry and Fisheries (MAFF) launched campaigns for BPH control, using nets [46]. While the national campaign was developed to avoid over-reliance on pesticides, there was no sustained and widespread adoption among farmers, partly due to mixed messages, with farmers still resorting to pesticides [46]. Over the years, the national IPM program with various international partners and NGOs continued to promote IPM (Table 3). The approaches are the same, in that they target farmers through ToT and FFS, but expanded to building extension networks that can sustain and support IPM practices. More alternative techniques were tested and recommended in the IPM programs promoted since 2007 [33]. Notably, there were projects on Ecologically-Based Rodent Management (EBRM) in the country, but they were not part of the mainstream IPM programs, which were more focused on insect management [47,48].

There were significant positive outcomes from these programs (Table 3). Indeed, where farmers tried the IPM recommendations, they reduced pesticide use [3,6,7]. Farmers applying IPM practices generated cost savings of 39 USD/ha and 80 USD/ha in the wet and dry season, respectively [49]. Assessments of these programs, however, found a disconnect between these and the national government. Where international organizations aimed at scaling up IPM, with limited coordination from the government [9], the creation of the National IPM Program in 2002 was to establish an entity that would coordinate IPM-related activities in the country regardless of varying donor priorities [50]. The National IPM Program continued to implement activities to a smaller extent compared with those in previous decades [51,52].

Meanwhile, pesticide importation and use dramatically rose in the early 2000s. The national figures on the use of pesticides rose from 200,000 L in 2002 to 3.4 million liters in 2004 [50,53]. Cambodia was seen as a 'dumping ground for unwanted and dangerous pesticides' [10,22] (p. 3). Furthering the IPM programs through policy support was one strategy to stop the rise in pesticide use despite the proliferation of pesticide products [6]. This narrative existed alongside the widely-held assumptions by farmers and many other stakeholders about the relationship between pesticides and boosting yields [36].

Moreover, porous borders facilitated the trade for pesticides between countries that have different laws and regulations concerning these materials [54]. Although the Cambodian government has implemented some bans on harmful pesticides [25], those may not be banned in neighboring countries and can continue to be sold illegally in Cambodian local markets. More often than not, the imported pesticides are sold as inexpensive brands that made them more appealing to low-income farmers [36], even though often, the instructions for use were in a foreign language. The Department of Agricultural Legislation is mandated to implement control for this, but there are limitations to the effective implementation of the regulations [10,21].

In 2002–2003, the government issued detailed guidelines requiring registration of pesticides distributed and sold in Cambodia. This included a policy on labelling to ensure farmers were able to read and understand the package instructions. Pesticides are supposed to be sold only by certified traders. Imports, however, remained hard to control, and most of the labels of pesticides were written in foreign languages [54]. Many farmers surveyed in this study could not identify the pesticide they used. Regardless of the situation on the ground, there is a regulatory framework in place for pesticides.

In contrast, registration for IPM-related products, particularly biological control agents, has only started recently in Cambodia. There has been no commercially available biological control products registered until 2014 (MAFF list of Biological Control Agents (BCA), unpublished). The process for registering and ensuring quality assessment for these alternative products is still being established [55].

3.3. Knowledge and Capacity Building

Since the 1990s, reports from the national IPM program stated that 219,226 farmers were trained in IPM. This was done through 3126 farmer-trainers, 956 trainers from the provincial departments of agriculture plus NGOs, and 8119 field schools [56]. While this may seem substantial, of 400 farmers surveyed in five provinces in 2016, only 13% reported to have been trained on IPM. These were farmers from intensive rice producing areas where programs for IPM may have been implemented over the decades. Other studies (e.g., [7–9]) have also pointed out the limitations in the number of farmers trained, on the farmer-trainers as knowledge conduits to other farmers and generally on effective diffusion mechanisms in the IPM programs.

Winarto (2005) noted that the national IPM program differentiated itself from the national policy in that the policy is considered 'top-down' and geared towards increasing production, whereas the IPM program promoted learning-by-doing and making decisions that address local needs [33]. Notably, the national program provided the structure for IPM extension through its network. As described by Ngin (2002), from the national level, the IPM extension activities are supervised through the national coordination office [6]. Then, at the provinces, they collaborate with the Provincial Department of Agriculture, Forestry and Fisheries (PDAFF). At this level, a provincial IPM Coordinator manages and leads the activities. Finally, at the district and commune levels, district trainers and farmer trainers implement the IPM activities and work together with farmers. The selection of farmer-trainers is based on their status within the communities. A wide and strong social network allows these trainers to easily share knowledge with the rest of the farmers [8,9]. The training included facilitation skills, aside from technical knowledge. However, as Waddington and White (2015) noted, few of these facilitation trainings were implemented, and trainings typically only covered technical aspects [9]. In addition, further support and technical assistance for the trained farmers was lacking.

The flexible nature of IPM as a technology allowed for it to be defined in specific ways by the extension intermediaries. The programs emphasized the management of different pests including insects, weeds, diseases and rats. This does not clearly come through in the implementation, however, as many of the local extension activities emphasized insect pest management, with pesticide reduction. Although 'integrated' pest management was aspired for, the implementation largely focused on insect and disease management, or simply reducing pesticide use [54]. A changed narrative, however, emerged as extension activities broadened the spectrum, where the recommendation was 'not only reduce pesticide but also implement other management techniques'. Among the new techniques for example were: improved seedbed management, reduced number of seedlings per hill, reduced chemical and increased organic fertilizer, judicious use of pesticides and incorporation of straw [33]. This essentially connects IPM with other technologies for crop management. Such were the recommendations promoted through 8769 IPM-FFS in the country [50,57]. A study that examined the practices of 90 randomly-sampled farmers from 270 FFS in Cambodia highlighted that farmers could obtain significantly higher yields and profits through IPM [49]. Furthermore, a study comparing 30 farmers each from groups of FFS trained, non-trained and an external control found that the trained farmers over time would employ integrated IPM options, with a reduction in pesticide risky behaviors and negative impacts [50]. Aside from this study [50] and a meta impact study [9], there are no impact studies of the IPM programs at a wider scale in Cambodia. Although reports document the number of trained farmers, there are no studies that followed up on the use of the various IPM techniques introduced from FFS at a wider scale in Cambodia.

In contrast, promotional activities for pesticides, particularly the new products, focused on a single technology and were mostly covered by private sector networks. There were also extension projects that partnered with various government agencies to specifically target the private companies to help disseminate pest management knowledge to farmers through the retailer networks. One example is a project that has produced the rice pest and disease diagnostic tool (RaPiD) [58]. The software can be run on smart phones and is targeted at retailers. These retailers will use RaPiD to assess pest problems brought to them by farmers and to give appropriate pesticide recommendations. The app recommends the use of reliable brands of pesticides, to prevent farmers from getting fake ones. Retailers can then sell these pesticides.

3.4. The Role of the Industry in the Technological System

Cambodia has no chemical plants producing pesticides. National companies primarily deal with importing and selling of pesticides [36]. In the last decade, pesticide imports for Cambodia increased by 285 times, implying a significant increase in pesticide use [10,59,60]. This trend is continuing: Cambodia formally imported 13,800 tons more pesticides in 2016 compared with 2015 [19,20]. According to Visarto and Kang (2016), there are 522 trade names (for 133 common names) of chemical pesticides available in local markets, most of them unregistered [21].

There is a broad network of producers, dealers, retailers and privately-funded extension disseminating not only the products, but also knowledge about using pesticides [25]. Local retailers have relationships with farmers on providing information about pests and pesticides, as well as on credit for inputs. Much of these pesticide products marketed to farmers have remained labelled in foreign languages that are incomprehensible to farmers [43]. Thus, farmers over the years have increased their dependence on the retailers who have access to knowledge about pesticide products through their network with companies, extension staff and dealers. Of the farmers surveyed (N = 400), 90% included the advice of pesticide retailers in their decision on pest management. Of these farmers, 60% source their pesticides from these local retailers. They have credit arrangements for fertilizers and pesticides with the retailers. Lastly, the reference to pesticide as 'medicine against pests' (in local terms, thnam samlab sat chongray), construes it as less risky and necessary. This has been pointed out as a notion that, whether employed purposefully or not, supports pesticide use by farmers (e.g., [30,36]).

Some of the IPM techniques involve crop management activities that do not require additional tools. Where tools are needed, the infrastructure for production and, ultimately, access by farmers, has to be in place. There are IPM options such as Biological Control Agents (BCA) that exemplify this situation. BCAs include microbial control agents (i.e., microbes that infect pests), macro-organisms (i.e., arthropods that feed on other arthropod pests), semiochemicals (e.g., pheromones) and natural products (e.g., plant extracts) [55]. The production and trade of BCAs started only recently in Cambodia. Between 2014 and 2015, there were 11 BCAs registered for commercial distribution in the country (MAFF list of BCA, unpublished). Hence, most of these products were not yet accessible to most farmers. None of the farmers surveyed reported use of BCA, although some had used organic fertilizers. A complicating factor is the need for additional facilities and procedures for storage and transport of BCA products [55]. Notably, the distribution of these products or accessibility for farmers is not widespread.

4. Discussion

We examined systemic conditions that influence pest management in Cambodia. Many factors and mechanisms have sustained a pesticide-based technological regime and prevented IPM from taking root and spreading, for the past two decades. This situation is not unique to Cambodia, but has also been experienced in many other countries in Asia and Africa [3,61]. To attribute the constraint on the adoption of IPM in Cambodia to the so-called lack of education and skills of farmers (e.g., [36]) or to the limitations of the extension methods is too simplistic. Assessments of the IPM programs makes clear that part of the explanation is, as we hypothesized, related to the wider system of production, regulation, trade and support (e.g., [9]). Due to the interconnectedness of these elements, we argue that the transition from a pesticide-based practice to IPM requires integrated multi-dimensional changes.

Our survey results show that pest management practices, specifically pesticide use, have indeed changed compared with findings on practices of Cambodian rice farmers from the 1990s. This corroborates the findings of surveys on vegetable producers in Cambodia, as well as the trend in pesticide imports (e.g., [19,25]). Pesticides have indeed become prevalent, despite many years of IPM programs. We further showed that many farm-level conditions and agronomic practices of farmers are interrelated with their pest management practice of using pesticides concurring with findings from another IPM study [50]. Limited coordination for community-wide implementation of pest management activities, or even for synchronous cropping, has implications for pest incidence and management. Ecological conditions such as water availability, irrigation access and the absence of coordinating mechanisms condition agronomic practices that make it difficult for farmers to implement IPM. Moreover, there are related technologies that are known to increase pest incidence and further the reliance on pesticides. High seed rate and crop establishment through broadcasting also entail that farmers have limitations in hand weeding or use of mechanical weeders. High nitrogen (N) use has been proven to affect pest and diseases; but the 82 kg N per ha commonly applied is higher than the recommended 20 kg/ton of produce (roughly 64 kg N/ha based on 2016 average rice production figures for Cambodia) [29,62].

The narratives on IPM at the policy level have changed over time, which affected the way IPM messages were communicated and which technologies were supported. In the early years, when pest pressure was relatively low, the message was couched in general and abstract terms, emphasizing agro-ecological knowledge, with limited or no emphasis on concrete 'alternative' tools or techniques to implement. The pest outbreaks of the late 1990s and the rapid increase of pesticide use were the wake-up call. Since then, many of the programs emphasized risk from pesticides and the need for pesticide reduction. Alongside this interest in sustainability and IPM, there are competing interests for increasing production, with an underlying narrative on pesticides being required to achieve yield targets. Both narratives exist and are used in national-level discussions. As such, the technological paradigm of pesticides continues to pervade even when IPM has been adopted in the national policy for crop management. Narratives as such are not sufficient, but even the increased effort to implement IPM was not enough to stop the growth in pesticide use.

Despite the new policies and programs, IPM seems primarily to convey a message to the farmers about 'pesticide reduction' with a lack of emphasis on alternative methods. There is recognition of the adverse effects of pesticides, but current practices ensure that pesticides remain key in the suite of options. The narrative on safe use, which is also promoted through the pesticide industry, has been found in other countries to be ineffective and faulty for addressing the problem of pesticide reliance [63]. There were IPM programs in Cambodia with documented effective outcomes on farmers who were trained, although there is no systematic longitudinal study that tracked the spread or adoption of varied approaches [50].

Part of what is considered successful about IPM programs in Cambodia is a 'discursive distribution', i.e., integration of the IPM narrative into existing networks and infrastructures, which theoretically can sustain it beyond the duration of projects [42]. Such policy support is important, but a 'performative distribution', i.e., implementation of social and technical changes that make IPM a viable alternative, is required to leverage sustained use of IPM. At the same time, there are competing sources of knowledge from the private sector that engage the networks of the pesticide market. These networks have been effective in reaching farmers with both information, as well as new products, whether registered, of good quality, or otherwise. Meanwhile, the regulatory frameworks and markets around alternative tools for IPM are not yet in place in Cambodia. For instance, the importation and registration of pesticides has been the practice for many years, but for competing IPM technologies, such as biological control agents, registration for commercial production started only in 2014. This limits the sale of this alternative, as well as access of farmers to these. Lastly, pesticides and the application of IPM also have effects on the wider environment and safety of food products.

This entails further changes and monitoring of practices beyond the farms, which could be tackled in further studies.

Various socio-technical elements affect pest management and the spread of IPM. Agronomic practices for pest management are interrelated with other technologies such as for fertilizers, crop establishment and irrigation. The practices favor individual-based pesticide application, whereas more coordination is needed to shift towards IPM. Lastly, learning effects, economies of scale and institutions that influence a pesticide-based regime [64–66] are furthered by the policy and industry conditions in Cambodia. To this end, routines within the technological system enable the pesticide trajectory at the expense of the spread of IPM. It is in the policy environment, the way knowledge about pest management is spread, in the industry around pest management technologies, as well as in the day-to-day practices of farming. All these together ensure that even if knowledge about IPM is present, and has been promoted for decades, the easiest course for farmers may still be to opt for pesticides.

5. Conclusions

The technological trajectory of IPM in Cambodia encountered multi-dimensional constraints. We showed through this review and survey that the lack of alignment of varied elements from policy, extension programs, access and market of alternative technologies, the pesticide industry context, as well as interrelated agronomic techniques of farmers has affected the spread of IPM. To change the current situation and promote an innovation environment that is supportive of an integrated pest management, aligning these varied elements of the technological system is necessary.

Bringing these insights to practical recommendations would entail broadening initiatives to affect IPM at the innovation system level. In the policy context, there is a need to check the narrative of IPM as merely reducing pesticide use, or replacing with another more effective product. The institutional mechanisms that support IPM need to be strengthened and perhaps emphasized with regard to the sustainability aspect rather than as part of intensification. More attention also is needed on research on ecological methods for pest management. Expanding the range of stakeholders involved, such as stronger roles for NGOs and experts on development communication from national universities, could help to balance the top-down extension infrastructure that is in place. Furthermore, it can help to strengthen institutions that enable coordination for pest management at a community level such as irrigation groups or farmer associations. Through this, information on not only pesticides, but also good agronomic practices that align better with IPM can be spread. Lastly, broadening the involvement of the private sector, especially retailers, should not be limited to enhancing their knowledge on pesticides, but should expand their portfolio and product base to include other IPM technologies. Apparently, although there are productivity and profitability incentives from the adoption of IPM techniques, these are not enough to tip the scales of decision making towards widespread adoption of IPM in Cambodia. Making the shift also requires supportive regulatory and governance frameworks that enable access to products and the implementation of interrelated practices. This type of innovation system alignment may help to further the existing national initiatives to wean farmers off of a pesticide lock-in.

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