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Analysis

‘Smart’ policies to reduce pesticide use and avoid income trade-offs: An agent-based model applied to Thai agriculture

Christian Grovermann [a,c,*], Pepijn Schreinemachers [b], Suthathip Riwthong [a], Thomas Berger [a]

[a] Dept. of Land Use Economics in the Tropics and Subtropics (490d), Universität Hohenheim, 70593 Stuttgart, Germany
[b] AVRDC – The World Vegetable Center, P.O. Box 42, Shanhua, Tainan 74199, Taiwan
[c] FAO – Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy

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ABSTRACT

Policy makers in developing countries need better evidence of how changes in pesticide regulation would affect pesticide reduction and farm incomes, but there are very few modeling tools that can provide such information. The present study develops a new model based on Mathematical Programming-based Multi-Agent System (MPMAS), a simulation software that allows assessing *ex-ante* the impact of alternative pesticide use reduction strategies, including combinations of pesticide taxes, the introduction of integrated pest management, a price premium for safe agricultural produce, and subsidies for biopesticides. The model is parameterized with farm and plot level data from northern of Thailand, where the adoption of high-value cash crops has been accompanied by a rapid increase in synthetic pesticide use. Simulation results suggest that a pesticide tax alone has little effect on synthetic pesticide use. A smart policy package – combining integrated pest management, a progressive pesticide tax based on toxicity and subsidies lowering the price of biopesticides – can reduce average use of hazardous pesticides by 34% over current levels without adverse effects on the average farm income.

1. Introduction

The intensification of crop production in many low and middle income countries is accompanied by a rapid increase in synthetic pesticide use in agriculture, often leading to overuse and misuse (Ecobichon, 2001; Schreinemachers and Tipraqsa, 2012). While synthetic pesticides provide benefits to farmers and play an important role in commercial agriculture (Cooper and Dobson, 2007), high levels of pesticide use are associated with high levels of environmental and human risk from pesticide exposure. When synthetic pesticides kill beneficial insects or pests become resistant, more or more expensive pesticides are required to sustain crop yields (Cowan and Gunby, 1996; Pimentel, 2005). Despite high internal and external costs, farmers continue using synthetic pesticides due to the perceived high withdrawal costs, getting locked into unsustainable production patterns. (Wilson and Tisdell, 2001; Hammond Wagner et al., 2016).

Developing countries often do not adequately address the issue, as policy-makers fear that taxing or otherwise discouraging pesticide use would harm food production and rural livelihoods (Carvalho, 2006). In fact, policies are often in place giving farmers direct or indirect incentives to use more pesticides. Uncertainty over impacts is a major obstacle to policy change. There is thus a need to support policy-making with better information about the potential consequences of changes in pesticide regulation.

Still, there are only few scientific studies on this topic and all of these focused on high income countries. Falconer and Hodge (2000, 2001) developed a case-study farm model for the UK to evaluate low-input farming in combination with pesticide taxation. They found significant trade-offs between economic and environmental objectives, with only high taxes showing a notable drop in hazardous pesticide use. Jacquet et al. (2011) developed a mathematical programming model (MP) at the national level for the French agricultural sector. Their model suggested that taxation would help reduce pesticide use considerably and, despite slightly lower production, not lead to significant income losses, as long as integrated farming techniques were widely adopted. Similar findings were produced by Femenia and Letort (2016) using an econometric approach. They showed that, if low-input practices are taken up by French farmers, a 25% reduction of pesticide use is possible with a 35% tax. Without alternative cropping options, the tax would need to more than double the price of pesticides. Skevas et al. (2012) also used econometrics to study of the effect of pesticide use reduction policies, but on Dutch cash crop producers. Their study revealed that even extremely high taxes, doubling the price of pesticides, result in only small reductions in pesticide use (ca. 4%). This confirms the literature reported by Pina and Forcada (2004), which generally considers that pesticide price elasticities are low. The authors also pointed out

* Corresponding author at: FAO – Food and Agriculture Organization of the United Nations, Viale delle Terme di Caracalla, 00153 Rome, Italy.
E-mail address: cgrovermann@gmail.com (C. Grovermann).

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the lack of empirical research on the impact of various economic instruments on farm income, pesticide use and the environment. This research gap is even more apparent in the context of developing countries, where synthetic pesticide use in agriculture has increased dramatically – exposing ecosystems and millions of farmers and consumers to the risk of pesticides.

This paper addresses the lack of evidence on which to base policy recommendations by developing a modeling tool to *ex-ante* assess a range of pesticide reduction strategies. Employing a bio-economic simulation model, the present research introduces several novel aspects as compared to the above-mentioned studies: (a) it combines a simulation model with econometrically estimated production functions with damage control specifications for pesticides; (b) it simulates the diffusion of integrated pest management (IPM) as based on the theory of innovation diffusion (Rogers, 2003); and (c) it uses an agent-based framework to avoid aggregation bias, which might occur in using a representative farm- or sector-level model. This study extents the approach taken by previous studies by simulating the response of a heterogeneous population of farm agents to policy interventions, incorporating a wide range of substitution possibilities. The model takes into account the nature of innovation diffusion in such a population. Trade-offs between pesticide use reduction and income changes can thus be more accurately assessed and traced back to agent-specific characteristics as well as land-use.

The model was built using the agent-based simulation software MPMAS (Mathematical Programming-based Multi Agent System), which was specifically developed and widely tested for *ex-ante* assessments of changes in technology, policies or environmental conditions in agriculture (Schreinemachers and Berger, 2011).

The paper starts by giving the relevant background information on the study area, which is important to understand the choice of model features. The methods section focuses on how the substitution between different pesticides was captured in the model and how it simulated the diffusion of IPM under alternative pesticide policies. It explains the adoption process of a low-input practice, such as IPM, in a social network of farm agents. The parameterized and validated model is then used to explore the introduction of IPM with a tax on pesticides, a price premium for safe agricultural produce, and subsidies on biopesticides. Alternative combinations are compared in terms of their impact on pesticide use and farm income, and possible trade-offs between these, providing a reference for evidence-based policy-making.

2. Materials

2.1. Study Area and Data Collection

Our primary research site was the Mae Sa watershed in northern Thailand representing an intensive horticultural production system. The watershed covers an area of 140 km^2, with altitudes ranging from 400 m to 1600 m above sea level (masl). Like other areas in northern Thailand, the watershed has experienced rapid land use intensification through the adoption of high-value cash crops by farmers, such as tomatoes, cabbages or onions (Riwthong et al., 2015). The high potential value of these crops gives farmers the incentive to apply more synthetic pesticides to insure their income. Also, incorrect cultivation practices, such as monocultures, have increased pest pressure.

The extent and adverse effects of heavy pesticide use in this area have been well-documented (Praneetvatakul et al., 2013; Sangchan et al., 2013; Schreinemachers et al., 2011). For northern Thailand, it has been shown that residue levels on fruit and vegetables in local markets exceed acceptable levels (Athisook et al., 2007), blood samples of farm workers provide evidence of widespread pesticide poisoning (Kunstadter et al., 2001), and rivers are heavily contaminated by pesticides, especially during the rainy season (Sangchan et al., 2012; Thapinta and Hudak, 2000). The area is thus well suited for pesticide-related policy analysis.

Each real-world farm household in the study area is represented as a unique computational agent in the MPMAS model. To parameterize the model, we collected farm household data using a structured questionnaire survey. From all agricultural villages in the watershed we took a random sample of 20% of the farm households, which gave a sample of 295 households. The remaining 80% of the households is generated randomly inside the model as explained in the methods section. The questionnaire used a one-year recall period, from April 2009 to March 2010 to collect data on farm resources (land, labor, and assets such as greenhouses, irrigation, orchards) and land-use and cultivation practices. For each piece of land (plot) cultivated by the household we recorded detailed information on inputs used, output obtained, encountered pests and pest control. All pesticide products used were recorded together with number of sprays, quantities of undiluted chemicals and the price and volume per container. Data on the active ingredients contained in the pesticide product were collected from traders, shops and producers.

2.2. Land Use, Pesticide Use and Farm Characteristics

Cropping patterns in the Mae Sa watershed vary according to land suitability (elevation and slope), accessibility and the contact of farmers to traders and the Royal Project, which is the main extension service in the area. The Royal Project Foundation was initiated by the King of Thailand to address the challenges of deforestation, poverty and opium production in the highland areas of Thailand (Highland Research and Development Institute, 2007). It is active across the North of the country and highly trusted by producers and consumers alike. In many parts of the region agricultural land use is very diverse, 58 crops being recorded in the survey for the study site. Many of these crops are minor in terms of planted area, pesticide applications and revenues, and it was impossible to collect detailed input-output data for each crop. We therefore focused on the major crops that jointly account for 80% of the revenues and planted area. The crops can be categorized as: (a) leafy vegetables: Chinese cabbage, white cabbage, Chinese kale and lettuce; (b) greenhouse vegetables: bell peppers and tomatoes; (c) other vegetables: chayote, fresh beans and onions; (d) flowers: chrysanthemums and roses; (e) cereals: upland rice and maize; and (f) litchi fruit trees.

Table 1 shows small average land holdings in the study area, ranging from 0.7 ha in the central lower part of the watershed to 2 ha and above in the other higher parts of watershed. A high population density and

Table 1
Average farm and household characteristics for the Mae Sa watershed by five main locations based on altitude and location, Thailand, 2009/10.

Part and altitude of the Mae Sa watershed	Central, mid	Central, high	Southern, high	Western, high	Northern, high
Household size (persons)	3.6	3.2	6.6	6.1	7.1
Respondent with formal education (%)	95	100	58	62	66
Liquidity per capita (1000 baht)	66.3	74.9	28.6	35.4	28.1
Debt per capita (1000 baht)	32.6	41.6	10.8	7.2	4.9
On-farm labor use (md/month/hh)	51.8	50.1	81.6	75.9	94.4
Off-farm labor use (md/month/hh)	21.3	15.6	22.3	11.6	18.2
Hired labor (md/month/hh)	8.8	10.7	14.1	19.1	17.6
Farm age (years)	22	24	25	24	21
Farm size (ha)	0.8	0.7	2	2.2	2.2
No. of greenhouses (#)	8.4	11	1.8	1.6	0.5
Irrigated area (%)	50	1	1	11	52
Area w/o land title (%)	35	29	97	100	96
Public GAP certification (%)	11	23	45	0	26
Grow >1 crop (%)	56	69	78	62	100
Royal Project member (%)	9	14	58	33	64

Note: $n = 295$. hh = household, md = mandays.