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Prof. Dr. Thomas Berger

Effects of agricultural commercialization on land use and pest management of smallholder upland farms in Thailand

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Suthathip Grovermann, née Riwthong

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Declaration

I can guarantee that this doctoral thesis is a result of my personal work and that no other than the indicated aids were used during its completion. All the quotations and statements used are indicated as such; furthermore, I can also provide assurance that this work has not been used, whether in whole or in part, for the achievement of any other academic degree.

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Suthathip Grovermann

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Examination committee

Supervisor and reviewer:	Prof. Dr. Thomas Berger
Co-reviewer:	Prof. Dr. Georg Cadisch
Additional examiner:	Prof. Dr. Regina Birner
Head of the committee:	Prof. Dr. Markus Rodehutscord

Summary

Over recent years, economic development, policy changes, new technologies and population growth have been motivating farmers in Thailand to intensify and commercialize their production activities. As part of this agricultural commercialization and intensification process, Thai upland farmers have adapted their farming practices to increase crop production and productivity levels. This thesis clearly demonstrates that there is a positive relationship between land use intensification/commercialization and the use of chemical-based pest management activities, i.e. farmers have increasingly relied on the use of chemicals for the protection of their crops.

As part of the agricultural intensification and commercialization process, concerns about the potentially negative impact of pesticide use is often downplayed, while the benefits of pesticide use in terms of improved crop returns ignore the indirect costs they also incur. This has also led to a situation in which local farmers do not always use pesticides in an appropriate way; they tend to overuse and misuse the chemicals, to avoid losses among their high-value crops. Due to farmers' limited awareness of and lack of protection against the potential dangers inherent in chemical pesticide use, they still use pesticides which contain cheap compounds such as the herbicides *Paraquat* and *Glyphosate*. The application of these chemicals is restricted in a number of other countries, but these represent two of the three most commonly used pesticides in the study area.

The survey described here sought to provide evidence that agricultural commercialization in Thailand over recent years has led to a reduction in the variety of pest management practices applied, and that many Thai farmers have become completely dependent on the use of agrochemicals, expecting that this approach will fully prevent any losses in crop yields. In this context, it can be observed that farmers have become locked into using chemical pest control methods, creating a situation in which attempting to control one risk through the increasingly heavy and exclusive use of pesticides, has led to a number of other, new risks developing.

This research also reveals that market prices, pests and diseases have become the dominant risks affecting farm performance within the Thai commercial farm sector, while among Thai subsistence farmers the loss of family labor is of key concern. The farmers in the study area have a variety of attitudes towards risk, and differences in expected rates of return influence the types of risk protection tools used. The findings show that agricultural commercialization is associated with a rapid adoption of synthetic pesticides and an exponential growth in the quantity of pesticides applied per hectare. As the risk management strategies used by commercial farmers are mostly aimed at crop protection, they use large quantities of synthetic pesticides to manage crop pests and diseases. The present research also finds that the effectiveness of pesticide use increases significantly as levels of commercialization increase. Pesticide use is perceived as increasingly useful in this process, being considered an essential factor for raising agricultural output and farm income. However, there is a need to pay more attention to the potentially adverse effects of pesticide use on human health and the environment and to improve producers' level of understanding of the risks involved in pesticide use, which will help them make better decisions regarding the risks and consequences involved.

A number of studies have suggested that pesticide regulations in Thailand should be better enforced, that consumer demand for certified products should be encouraged, and that training on food safety should be offered to farmers. The Thai government has reacted to these calls by introducing policies and projects aimed at the adoption of sustainable agricultural practices; however, these policies have not been promoted effectively, and so have not fixed the core problem. The Q-GAP program is a good example of this. This thesis reveals that Thai upland farmers still do not understand the logic behind the program introduced, and so lack any motivation to follow sustainable farming practices. This situation is made worse by the lack of any effective program implementation and follow-up activities, such as farm auditing. The Q-GAP program has been implemented with a strong focus on farm auditing and residue testing, and little focus on the positive consequences of a reduction in pesticide use levels. The program also does not provide farmers with suitable alternatives to manage their pest problems. Certified farmers continue to almost entirely depend on synthetic pest control. In principle, under the program farmers are encouraged to practice integrated pest management (IPM) methods in order to achieve Q-GAP certification. But it was found that a considerable number of farmers were not familiar with the term IPM and have a limited understanding of the approach. IPM offers alternative pest management methods to farmers and also takes into account traditional pest control methods, not just the use of pesticides. Therefore it could have a positive role to play in helping to reduce pesticide use. However, in reality, the promotion of integrated pest management methods is not enough in isolation. As this thesis shows by means of an *ex-ante* assessment of pesticide use reduction strategies with the MPMAS simulation package, the use of a combination of measures, such as the promotion of IPM through financial adoption incentives combined with the introduction of a sizeable sales tax on pesticides, could lead to a very substantial reduction in pesticide use – by up to 34% on current levels, without adversely effecting general farm income levels. Thus, policymakers should promote alternative pesticide use reduction strategies by combining pesticide taxation with the introduction of integrated pest management methods, the application of a price premium on safe agricultural produce or the introduction of subsidies for bio-pesticides.

Furthermore, there is a need to raise farmers' awareness about pesticide risks and to increase investment in the diffusion of integrated pest management practices. Thai upland farmers might be willing to introduce more sustainable agricultural methods if they were to fully understand the consequences of pesticide use on their health and the environment, as well as know more about the biology, behaviors and physiology of the pests themselves. Building knowledge is critical in this regard. To achieve this, there needs to be more interaction between researchers, extension workers and farmers, plus more policy options introduced to support farmers in their transition to a more market-oriented production environment.

Zusammenfassung

Wirtschaftliche Entwicklung, politischer Wandel, die Verfügbarkeit neuer Technologien und ein rasantes Bevölkerungswachstum haben zur Intensivierung und Kommerzialisierung der landwirtschaftlichen Produktion in Thailand beigetragen. Als Teil dieses Prozesses haben die thailändischen Bergbauern ihre Anbaupraktiken angepasst um Produktion und Produktivität zu steigern. Diese Forschungsarbeit zeigt eindeutig, dass ein positiver Zusammenhang zwischen der Intensivierung der Landnutzung und dem Einsatz chemisch ausgerichteter Schädlingsbekämpfungsmaßnahmen besteht. Kleinbauern in Thailand verlassen sich in zunehmendem Masse auf synthetische Pflanzenschutzmittel.

Im Verlauf der landwirtschaftlichen Intensivierung und Kommerzialisierung werden Bedenken über die negativen Auswirkungen des hohen Pestizideinsatzes oftmals heruntergespielt, während bei der Bewertung des Nutzens für Ernteerträge die externen Kosten vernachlässigt werden. Mitunter auf Grund dieser Situation verwenden die Bauern vor Ort Pestizide auf unangemessene Weise. Übernutzung und fälschlicher Gebrauch sind weit verbreitet um Ernteausfälle bei Kulturpflanzen von hohem Produktionswert zu vermeiden. Die Bergbauern, welche die Pestizide regelmäßig einsetzen, steigern stetig die ausgebrachten Mengen. Auf Grund des begrenzten Bewusstseins gegenüber und trotz des Mangels an Schutz vor den potenziellen Gefahren der Pestizidnutzung, kommen billige toxische Präparate, wie *Paraquat* und *Glyphosat*, häufig zum Einsatz. Wohingegen die Anwendung dieser Chemikalien in anderen Ländern reglementiert und beschränkt ist, gehören Sie im Untersuchungsgebiet zu den meist verwendeten Pestiziden.

Die für diese Arbeit durchgeführte Umfrage weist nach, dass die Kommerzialisierung der Landwirtschaft in Thailand in den vergangenen Jahren die Vielfalt der verwendeten Schädlingsbekämpfungsmaßnahmen verringert hat und dass viele Bauern in Thailand sich ausschließlich auf den Einsatz von Agrochemikalien verlassen. Dies geschieht in der Erwartung dadurch Ernteausfälle vollständig vermeiden zu können. In diesem Zusammenhang, ist ein sogenannter „Lock-In-Effekt“ zu beobachten. Dabei entsteht eine Situation, in der die eigentliche Kontrolle von Risiken durch verstärkten und heftigen Pestizideinsatz eine Reihe anderer Risiken mit sich bringt.

Durch diese Forschungsarbeit tritt zutage, dass in der kommerziellen Landwirtschaft in Nordthailand neben Marktpreisen, Schädlinge und Pflanzenkrankheiten zu den bestimmenden Risikofaktoren für die Leistungsfähigkeit kleinbäuerlicher Betriebe gehören. Für Subsistenzbauern spielt das Risiko Arbeitskräfte zu verlieren eine Schlüsselrolle. Die Bauern, die Teil dieser Untersuchung sind, weisen eine Vielzahl an Einstellungen und Schutzmechanismen gegenüber Risiken auf. Diese werden vom zu erwarteten jeweiligen Betriebsergebnis beeinflusst. Anhand der Untersuchungsergebnisse wird ersichtlich, dass die Kommerzialisierung der Landwirtschaft mit einer rasanten Übernahme synthetischer Spritzmittel und einem exponentiellen Anstieg der pro Hektar ausgebrachten Pestizidmengen einhergeht. Da Strategien des Risikomanagements der kommerziell orientierten Betriebe hauptsächlich zur Vorsorge gegen Pflanzenschäden dienen, werden dort große Mengen von Spritzmitteln eingesetzt. Die vorliegende Forschungsarbeit stellt fest, dass die Wirkung des Pestizideinsatzes sich erhöht mit dem Grad an Kommerzialisierung. Im Verlauf der Kommerzialisierung werden Spritzmittel von den befragten Bauern als zunehmend nützlich und als unentbehrlicher Faktor für steigende Erträge und Einkommen betrachtet. Es ist jedoch von Nöten, dass auch Gesundheits- und Umweltaspekte vermehrt berücksichtigt werden. Das Verständnis der Produzenten bezüglich der Risiken, welche die Nutzung von Pestiziden mit sich bringt, kann dabei helfen die mit der Nutzung verbundenen Risiken und Konsequenzen auf ausgewogenere Weise zu betrachten.

Etliche Studien legen nahe, dass Vorschriften zu Pestiziden in Thailand besser durchgesetzt, die Verbrauchernachfrage nach zertifizierten Erzeugnissen gestärkt und Schulungen für Bauern zu Lebensmittelsicherheit und Handhabung von Pestiziden angeboten werden sollten. Die thailändische Regierung hat auf diese Forderungen mit der Einführung politischer Maßnahmen und mit gezielten Projekten zur Förderung nachhaltiger Anbaupraktiken reagiert. Diese wurden jedoch nicht mit Nachdruck vorangetrieben und konnten bisher das Kernproblem nicht beheben. Der von der Regierung eingeführte Q-GAP Standard ist ein Beleg dafür. Diese Dissertation offenbart, dass den Bergbauern in Nordthailand die Logik der Vielzahl an Programmen oftmals schwer verständlich ist. Dies wird durch die mangelnde Effektivität der Umsetzung und des Monitorings, wie z.B. der Betriebsprüfung, verschlimmert. Der Q-GAP Standard wurde mit einem Schwerpunkt auf Betriebsprüfung und Rückstandsanalyse ins Leben gerufen, wobei die betriebliche Reduzierung des Spritzmitteleinsatzes und die damit verbundenen positiven Effekte zu wenig Bedeutung

erhalten. Der Standard bietet den Landwirten keine geeigneten Alternativen zur Schädlingsbekämpfung an. Zertifizierte Betriebe verlassen sich nach wie vor fast ausschließlich auf synthetische Pflanzenschutzmittel. Im Prinzip werden Bauern dazu ermutigt für die Erlangung der Zertifizierung integrierten Pflanzenschutz (IPM) zu praktizieren. Aus der vorliegenden Untersuchung wurde jedoch ersichtlich, dass der Begriff IPM und der damit verbundene Ansatz zur Schädlingsbekämpfung vielen mit dem Standard versehenen Bauern unbekannt ist. Unter Berücksichtigung traditioneller und anderer Pflanzenschutzmethoden bietet IPM den Bauern eine Vielzahl an Schädlingsbekämpfungsalternativen zur ausschließlichen Pestizidnutzung und könnte somit zur Reduzierung des Spritzmitteleinsatzes beitragen. Die Verfügbarkeit von IPM für kleinbäuerliche Betriebe allein ist allerdings nicht ausreichend. Im Rahmen dieser Forschungsarbeit wurde mit dem Agenten-basierten Simulationsmodell MPMAS eine Evaluierung verschiedener Nachhaltigkeitsstrategien durchgeführt. Diese zeigt, inwiefern es möglich ist durch ein Maßnahmenbündel aus Einführung von IPM Praktiken, Pestizidsteuer, gestaffelt nach Toxizität, und finanziellen Anreizen zur Übernahme von IPM das Niveau des Spritzmitteleinsatzes in der Landwirtschaft in Nordthailand erheblich zu senken. Gemäß den Simulationsergebnissen kann eine Reduktion von bis zu 34% erreicht werden, ohne dass dadurch das allgemeine Einkommensniveau der Agenten negativ beeinträchtigt wird. Entscheidungsträger sollten eine nachhaltigere Landwirtschaft durch ein Bündel aus Reduktionsmaßnahmen fördern.

Zudem besteht die Notwendigkeit das Bewusstsein der Bauern bezüglich der Risiken des verstärkten Pestizideinsatzes zu schärfen und Investitionen in die Verbreitung von integrierten Schädlingsbekämpfungsmethoden zu erhöhen. Es gilt das Wissen der Bauern über die gesundheitlichen und ökologischen Konsequenzen des übermäßigen Pestizideinsatzes auszubauen, ebenso wie deren Wissen über die Biologie und das Verhalten von Schädlingen. Um dies zu erreichen, muss, neben den richtigen Impulsen aus der Politik, welchen einen Übergang zur einer nachhaltigen marktorientierten Landwirtschaft erlauben, das Zusammenspiel von Forschung, landwirtschaftlicher Beratung und kleinbäuerlichen Betrieben erleichtert werden.

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List of abbreviations

ACFS	National Bureau of Agricultural Commodity and Food Standards
ANOVA	Analysis of variance
ASEAN	Association of South East Asian Nations
DoA	Department of Agriculture
DoAE	Department of Agricultural Extension
EU	European Union
GAP	Good Agricultural Practices
IPM	Integrated Pest Management
LTP	Land Titling Program
MoAC	Ministry of Agriculture and Cooperatives
MPMAS	Mathematical Programming-based Multi-Agent Systems
MRL	Maximum Residue Limit
OLS	Ordinary least squares
OVF	Organic vegetable farming
PCA	Principle component analysis
PCD	Pollution Control Department
PEA	Pesticide Environmental Accounting
SPG	Sor Por Gor (land without a title), is an allotment of land from the land reformative committee and land may be used for agriculture only. It confers the right to occupy only and be transferred only by inheritance, can't be bought or sold.
STG	Sor Tor Gor (land without a title), is a land certificate issued by the Thailand Forest Department only in the zone of national reserved forest. The holder of this document has the right to reside and live on the land. This land can be passed on heir by inheritance and is prohibited for sale.
UN	United Nations
WHO	The World Health Organization

1 General introduction

1.1 The transformation of agriculture in the tropics and the case of the Thai uplands

Agricultural production in the tropics and subtropics is generally characterized by semi-commercial smallholder farms. In the past, growth in agricultural output was measured in terms of increases in the land area under cultivation, but more recently growth in terms of output has mostly stemmed from increases in land use intensity (Upton, 1996). The adoption of cash crops and associated farming technologies has boosted both agricultural production and farm incomes, in turn contributing towards economic development and poverty reduction in many low and lower-middle income countries. In the wake of the Green Revolution, agricultural systems in many Asian countries have undergone steady commercialization (Pingali and Rosegrant, 1995). As part of this, the high demand for agricultural products and better access to input and output markets have both created incentives for farmers to change their agricultural cultivation practices. Increased commercialization has shifted farm households away from subsistence farming; moving them towards more intensive forms of farming, those which entail growing high value fruit and vegetable crops, as well as staple cash crops, on a larger scale based on the principles of profit maximization. Production systems across Asia have been profoundly transformed by the increased availability and use of new varieties, growth hormones, fertilizers, machinery and chemical pesticides.

Population growth has placed pressure on the land, and alongside increased levels of accessibility, has pushed agricultural commercialization and intensification into highland areas (Burgers et al., 2005). Highland farmers in the north of Thailand have, as a result, started to focus more on commercially driven production methods aimed at producing higher yields, while at the same time using less labor and less land. Most upland farmers' agricultural activities in northern Thailand used to be associated with shifting cultivation practices, with upland rice being the main crop grown and a variety of vegetables also grown for home consumption. However, shifting cultivation methods led to soil erosion and were considered to be unsustainable (Keen, 1978). In 1961, the Thai government designated most of the nation's forests, and especially those in the northern highlands, as protected areas (Delang, 2002). As a result, the expansion of agricultural land in such areas was thereafter restricted by the Royal Forestry Department, with traditional farming practices in particular considered inappropriate (Delang, 2002; Forsyth and Walker, 2008). At that time, pioneer shifting cultivation largely stopped in the country (Rerkasem, 1998), and Thai farmers faced a number of changes and challenges to their livelihoods. These challenges included land scarcity and the pursuit of industrialization, for which a large number of workers were required. As a result, in the 1980s and early 1990s many farmers moved off their farms in pursuit of work in the industrial sector (Rigg, 1993, 1995). In 1997, however, many such workers lost their jobs due to the Asian financial crisis, and at this time farmers returned home and entered the farming sector again. With limited agricultural land available and yet rising demand for agricultural products, farmers were motivated to modernize their agricultural systems, causing the sector to move from a largely agrarian focus, to a more industrialized approach, with agriculture becoming more profit-oriented at the same time (Ecobichon, 2001). As a result, subsistence farming was no longer seen as able to meet the needs of a growing population, or provide decent incomes for farm households. Since that time, some farms have moved straight from subsistence farming into cash cropping, as driven by the steady agricultural commercialization process (Vanwambeke et al., 2007; Zeller et al., 2013).

1.2 Agricultural commercialization and land use intensification

There are different concepts in relation to what agricultural commercialization actually means. Market access is one of the most obvious criteria used to measure commercialization, while Jayne et al. (2011) refer to commercialization as the more intensive use of technologies to increase productivity and output, and to create a greater surplus, that helps increase market participation and enhances farmers' livelihoods. Mahaliyanaarachchi and Bandara (2006) define commercialization as the amount of market surplus produced as a proportion of total production. The higher the amount of surplus, the more commercially-oriented a farmer is. The use of inputs has also been considered an indicator of commercialization in a number of studies; for example, in 1995 Pingali and Rosegrant stated that “Agricultural commercialization means more than the marketing of agricultural output; it means [that] the product choice[s] and input use decisions are based on the principles of profit maximization” Similarly, von Braun and Kennedy (1995) and Zeller et al. (2013) looked at agricultural commercialization from an output and input perspective. This research is based on quantitative data gathered in relation to both inputs and outputs, with inputs including bought-in items such as seeds, fertilizers, hormones and labor, and with outputs being gross farm outputs. For the purpose of classifying the level of market orientation, Farm household in the study area were divided into three: (i) subsistence, (ii) semi-commercial and (iii) commercial systems. Whereas the objective of commercial farms is to maximize profits and trade inputs, through the use of irrigation systems and chemical fertilizers, the opposite of this, the objective of subsistence farming is to achieve food self-sufficiency based on household generated inputs, using rain-fed land and farmyard manure.

The concept of land use intensification is defined in a different way to commercialization. Netting (1993) described intensification as the greater utilization of a given area of land under production, while Shriar (2000) described intensification as the process of enhancing land productivity through the use of more inputs within a given area. Intensification can be measured using any combination of the substitution of labor, capital or technology for land, based on a constant land area used to acquire long-term production (Brookfield, 1993). Dietrich (2012) meanwhile, defined land use intensification as the process used by humans to increase land productivity through their interaction with agricultural activities, but without the influence of environmental interactions. Land use intensification can be measured either in terms of agricultural output or input use levels. Outputs can be measured in production units or values, while inputs can be measure based on the amounts or values of input use. For the purpose of this thesis, five variables were used to define land use intensification, these being the value of crop outputs, the value of variable inputs used (e.g. fertilizers, seeds and labor), the value of fixed costs, and the length of both fallow and irrigation periods. Hence, land use intensification is measured in a different way to commercialization, as it is based not only on inputs and outputs, but also takes into account factors influenced by human interactions, such as the influence of increasing agricultural production.

1.3 Commercialization and risk

Risk can affect an individual’s welfare, and is associated with difficulty and loss (Zeller et al., 2013). Agriculture is a unique sector, and is exposed to risk to a greater extent than many other business sectors, with the sources of such risk being multi-faceted, including inter alia production, marketing, financial, institutional and human risks. These risks are not independent of each other and are all closely linked to farm outcomes (Akcaoz, 2012; Girdžiūtė, 2012; Kahan, 2008). Farmers face a great number of risks, and their decisions regarding these risks directly affect the performance of their farms, and so pose many challenges. Many negative factors that influence farm outcomes cannot be predicted, such as variable weather conditions, low prices during the harvest season, and a loss of labor due to accidents or unfavorable government policies (Aimin, 2010; Akcaoz, 2012). Each of these risks can play an important role in farmers' decision making processes, meaning they have to find ways to deal with such risks in order to reduce uncertainty. However, farmers are able to tolerate risk to different degrees, and some are willing themselves to take more risks than others (Kahan, 2008). In the production process, there are several stages at which farmers have to make decisions, but there is only one result: crop outputs. At the time when decisions are made, outcomes are usually uncertain, so farmers have to make the best decisions they can, based on their knowledge and experience. Even though there are some sources of risk in farming which are beyond the control of any individual farmer, farmers still need to understand the relevant risks they face and have the appropriate risk management skills needed to better anticipate and cope with such problems, and so reduce the impact of any negative consequences (Harwood et al., 1999). To sum up, risk and uncertainty are inherent to agricultural production and affect farming systems in different ways. As farming systems in developing countries transit from subsistence to market-oriented forms of production, so the sources of risk to which farm households are exposed will also change (Kahan, 2008).

Within the commercialization process, agricultural input and output markets play a major role. In particular, farmers benefit from improved access to credit, increasingly depend on traded inputs and start participating more fully in output markets. Farmers are thus faced with an array of new potential market and financial risks, such as those arising from the loans they take out. At the same time, the intensification of crop cultivation activities and the introduction of high-value crops augment these production risks. One source of risk which is usually of great concern to farmers, as well as to consumers, is crop pests (Byrne et al., 1991; Roitner-Schobesberger et al., 2008). Farmers' pest management approaches are determined by how they evaluate the economic losses caused by pests and what management strategies are available to them in order to mitigate such losses. Some farmers use traditional, cultural methods to control this risk, while many farmers choose to spray pesticides curatively as well as prophylactically, to increase the odds of a good harvest at the end of the cropping season. A perceived high risk of pest infestation is often met with increased levels of pesticide use, if such chemicals are available, but although the benefits of using pesticides are real, at the same time they also cause a number of problems. Previous studies have shown that, based on their limited level of knowledge, farmers tend to underestimate or fail to correctly assess the risks they face when using pesticides (Atreya, 2008; Lamers et al., 2013). For instance, rural producers tend to neglect the health and environmental risks associated with the increased use of synthetic pesticides (Liu and Huang, 2013; Obopile et al., 2008). Agricultural policies such as crop insurance and input subsidies can help mitigate certain risks; however, effective policymaking requires information to be available regarding the sources of risks faced by farm households and the risk management methods available to them. Although commercialization in Asia has been widely studied (Pingali and Rosegrant, 1995; Tipraqsa and Schreinemachers, 2009), its overall relationship with risk perception and risk management has been neglected.

1.4 Positive and negative externalities of pesticide use

Pesticides are applied to control pests such as weeds, insects and fungi, and so correspondingly, the most common classes of pesticide used are herbicides, insecticides and fungicides. Chemical pesticides are most widely used in the agricultural sector to prevent damage to crops and so enhance crop yields. Early broad-spectrum pesticides had a toxic effect on most organisms, and required the application of large amounts of active ingredients, while more recent pesticide types are more specific and theoretically require smaller amounts to be applied. Pesticides are used worldwide to manage agricultural pests, and the benefits of such pesticides are real and important to farmers. Studying the benefits of pesticides to mankind and the environment, Cooper and Dobson (2007) explained the positive outcomes of pesticide use in terms of their primary and secondary benefits. The primary benefits of pesticides are a direct consequence of their use; controlling pests and plant diseases, controlling human and animal diseases, and controlling organisms that harm other human activities and structures. The secondary benefits of using pesticides are less obvious but manifest themselves at a later stage. First, there are benefits to communities that can be measured in terms of food security, children's education and an improved quality of life among farmers. Secondly, national benefits are derived from export revenues and reductions in urban migration. Lastly, global benefits can be estimated through the diversity of crop species which contribute to the world's food supplies, as well as prevention of the spread of a range of transboundary diseases.

Even though farmers and societies as a whole obtain considerable of benefits from chemical pesticides, undesired and unintended consequences also frequently occur, those which go far beyond the main purpose and site of pesticide application. Pesticide use is widely seen to harm ecosystems and human health, and especially the health of farmers. The negative and external effects of pesticide use have been recorded in a number of studies. For example, pesticides have been found to contaminate water bodies and soils, disturb natural pest control and poison animals, before finally being transferred to humans through residues accumulated in the food chain (Thapinta and Hudak, 2000; Van Hoi et al., 2009). One study conducted Mae Sa watershed, Thailand, found that the concentration of pesticides in surface water exceeded toxicity criteria for both aquatic vertebrate and invertebrates (Ciglasch, 2006). During the pesticide application process, farmers often experience the direct, negative health impacts of pesticides, which include headaches, dizziness, fainting, numb fingers, a loss of appetite and skin problems (Van Der Hoek et al., 1998). Consumers are also exposed to the negative effects of pesticide use when they consume polluted fruit and vegetables.

1.5 Facts about agricultural pesticide management in Thailand and beyond

Pesticides have become an important agricultural input in Thailand as a whole (Thapinta and Hudak, 2000); for example, from 2000 to 2009, Thailand increased its pesticide use by 9.1% per hectare. In the highlands of northern Thailand, farmers have gradually come to rely more on pesticide use than on traditional pest control methods to manage pest risks (Schreinemachers et al., 2011). As the importance of cash crops has increased, so farmers in northern Thailand have adapted their agricultural practices by using more industrially produced inputs. Rice is no longer the main crop grown in the area (Vanwambeke et al., 2007); the commercial production of high-value crops such as vegetables, soybeans and fruit has instead become widespread (Rerkasem, 1998). Farmers growing high-value crops in particular, often carry high risks and so spray pesticides indiscriminately. At the same time, such farmers often do not have to hand information and data on the exact effects of pesticide use on the environment and human health. Often, they also do not have enough knowledge on how to handle pesticides properly (Snelder et al., 2008). Similar problems exist in other countries. A study in Nepal found that most farmers accept that pesticides are harmful to human health, livestock and plant diversity, nevertheless only a small number of farmers wear protective clothing, gloves or mouthpieces (Atreya, 2007). Meanwhile, a study in Sri Lanka found that although farmers are aware of the health risks posed by pesticide use, they do not read the usage instructions, as to do so is not convenient (Van Der Hoek et al., 1998). It has been shown that farmers exposed to high levels of health risk from the use of pesticides, increasingly heavy pesticide use is related to their limited awareness of the adverse impacts of such pesticides on their health (Praneetvatakul et al., 2013). In general, the heavy use of pesticides reduces an ecosystem's natural capacity to control pests, and leads to the development of pesticide resistance, secondary pest outbreaks and eventually pest resurgence (Liu and Huang, 2013; Pimentel et al., 1993; Wilson and Tisdell, 2001). Studying pesticide distribution and use in the Red River Delta in Vietnam, Van Hoi et al. (2009) found that most farmers use pesticides excessively; 75% apply higher amounts than are recommended. However, it was also found that crop losses in the area have not declined in line with this increase in pesticide use. Adopting a total system approach to sustainable pest management, Lewis et al. (1997) also showed that global crop losses due to pests grew from 34.9% in 1965 to 42.1% over the period 1988 to 1990, despite the intensification of chemical pest control. In fact, a general resistance to pesticide use has been an important, global pest management problem over the last four decades.

1.6 Alternatives to chemical pest management

Current agricultural practices focused on high value crops, improved varieties and mono-cropping have increased the need for pesticides to be used, and the steady expansion of agricultural land has brought with it heavy applications of fertilizers and pesticides (Thapinta and Hudak, 2000). The use of traditional pest management techniques can be seen as an alternative to pesticide application for controlling pests, and such techniques also help regenerate and sustain the health of farmland, which will be particularly important as the global demand for food continues to rise (Rai, 2011). Traditional pest management involves several farm activities, such as soil management, the timing of planting and harvesting, intercropping, mechanical control, the use of repellents and traps, site selection, slash and burn activities, and natural crop resistance. Traditional farming methods have the potential to control pests effectively, and their use should be considered as a part of modern Integrated Pest Management (IPM) activities (Morales, 2002; Zehrer, 1986). As a technique used for pest control based on predicted economic, ecological and sociological consequences, those related to biological knowledge and principles. IPM is not a new concept. IPM combines the appropriate selection of pest control actions based upon dynamic principles, and helps identify the most threatening pest economically (Bottrell, 1979; DeMoranville et al., 1996; Sandler, 2010; Tweedy, 1976). The basic IPM process involves the use of education, monitoring and appropriate decision making. Farmers first learn about IPM concepts, including the techniques used to monitor pests and choose the right management options, before continuing on to the practical processes involved (DeMoranville et al., 1996; Sandler, 2010). However, limited knowledge is a major constraint on the use of effective and sustainable pest management activities. Studying agricultural transformation in Nepal, Rai et al. (2011) analysed a sample of 100 farm households, many of which lacked ecological knowledge. While some farmers said they did not classify insects as pests if they did not cause economic damage, other farmers considered all insects to be pests. Farmers in many developing countries grow-up learning about traditional cultivation systems; however, this situation is changing rapidly, as their knowledge tries to catch-up with the new, commercial realities they face. Even pest management professionals have been used to improve pest control practices, but many barriers to effective practice exist; for example, ecological theory and pest management practices have not been integrated, there is a lack of coordination between social and biological scientists, and also not enough effort is made to work with farmers on an equitable basis and improve the transfer of knowledge from researchers to farmers (Morales, 2002).

1.7 Pesticide policies in Thailand

Pesticides are now widely used in Thailand, and according to the Thai Ministry of Agriculture and Cooperatives, sales of pesticides such as insecticides, fungicides and herbicides are worth around €220 million per year. The largest players in the Thai pesticides market include Bayer, Monsanto, Syngenta and Dow (Bartlett and Bijlmakers, 2003). The use of chemical pesticides in Thailand started in the early 1950s, when most pesticides were imported. In 1967, a policy of free pesticide distribution was introduced to deal with major pest outbreaks. Due to the indirect subsidies provided, pesticide prices, when compared to other agricultural inputs, have tended to stay low over the last 50 years in Thailand. Before 1991, the tax rate for pesticides was set at 6.9%, as compared to 32.4% for fertilizers and 27.6% for agricultural machinery (Waibel, 1990). In the 1990s, there were 298 active ingredients registered in Thailand with a wide range of product names, and the trend since then has been for this number to keep on increasing (Jungbluth, 1996). At the same time, many illegal pesticide products have circulated in the Thai market (Grandstaff, 1992). In 1991, the Thai government completely eliminated import taxes on pesticides, if they were to be used only for agricultural purposes (Jungbluth, 1996). In 1992, it was revealed that more than 60% of imported pesticides belonged to the classes “extremely“ and “highly hazardous“, according to the standard WHO classification (Sinhaseni, 1994). Over the period 1976 to 1995, the quantity of insecticide imports increased from 5,960 tons to 10,560 tons at an average annual growth rate of 2.9%, while herbicide imports increased from 2,293 tons to 19,954 tons at an average annual growth rate of 11.4%, and fungicide imports increased from 1,299 tons to 6,937 tons at an annual average growth rate of 8.7% (Jungbluth, 1996). A recent study by Praneetvatakul et al. (2013) for the period 1997 to 2010 used the Pesticide Environmental Accounting (PEA) tool to estimate the external cost of pesticide use in agriculture, and showed that 83% of farm workers suffer external impacts from pesticide use, while the same figure for consumers is around 11%. The study also found, for the years 2006/7, that 15% of the fruit and vegetable products examined exceeded the maximum allowable pesticide residue levels, representing a total pesticide use cost of USD 228.13 million – taking into account the health, research and Q-GAP program costs incurred from such use.

However, some studies have revealed that Thailand took seriously sustainable agricultural development policies in the early 1990s, those based on the sufficiency economy concept. At this time, many policies were introduced aimed at crop diversification, a reduction in chemical fertilizer and pesticide use, and the promotion of organic farming and healthy food (Kasem and Thapa, 2012). In 2010, the Thai government spent about USD 15.77 million on controlling a brown plant hopper outbreak, one that led to insecticide misuse, and it also spent USD 38.85 million on pesticide research and another USD 0.48 million on research and development for pesticide inputs. Another USD 60.34 million is budgeted for the public GAP program, the aim of which is to prevent pesticide residues from appearing on food. Furthermore, the National Bureau of Agricultural Commodity and Food Standards also has also set-aside USD 5.89 million for setting-up and monitoring food safety standards (Praneetvatakul et al., 2013). Even though a number of policies have been implemented in order to support sustainable agriculture, the results have not been impressive (Kasem and Thapa, 2012). In fact, official policies play an important role in supporting the pesticide industry in Thailand, meaning that the chances of achieving sustainable agriculture will remain rather slim unless major changes in government policy take place.

1.8 Pesticide use reduction policies

At present in Thailand, pesticide use is widely considered necessary to improve crop productivity (Madhaiyan et al., 2006). The use of pesticides has been shown to be effective at controlling pests, avoiding crop damage and increasing agricultural output (Ecobichon, 2001), as well as directly and positively affecting farm revenues and household welfare (Cooper and Dobson, 2007). However, and as described above, the use of pesticides does not only influence agricultural production, but also has an adverse impact on ecosystems and the safety and quality of water sources, threatening human health (Margni et al., 2002). In response to these problems, pesticide monitoring programs have been implemented in Thailand by both the Pollution Control Department (PCD) and Department of Agriculture (DOA), though these two programs have different objectives. The PCD’s objective is to measure the contamination and health impacts caused by pesticide use, while the DOA is focused on agricultural research projects (Thapinta and Hudak, 2000). To improve food safety, the good agricultural practice (GAP) initiative was first introduced in Thailand in 1988, and this was then followed by the Organic Agriculture Certification Thailand scheme. The general idea of the GAP programs is to support small-scale farmers by ensuring food safety, creating market channels, improving working conditions, improving production efficiency, ensuring safer production practices are introduced, reducing poverty among farmer and protecting the environment around farms. Since 2004, the Q-GAP program has expanded rapidly in Thailand, providing free extension and inspection services in support of GAP certification. This scheme is focused on ensuring food safety at the local, domestic and export market levels (Amekawa, 2013). In 2005, attainment of the Global GAP standard became mandatory for those companies trading with countries in the European Union (EU) (Holzapfel and Wollni, 2014). To obtain Global GAP certification, farmers are required to adjust their farm management and production practices, this requires significant investment in farm infrastructure and equipment, such as sanitary facilities and appropriate pesticide storage (Asfaw et al., 2009; Holzapfel and Wollni, 2014; Mausch et al., 2009). However, small-scale farmers in developing countries are often not familiar with practices such as IPM, traceability and record-keeping, all of which are required by the Global GAP standards, and the information provided by Thai extension services regarding these standards is limited (Humphrey, 2008). A study into the sustainability of Global GAP certification among small-scale farmers by Holzapfel and Wollni (2014) found that Global GAP certification might not be a feasible option for small-scale farmers in developing countries, and that the implementation of good agricultural practices focused on the domestic market are likely to be more achievable and sustainable.

Although GAP was first introduced into Thailand over 20 years ago, chemical pesticides – including herbicides, insecticides and fungicides – continue to play a prominent role in relation to pest management within the Thai agriculture sector. The public GAP standard has been shown not to act as a catalyst for the introduction of alternative pest control practices, and has not contributed significantly to any reduction in agricultural pesticide use in northern Thailand. Therefore it can be useful to understand the reasons why public GAP standards do not contribute to reducing agricultural pesticide use as well as to better understand how the workings of the public GAP certification process in Thailand.

1.9 Research objectives

The first objective of this thesis is to analyze the pest management activities that take place within the Thai smallholder agriculture sector – which is undergoing a rapid process of land use intensification – in order to understand the constraints farmers face and identify policy approaches that may be taken to achieve a more sustainable pest management framework in the country. More specifically, this thesis studies the relationship between land use intensification and the number of pest problems perceived by farmers, the intensity of such pest problems, the pest management methods used and the health problems associated with pesticide use. The second objective is to improve the level of understanding on how risk perceptions and risk management strategies have changed as part of the agricultural commercialization process. To explore the relationship between commercialization, risk perception and risk management more closely, the analysis in this study focuses on a particular risk: pest infestations and their management through the use of pesticides. The third objective is to examine the public GAP certification process in Thailand, and especially its impact on pesticide use. The fourth objective is to *ex-ante* assess with the agent-based simulation model MPMAS what impact possible pesticide use reduction policies in Thailand, such as pesticide taxes, the promotion of integrated pest management (IPM), premium prices for safe products and the provision of subsidies for bio-pesticides, could have on levels of pesticide use and farm agent incomes.

The above four main objectives can be classified into the following six activities:

i) To describe and analyze how the agricultural system in the mountainous areas of northern Thailand has moved from one based on shifting agriculture to a more intensive cultivation form aimed at profit maximization, and which relies on pesticide use and a decrease in the use of integrated pest control methods.

ii) To analyse the number of pest problems and any increases in pest intensities as farmers have come to increasingly rely on synthetic pesticides. This will include a description of any non-anticipated problems such as pesticide resistance and health problems that may have arisen.

iii) To investigate how agricultural commercialization has exposed farmers to relatively greater levels of production risk, leading them to resort to the use of synthetic pesticides to control these risks.

iv) To identify farmers' perceptions of the risks they face, and the risk management strategies they use at different levels of commercialization.

v) To assess whether fruit and vegetable farmers who follow the public GAP standard use less pesticides than those farmers who do not follow the standard.

vi) To evaluate alternative pesticide use reduction strategies in terms of economic and environmental effects. .

1.10 Structure of the thesis

This thesis consists of six chapters. Chapters 2 and 4 contain articles which have already been published – in the 'Journal of Environmental Science and Policy', and 'Agriculture and Human Values' respectively. Chapter 3 has been submitted to Asian Journal of Agriculture and Development, while Chapter 5 has been submitted for publication in Ecological Economics. Chapter 2 describes how pest and plant disease management methods used by smallholder farmers in the highlands of northern Thailand have changed as part of the land use intensification process. It also assesses for which crops pesticide use is particularly high, and also the health problems experienced by farmers in relation to pesticide use. Chapter 3 describes how perceptions related to pest risks and risk management strategies have changed as part of the agricultural commercialization process, as well as the relationship between commercialization, the quantities of pesticides used and the ways in which commercialization have taken place, that is, based on moving from subsistence crops to perennial crops, or to seasonal crops. Chapter 4 presents the results of the study's analysis of how public GAP standards have performed in practice in Thailand, how farm audits have been implemented as part of the program, and also the level of understanding that exists among farmers regarding the program. Chapter 5 assesses the impacts of policies aimed at encouraging alternative pesticide use reduction strategies, including the application of pesticide taxes, the introduction of integrated pest management activities, the use of price premiums on safe agricultural produce, and the provision of subsidies for the use of bio-pesticides. Chapter 6 discusses the implications of the studies' finding in terms of commercialization, land-use patterns and agricultural practices, as well as crop choices, perceptions related to pests and pesticide use, and the constraints on reducing pesticide use in the highland areas of northern Thailand. It also highlights the opportunities available for introducing sustainable farming practices into such areas, and offers directions for future research.

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2 Publication I

Land use intensification, commercialization and changes in pest management of smallholder upland agriculture in Thailand[1]

Suthathip Riwthong [a], Pepijn Schreinemachers [b], Christian Grovermann [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

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2.1 Abstract

Agricultural development in lower-income countries and resulting increases in agricultural productivity are generally accompanied by a shift from extensive to more intensive types of land use. The objective of this paper is to analyze how pest and plant disease management among smallholder farmers has changed along with the process of land use intensification, the aim being to identify constraints as well as possible approaches to the use of more sustainable pest and plant disease control practices. Using survey data from 240 smallholder farms located in the upland areas of northern Thailand, we show that land use intensification is accompanied by a reduction in the use of traditional methods of pest management and an increase in the use of synthetic pesticides. While farms with a low level of land use intensity sprayed on average twice a year and used a total of 1.4 kg of active ingredients per ha, farms with a high level of land use intensity sprayed on average 16 times per year and used 22.0 kg/ha. They also used a greater number of different products and tended to mix them together. The intensity of pesticide use was particularly high for cash crops such as tomatoes, chilies and strawberries. Many farmers experienced health problems related to pesticide use because pesticides were not correctly handled. Greater investment is needed in the development of integrated pest management in the long-term, and health problems may be reduced in the short-term by raising awareness among farmers regarding the risks they are exposing themselves to, as well as by promoting good agricultural practices.

Keywords: Agricultural development, developing countries, Thailand, pesticide, pesticide risk

2.2 Introduction

Agricultural development in lower-income countries generally implies an increase in agricultural productivity, associated with a shift from extensive to more intensive land use methods (Nesheim et al., 2014). This form of development is normally associated with shorter fallow periods, a simplification of agro-ecosystems, the use of irrigation, and the adoption of external inputs such as synthetic pesticides, fertilizers, improved crop varieties and farm equipment (Ecobichon, 2001; Grovermann et al., 2013; Pandey, 2006; Pingali, 2001). Whereas higher-income countries have generally experienced a gradual land use intensification process, farmers in many lower-income countries have seen very rapid changes taking place in their farming systems. This fast pace of change has often led to dramatic improvements in farmer livelihoods, but has also created frictions as knowledge systems and institutions – including policies, take longer to catch up with the new reality of farming (Rai, 2011; Van Hoi et al., 2009).

One such area of friction relates to a rapid increase in the use of synthetic pesticides in developing countries (Ecobichon, 2001; Lewis et al., 1997); for example, Argentina, Brazil, Cameroon, China, Malaysia, Mexico, Nicaragua, Pakistan, Thailand and Uruguay have recently experienced an average annual growth in their pesticide use per hectare of 9 percent or more (Jin et al., 2010; Schreinemachers and Tipraqsa, 2012). Frequent reports of pesticide misuse in these and other developing countries are associated with the fact that farmers and consumers are still largely unaware of the risks they and their family members are exposed to, and also the absence of an enforceable legal framework to address the problems experienced (Panuwet et al., 2012; Xu et al., 2008).

The objective of this paper is to analyze pest management activities within Thai smallholder agriculture which is undergoing a rapid process of land use intensification, in order to understand the constraints farmers face and to identify policy approaches that may be taken to achieve a more sustainable pest management. More specifically, we study the relationship between land use intensification and the number of pest problems perceived by farmers, the intensity of such pest problems, the pest management methods used and the health problems associated with pesticide use.

Most previous studies analyzing this situation have been static in nature, as panel data related to changes in pest management activities are rarely available. One way to circumvent this is to use cross-sectional data from farms cultivating their land at different levels of intensity. Agricultural systems in mountainous areas offer an ideal setting for collecting such data, because differences in road infrastructure and distances to urban centers, as well as variations in agro-climatic conditions, provide varying opportunities for land use intensification to take place within a relatively small geographical area. Therefore, this study is based on data drawn from the highlands of northern Thailand.

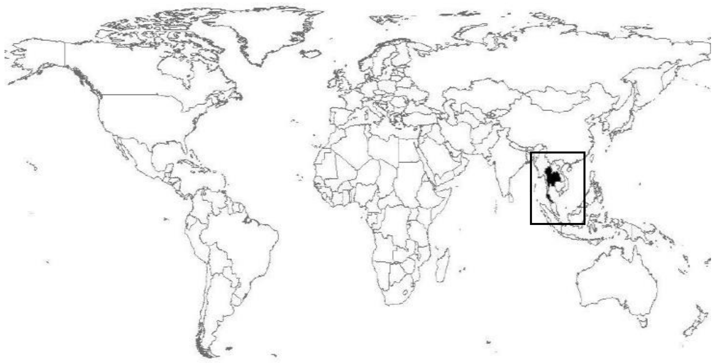
The mountainous north of Thailand is home to numerous ethnic minorities who traditionally engaged in rice farming to meet their subsistence needs, as well as commercial crops (such as maize and poppies) to meet their cash needs. The area has been subject to rapid land use change since the 1980s, as driven by restrictive land use policies, population growth, general economic development, infrastructure development and agricultural innovation (Schreinemachers et al., 2013). Farming systems nowadays are much more diverse, and although traditional farming systems remain in some villages, maize, coffee, fruit trees, vegetables and flowers are also widely grown (Jiang et al., 2007; Jungbluth, 1996; Rerkasem, 1998; Vanwambeke et al., 2007). Previous studies have found that that there is a strong association between the amounts of synthetic pesticide used and the gross margins generated by different cropping activities (Schreinemachers et al., 2011), but also that farmers practicing commercial agriculture in mountainous areas are exposed to significant health risks due to pesticide use (Panuwet et al., 2008; Praneetvatakul et al., 2013; Stuetz et al., 2001).

The paper is organized as follows. Section 2 describes the data collection and method to quantify land use intensification. Section 3 presents the results of our analysis regarding the process of agricultural intensification, and identifies the factors associated with pesticide use, pest pressure and pest/plant disease control methods. Section 4 discusses the empirical findings and Section 5 concludes.

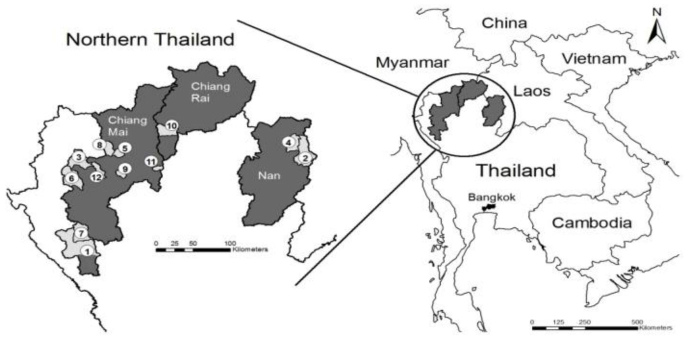
2.3 **Materials and methods**

For this study, we collected data in three provinces of northern Thailand, as shown in Figure 2.1. There are a total of 1,079 upland villages in these provinces, with a total of about 85 thousand rural households. Twelve villages were selected for our study. We first ranked the villages by their level of agricultural development, which was assessed based on secondary data obtained from the Highland Research and Development Institute (personal communication) regarding the average income per adult working in agriculture. The villages were divided into ten equal segments. From each segment, the village situated at the 50th percentile was selected for the study. Those villages situated at the 25th percentile in the first segment and at the 75th percentile in the last segment were also included, in order to ensure that villages with a very low and a very high level of agricultural development would be included in the study.

A list of all farm households in each sample village was compiled with the help of the local village headmen, and these lists were used to randomly select 20 households for an interview. This gave a sample of 240 households. The stratified sampling procedure applied here ensured that the data had a large variation in terms of farming systems and much diversity in terms of ethnicity, as shown in Table 2.1. The sample included households of Karen, Lua, Hmong and Thai ethnic origin. Farming systems that are oriented towards meeting the household subsistence needs are mainly characterized by the growing of upland rice and paddy rice, and also a range of fruit and vegetables in home gardens, while the more commercially-oriented systems include strawberries, chilies, tea and various other cash crops.



(a)



(b)

Figure 2.1a: Location of Thailand; and 1b: Location of the sub-districts in northern Thailand in which the sample villages are located (the numbers in the map refer to the villages listed in Table 2.1)

Table 2.1: Ethnicity and land use types in the twelve sample villages, ranked in ascending order by average agricultural income per adult person working in agriculture

Village name	Ethnic group	Main cash crops	Main food crops
1. Teelerperkee	Karen	Soybeans	Upland rice, home gardens
2. Khokuang	Lua	None	Upland rice, maize, home gardens
3. Pongkao	Karen	Peanuts	Paddy rice, home gardens
4. Jarangluang	Lua	Maize	Upland/paddy rice, home gardens
5. Maejew	Karen	Coffee, bananas	Upland rice, home gardens
6. Palapiklang	Karen	Maize	Upland/paddy rice
7. Yongkeau 3	Karen	Tomatoes, chilies, pumpkins	Paddy rice
8. Maemam	Karen	Tea	Upland/paddy rice, home gardens
9. Namzum	Hmong	Cabbages, maize, litchis	Upland rice
10. Maetala	Hmong	Maize, cabbages, spring onions	Upland rice
11. Poknai	Thai	Tea, coffee, persimmon	Home gardens
12. Nongkrizu	Karen	Strawberries, peanuts, chilies	Upland/paddy rice

Farm-level data were collected using structured questionnaires completed during face-to-face interviews with farm managers. Prior to the individual interviews, general information about each relevant village was collected through focus group discussions. Interviews were conducted in the Thai language, but the enumerators were also able to ask questions in the Karen and Hmong languages, in case the respondents were not fluent in Thai. The survey was conducted between November 2011 and March 2012, and questions were based on a 12-month recall covering the period November 2010 to October 2011. Information was collected about general farm characteristics, crops grown, inputs and outputs, as well as sources of income. Respondents were asked to identify crop pest and disease problems using a photo album prepared specifically for the survey. For each problem identified, detailed questions were asked about its intensity and, if applicable, the methods used to control it. If respondents said they were using pesticides, product names, quantities and expenditures were also recorded. This information was later matched with secondary data on the types and percentages of active ingredients contained within the pesticides being used. Pesticides included insecticides, fungicides, herbicides, rodenticides and other chemicals used to manage biotic stresses.

From a review of the relevant literature, we identified five variables used to define land use intensity (Dietrich et al., 2012; Pandey, 2006; Ruthenberg et al., 1971; Tipraqsa and Schreinemachers, 2009), as follows:

- Value of crop outputs per hectare, including outputs sold and consumed – valued at farm-gate selling prices.
- Value of inputs use per hectare, including fertilizers, hormones, seeds and hired labor, and other farm inputs such as fuel and planting materials.
- Fixed costs per hectare, including the value of farm structures, equipment and machinery, calculated as the purchasing value of the equipment divided by its expected useful life.
- The length of the fallow period, calculated as the average number of months of fallow per plot, weighted by the respective plot areas.
- The length of the irrigation period, calculated as the average number of months using irrigation per plot, weighted by the respective plot areas.

Principle component analysis (PCA) was used to detect the structure of the variable relationships. Based on the analysis, all variables were found to be strongly correlated and so exhibited high factor loading on the first component. Other components had low Eigen values and were not used in the analysis. The factor loadings on the first component were standardized and used to create an index of land use intensity, with values ranging from 0 (lowest land use intensity) to 1 (highest land use intensity).

To present the results we divided the sample into three equal groups using this index, these being low, medium and high land use intensity groups. Since land use intensity is a continuous variable (standardized to values between 0 and 1), we used a pairwise correlation to determine the significant relationships between land use intensity and the variables of interest, as well as ANOVA to detect significant differences between the categories. For discrete variables such as the number of farmers using pesticides or the number of farmers buying seeds, we used a Chi-square test to establish if differences in the means were significant.

Pest management was characterized using two variables. First, pest pressure was calculated by counting the number of pest problems the respondents identified from the pest photo album. Second, the quantity of synthetic pesticides used was expressed as active ingredients (in kg) and calculated from the undiluted quantity of pesticides used per application, the application frequency per cropping cycle and the percentage of active ingredients the products contained (obtained from secondary data). Various alternative methods of pest management were recorded in the survey in addition to the use of pesticides, these being handpicking, trapping, slashing and burning, plus the use of bio-pesticides.

2.4 **Results**

2.4.1 Land use change

Table 2.2 shows the variables used to quantify land use intensity. It illustrates that land productivity, variable and fixed input use per hectare, and months using irrigation, all increased with land use intensity, while the length of the fallow period decreased dramatically. The gross output per hectare for farms with high levels of land use intensity was found to be about 15 times greater than that of farms with low levels of land use intensity, while per-hectare variable costs were also about 15 times higher. These results reveal striking differences in land use intensity, and suggest that the process of land use intensification has led to a marked divergence in economic performance in the study area.

Table 2.2: Variables used to quantify land use intensity for the 240 study farm households in northern Thailand, 2011

Land use intensity	Land productivity (USD/ha)	Variable inputs used (USD/ha)	Fixed inputs used (USD/ha)	Irrigation applied (months/ year)	Fallow period (months)	Land use intensity index (0-1)
Low (A)	324[c]	82[c]	18[c]	0.04[c]	20.55[bc]	0.17[bc]
Medium (B)	777[c]	249[c]	61[c]	0.23[c]	2.31[a]	0.23[ac]
High (C)	4367[ab]	1198[ab]	308[ab]	1.54[ab]	0.19[a]	0.45[ab]
Average	1823	509	129	0.61	7.68	0.29
Correlation	0.82	0.62	0.44	0.69	-0.53	-
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	-

Notes: The letters a, b and c indicate that the value in question is significantly different from those categories (based on ANOVA). Correlation values reflect a pairwise correlation coefficient.

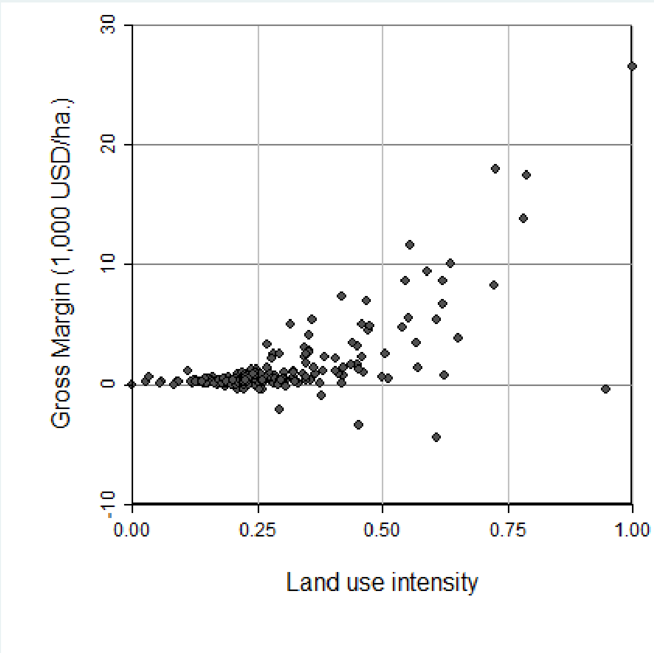


Figure 2.2: Gross margins plotted against land use intensity for the 240 study farm households in northern Thailand, 2011

The data also suggest that land use intensification increases the level of risk faced by farm households. Figure 2.2 and Table 2.3 show a wide spread of farm-level profitability levels (gross margins) among farming systems, with the coefficient of variation for gross margins being 90% for households with low levels of land use intensity, but 150% for households with high levels. Some farmers with a higher level of land use intensity had negative gross margins. We will now describe some of the differences in land use that underlie this.

Households with a low level of land use intensity were found to be mostly growing rain-fed upland rice and practicing swidden agriculture, with an average fallow period of nearly two years. Fallowing and subsequent slashing and burning are used to rebalance soil nutrients and to break crop pest and disease cycles. Households consumed nearly all rice they produced, and grew a diverse range of food crops such as taro, yams, muskmelons, maize, sweet corn and pumpkins in home gardens, or interspersed these with rice, but these crops only supplied small quantities. In terms of output values and cropping areas, farms with low levels of land use intensity were found to be highly specialized towards rice. The slashing and burning of vegetation, plus sowing and harvesting activities, were being carried out jointly with other smallholder households in the community, meaning that 62% of farm labor was being shared and that the hiring of labor was uncommon.

For households with medium or high levels of land use intensity, irrigated paddy rice was relatively more important than rain-fed upland rice. No vegetables or other crops were combined with rice in the paddies, but most households continued to grow vegetables in their home gardens for their own use. Perhaps surprisingly, with increasing land use intensification, rice had not disappeared from the farming system, with 88% of farmers in the high intensity group continuing to grow it. This shows that households in the area place great importance on being able to secure at least a part of their rice consumption needs, although they may also purchase rice from the market. The information obtained from the focus group discussions confirmed this. The share of the harvest sold increased with land use intensity, but still 43% of farm output was home consumed – even among the high land use intensity group (Table 2.3).

As fallow periods shortened and cash crops became more important, the use of mineral fertilizers increased dramatically, from 17 kg/ha for farms with low levels of land use intensity, to 414 kg/ha for farms with high levels (Table 2.3). In addition, households became more reliant on external seed supplies, with 65% of households in the high land use intensity group buying seeds as compared to 39% in the low land use intensity group. Hired labor also became more important as land use intensification increased, but even for the high land use intensity farms, it only constituted 7% of total labor use, and was used exclusively for cash crops, whereas labor sharing continued to dominate rice cultivation.

Table 2.3: Variables correlated with land use intensity for the 240 study farm households in northern Thailand, 2011

Land use intensity	Gross margins (USD/ha)	Percentage of harvest sold	Percentage of farmers buying seeds	Mineral fertilizer use (kg/ha)	Source of agricultural labor (% of total labor)[d]	
					Shared	Hired
Low (A)	242[c]	27[bc]	39	17[c]	62	1[c]
Medium (B)	529[c]	58[a]	53	102[c]	60	3[c]
High (C)	3168[ab]	57[a]	65	414[ab]	52	7[ab]
Average	1313	47	52	178	58	3
Correlation	0.69	0.30	-	0.60	-0.14	0.27
P-value	<0.0001	<0.0001	0.004	<0.0001	0.0317	<0.0001

Notes: The letters a, b and c indicate that the value in question is significantly different from those categories (based on ANOVA). Correlation refers to a pairwise correlation coefficient. Where the variable is expressed in "% of farmers", a Chi2 test was conducted instead of ANOVA or pairwise correlation. [d] The remainder is own household labor.

The rapid substitution of rice with cash crops, particularly upland rice, is shown in Figure 2.3, with the graph therein based on regressions of the land use intensity index for three land-uses. The figure shows that the process of land use intensification went together with the adoption of cash crops, including vegetables (cabbages, kale, tomatoes and chilies), fruit (strawberries and litchis), flowers, tea and coffee. This suggests that land use diversification took place alongside the process of land use intensification, but that it had occurred at the landscape level rather than the farm level, because each household tended to specialize in only one or two cash crops. Land use intensification did therefore not lead to a homogenization of land use.

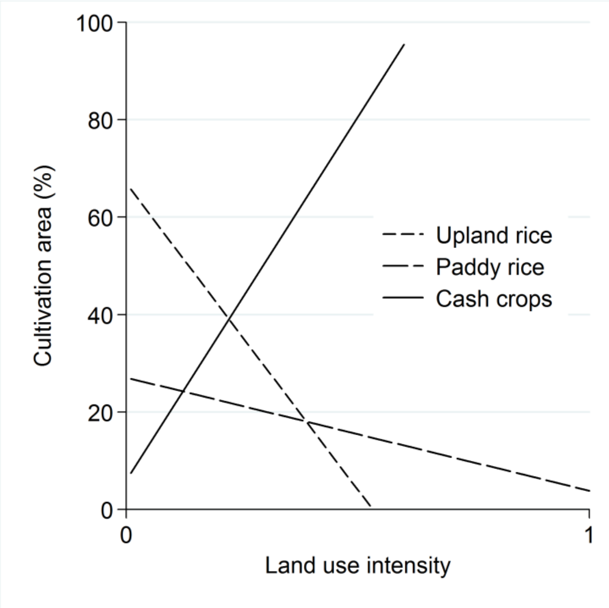


Figure 2.3: Relative importance of upland rice, paddy rice and cash crops by level of land use intensity, for the 240 study farm households in northern Thailand, 2011

Notes: N=240. LUI= 0.36 - 0.0024 % Upland rice (R2=0.31); LUI= 0.30 - 0.0006 % Paddy rice (R2=0.01); LUI= 0.19 + 0.0019 % Cash crops (R2=0.29). All coefficients were significant to a 99% confidence level.

2.4.2 Pests and pest management

Our results provided no evidence that the process of land use intensification had significantly increased pest intensity – based on the number of pests observed by farmers. In all the villages, farmers selected about 10 pests and plant diseases from the photo album. For rice cultivation, the main pest and disease problems found were rodents (rice rats), dirty panicle disease, leaf-folder and bacterial blight. For the cash crops, pest and disease problems varied with the types of crop grown, but the main problems reported were rodents (rats), downy mildew, leaf spot and rust, and various types of caterpillar. In terms of rodent management, 55% of the low land use intensity farmers used trapping devices, but only 13% of the high land use intensity farmers did so.

Weeds were the main problem faced by low level land use intensity farmers. Slashing and burning was commonly carried out (Table 2.4) to control weeds, but this did not create temperatures high enough to destroy most of the seeds, particularly during short fallow cycles when not enough biomass has accumulated. Hand hoes and machetes were the most common methods of weed control used, but 35% of the farmers said they also used salt (sodium chloride) as an inorganic herbicide (defoliator). The use of synthetic herbicides was also common, with 51% of farmers in the low intensity land use group applying them. Within the high land use intensity group, the use of synthetic herbicides was even more widespread, with 79% of farmers spraying herbicides at an average rate of 5.4 kg/ha, as compared to 1.4 kg/ha within the low intensity group. Farmers mentioned that the use of inorganic herbicides had tended to disappear as land use intensified, with the most commonly applied synthetic herbicides among the study households including paraquat dichloride, glyphosate and atrazine.

Table 2.4: Pest management methods used and levels of land use intensity for the 240 study households in northern Thailand, 2011 (% of farmers using a method)

Land use intensity	Weed management				Trapping	Hand-picking	Synthetic insecticides	Synthetic fungicides
	Slash and burn	Mech-anical	Inorganic herbicides (salts)	Synthetic herbicides				
Low	58	100	35	51	55	13	19	3
Medium	51	91	18	60	24	9	28	9
High	34	74	8	79	13	5	65	46
Average	48	88	20	63	30	9	37	19
P-value[a]	0.008	<0.001	<0.001	0.001	<0.001	0.244	<0.001	<0.001

Note: a Chi2-test

Table 2.5 confirms that the use of synthetic pesticides had become more common as land use intensity increased (Table 2.5), with the quantity of synthetic pesticides used being 1.4, 4.0 and 22.0 kg of active ingredients per hectare in the low, medium and high land use intensity groups respectively. The use of fungicides such as mancozeb, and insecticides such as methomyl and cypermethrin, also increased dramatically. The average quantity of synthetic pesticides applied depended much on the cash crops grown, and was particularly high for tomatoes (40 kg/ha), chilies (50 kg/ha) and strawberries (52 kg/ha).

Table 2.5: Quantity of synthetic pesticides used by land use intensity for the 240 study farm households in northern Thailand, 2011 (active ingredients: kg/ha/year)

Land use intensity	Herbicides	Insecticides	Fungicides	Other pesticides	All pesticides
Low (A)	1.4[c]	<0.1[c]	<0.1[c]	<0.1	1.4[c]
Medium (B)	3.9	<0.1[c]	<0.1[c]	<0.1	4.0[c]
High (C)	5.4[a]	2.3[ab]	13.5[ab]	0.4	22.0[ab]
Average	3.6	0.8	4.5	0.1	9.0
Correlation	0.13	0.40	0.40	0.07	0.44
P-value	0.0468	<0.0001	<0.0001	0.2629	<0.0001

Notes: The letters a, b and c indicate that the value in question is significantly different from those categories (based on ANOVA). Correlation figures refer to a pairwise correlation coefficient.

The data in Table 2.6 show farmers' increasing reliance on synthetic pesticides as land use intensifies. Of the farmers in the high land use intensity group, 16% reported they only used synthetic pesticides, applying them 16 times a year, while the low land use intensity farmers said they only applied them twice a year. An increase in the number of different pesticides used was also accompanied by an increase in the mixing of different pesticide products – a practice not recommended because chemical reactions between different products can increase health risks to farmers and reduce the effectiveness of their application.

Farmers did not seem to be aware of the impact of pesticide use on their health, and generally had only limited knowledge of their correct usage (Table 2.7). In total, 16% of the households using pesticides were storing them inside their homes, while 32% mentioned they simply left containers in the fields. Of this group, 38% said they never followed the instructions shown on the containers' labels. The fact that 52% of the respondents were not able to read Thai largely explains this because the information on the label is only given in Thai language. Other farmers were the main major source of information about health and safety issues related to pesticide use as 67% of the respondents said they received such information from their peers, 28% from pesticide sellers, and only 3% from government officers.

Table 2.6: Use of synthetic pesticides by level of land use intensity for the 240 study farm households in northern Thailand, 2011

Land use intensity	% of farmers using	% of farmers using as only method	Applications per year	Number of different pesticides used	% of farmers mixing pesticides	Share of input costs (%)
Low (A)	51	0	2[c]	1.7[c]	18	12
Medium (B)	63	3	3[c]	2.4[c]	14	10[c]
High (C)	85	16	16[ab]	4.5[ab]	35	16[b]
Average	66	6	7	2.9	22	13
Correlation	-	-	0.56	0.44	-	0.23
P-value	<0.001	<0.001	<0.0001	<0.0001	0.003	<0.001

Notes: The letters a, b and c indicate that the value is significantly different from categories A, B and C, respectively, based on ANOVA. Correlation figures refer to a pairwise correlation coefficient. Where the variable is expressed as "% of farmers", a Chi2 test was conducted instead of ANOVA or pairwise correlation.

Table 2.7: Pesticide usage and health impacts for the 240 study farm households in northern Thailand, 2011 (% of farmers using synthetic pesticides)

Land use intensity	Store pesticides inside the house	Always leave empty containers in or near the fields	Do not follow instructions on the labels	Regularly experience dizziness after spraying	Regularly experience nausea or vomiting after spraying
Low	24	46	51	56	34
Medium	10	27	41	43	18
High	16	27	27	43	24
Average	16	32	38	47	25
P-value[a]	0.263	0.593	0.819	0.432	0.303

Note: [a] Chi2 test

No significant correlation was found between the level of land use intensity and these handling practices, which suggests that pesticide handling practices did not improve with higher levels of land use intensity. Due to the limited awareness of their impact and the lack of protection used during spraying, farm workers applying the pesticides – male in 80% of cases – were being highly exposed. The results show that 47% of the applicators reported they regularly felt dizzy and 25% that they regularly experienced nausea or vomited after applying the chemicals (Table 2.7).

2.5 Discussion

Our results show that farmers who cultivate their land more intensively use a greater number and greater quantity of synthetic pesticides and use fewer alternative methods of pest control than farmers who cultivate their land less intensively. These results suggest that the process of land use intensification is accompanied by an increasing reliance on synthetic pesticides.

The fact that there is a strong correlation between gross margins, land use intensity and pesticide use suggests that the increase in pesticide use is largely driven by farmers seeking higher profits. It was not the objective of our study to identify the drivers of pesticide use, but we think that other factors might also play an important role. One such factor is the easy availability of pesticides in all locations in the Thai uplands and an active private sector promoting their use. Another factor is labor saving, which particularly drives herbicide use and has been identified in other country studies as well (e.g. Pedlowski et al., 2012). Cash crops also require relatively large investments for which credit is used, and farmers tend to overuse pesticides to reduce the risk of crop losses and subsequent indebtedness (Grovermann et al., 2013). Another factor that was apparent in our study is that integrated pest management had not been promoted yet and farmers therefore had only limited knowledge about this management option. They seemed to perceive pesticides as the only control method available to them.

Our results do not confirm that homogenization of land use is a driver of pesticide use because we found that the adoption of cash crops actually diversified agricultural land use, as compared to the traditional system dominated by rice cultivation. Diversification, however, is more apparent at the landscape level than at the individual farm level because different farmers adopted different cash crops. Our findings do also not confirm that farmers have entered into a vicious cycle of pesticide resistance buildup, increasing pesticide use and increasing withdrawal costs as, for instance, described by Cowan and Gunby (1996) and Wilson and Tisdell (2001). We did not find that high intensity farms had a greater number or greater intensity of pest problems, nor had farmers noticed a marked decrease in the effectiveness of pesticides. We must caution, however, that most farmers had only recently started using pesticides, and pesticide resistance might be observed at a later stage. We can therefore not rule out the existence of such a vicious circle.

Our empirical analysis was based on a land-use intensity index constructed using PCA. We checked the robustness of our findings, by repeating the analysis using an alternative index, one constructed by first standardizing the five variables listed above – from 0 to 1, then averaging across all variables. This gave slightly different results for some variables, but our findings and conclusions remain the same.

Some aspects relevant to the process of land use intensification were not well-captured in our study, including changes in the level of knowledge among farmers about pests and diseases, and also changes in the roles of men and women with regard to pest and plant disease management. It was also difficult to fully capture the diversity of crop species grown by farmers operating with low levels of land use intensity, since estimating crop areas and output quantities proved difficult for minor crops used only for home consumption.

Within the group of farmers with intensive land use, the variation in pesticide use was high. Average levels of pesticide use on cash crops such as tomatoes, chilies and strawberries were alarmingly high, while levels were relatively low for cash crops such as coffee and tea. This confirms earlier findings of Tipraqsa and Schreinemachers (2009). This information can be used to better target interventions aimed at reducing pesticide risk. Farmers cultivating tomato, chili and strawberry would benefit most from training in pest and disease diagnosis and management. As a consequence, extension services could target their efforts at locations where these crops are predominantly grown.

Such training efforts can include rather simple methods to reduce health risks to farmers, such as the use of protective clothing or following application instructions, as we found that these were not generally being used, and it appeared that farmers' practices did not improve as land use intensified. Farmers with a high land use intensity commonly mixed different pesticide products together into single sprays. As a result of incorrect handling practices, respondents reported to suffer from health problems such as dizziness, nausea and vomiting after applying pesticides, which corresponds to the findings for other countries (Ngowi et al., 2007; Van Der Hoek et al., 1998). The focus group discussions revealed that most farmers experienced such problems, but concerns that side-effects could do long-term damage to their health appeared to play a secondary role for farmers. On the contrary, farmers were generally satisfied with the level of crop protection offered by synthetic pesticides. There is therefore an urgent need to raise the level of awareness of such impacts. If farmers were more aware of the potential danger of pesticides, they would probably have greater incentives to reduce usage and exposure.

2.6 **Conclusion**

Land use intensification in the upland areas of northern Thailand are accompanied by a reduction in the use of traditional methods of pest management and an increase in the use of synthetic insecticides, fungicides and herbicides. Farms with a low level of land use intensity sprayed on average twice a year and used a total of 1.4 kg of active ingredients per ha, while those at a high level of land use intensity sprayed on average 16 times and used 22.0 kg/ha. They also used a greater number of different products and tended to mix them together. Extremely high levels of pesticide were found in tomatoes (40 kg/ha), chilies (50 kg/ha) and strawberries (52 kg/ha). Many farmers experienced harmful side-effects such as dizziness, nausea and vomiting after spraying, but only few were truly concerned. Awareness raising and training in good agricultural practices together with the development and promotion of integrated pest management will be needed to reduce the risk of pesticide exposure.

2.7 **Acknowledgments**

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3 Publication II

Agricultural commercialization: Risk perceptions, risk management and the role of pesticides in Thailand[2]

Suthathip Riwthong [a], Pepijn Schreinemachers [b], Christian Grovermann [c], 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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3.1 Abstract

The transformation of agriculture in lower income countries from subsistence- to market-oriented production systems has important implications for farmers' risk exposure and risk management yet only few studies have paid attention to this. This paper fills this gap and particularly focuses on the role of pesticides in managing the risk from crop pests and diseases, which is major source of risk to farmers. Data were collected for 240 Thai upland farmers stratified by ten levels of agricultural commercialization. The results show that risk perceptions and management strategies are strongly associated with levels of agricultural commercialization. Key strategies for commercial farmers included monitoring market prices, diversifying sales channels and applying large quantities of pesticides, while crop diversification and debt avoidance were more important for subsistence-oriented farmers. High levels of pesticide use at commercial farms were not accompanied by a safer handling practices, as farmers largely neglected pesticide health risks. The results point at the importance of tailored agricultural policies to strengthen farmers' resilience against risk at varying levels of commercialization, rather than following a one size fits all approach.

Keywords: Land use intensification, pest management, developing countries, Thailand

3.2 Introduction

Risk and uncertainty are inherent to agricultural production. In the context of lower income countries, risk and uncertainty are closely linked to vulnerability of farm households to remaining in or falling into poverty. Yet sources of risk and uncertainty are not uniformly spread over all farmers, neither are they constant over time. As farming systems in lower income countries transform from subsistence- to market-oriented production, the sources of risk to which farm households are exposed change (Kahan 2008). Understanding the change brought about by commercialization is important for policy-makers to better manage the sustainable intensification of agriculture.

Whereas commercialization and land use change in Asia have been widely studied (e.g. (Pingali and Rosegrant 1995, Tipraqsa and Schreinemachers 2009, Vanwambeke, Somboon, and Lambin 2007, von Braun 1995), the relationship of commercialization to risk and risk management has received little attention. Most likely this is because commercialization and changes in risk are difficult to study as they require longitudinal data. Some studies have examined commercialization as a driver of farm productivity and rising farm household incomes, partly also considering market risk (Jayne et al. 2011, Pandey 2006, Zeller et al. 2013). Other studies have put a focus on analyzing farmer decision-making under risk (Aimin 2010, Akcaoz 2012, Harwood et al. 1999, Liu and Huang 2013, Waibel 1990).

However, the role of risk that farmers face in the process of commercialization and market integration is underappreciated. It is therefore the first objective of this study is to improve the understanding of how risk and risk management of farmers change in the course of agricultural commercialization.

One of the sources of risk of greatest concern to farmers is crop pests and diseases. The unpredictability of pest and disease incidence and resulting crop damage creates much anxiety among farmers. Lack of functioning extension services, absence of pest and disease monitoring systems, and poor levels of education, magnify such anxieties. The introduction of cash crops that are often ecologically unsuitable and the simplification of cultivation patterns with widespread mono-cropping characterize agricultural commercialization. This heightens pest pressure. Therefore, in the process of commercialization, farmers turn to using synthetic pesticides, which also become more accessible, to lower their risk exposure and to increase the odds of a good harvest. The second objective of this study thus is to analyze the relationship between commercialization and the role of synthetic pesticides in managing the risk of crop pests and diseases.

The paper starts in Section 2 by describing our methods and data. Section 3 identifies the various sources of risk as perceived by the farmers, shows their main risk management strategies, and shows how these vary with the level of agricultural commercialization. The second part of the results section then concentrate on the role of pesticides in risk management and estimates a regression model to identify drivers of pesticide use. Section 4 discusses our findings and Section 5 concludes.

3.3 Material and methods

3.3.1 Data

The uplands of northern Thailand are ideal for this type of study because the mountainous terrain creates unequal opportunities for agricultural development within a relatively small geographical area. A few decades ago, rice was the main crop grown virtually everywhere. Yet current land use patterns are much more diverse and include rice alongside many high-value crops such as maize, soybean, vegetables, fruits and flowers (Rerkasem 1998, Vanwambeke, Somboon, and Lambin 2007).

We selected three northern provinces for our research: Nan, Chiang Rai and Chiang Mai because they form a north-south axis from the main urban center of Chiang Mai. It appeared logical to assume that opportunities for commercial agriculture increase with the proximity to a major urban center. These provinces have 1,079 rural upland villages. We used secondary data from the Highland Research and Development Institute in Chiang Mai to find a proxy for agricultural commercialization. The best available proxy variable was the average income per adult employed in agriculture. We ranked the villages by this variable and divided them into ten equal segments. We selected the median village from each segment. To represent the extremes, we additionally selected the village at the 25th percentile of the first segment and at the 75th percentile in the last segment. This resulted in 12 villages on a spectrum of agricultural commercialization.

We developed a structured questionnaire to collect data on risk perceptions and risk management strategies as well as about farm production and farm household characteristics. The questionnaire was tested in three out-of-sample villages (one subsistence, one semi-subsistence and one commercial village) and refined after each test. Survey data were collected over a five-month period between November 2011 and March 2012, using a 12-month recall period. In each sample village we first conducted a focus group discussion with a small group of farmers and then compiled a list of all households with the village headmen. From this list we randomly selected 20 farm households for an interview.

Respondents were asked to indicate the level of importance of various sources of risk using a 5-point Likert scale ranging from one (not important) to five (very important). Sources of risk were grouped into four categories, including production, market, financial as well as human and personal risk. For each source, respondents were asked to explain how they tried to control it and how effective each of the mentioned control methods were; again, using a 5-point Likert scale ranging from one (useless) to five (very useful). These risk management strategies were initially taken from the literature and refined through the pre-tests and focus group discussions. We also quantified the value of input use and output for each crop. For pesticide use, we recorded the product name and the quantity applied. Secondary data were collected for each pesticide product to convert quantities of formulated product into quantities of active ingredients.

3.3.2 Quantifying commercialization

Agricultural commercialization was quantified using farm performance indicators as originally suggested by Dillon et al. (1993) and later applied by Tipraqsa and Schreinemachers (2009) for a study in northern Thailand. More specifically, we used two indicators: (1) integration into farm input markets, defined as the value of variable inputs bought relative to the total value of variable inputs used on the farm (including seeds, fertilizers, hormones, labor and any other inputs, but excluding pesticides); and (2) integration into farm output markets or marketable surplus, defined as the gross farm output sold as a quotient of the total gross farm output at average farm gate selling prices.

$$\text{Integration into variable input markets} = \frac{\text{Value of variable inputs bought}}{\text{Total value of variable inputs used}} \tag{1}$$

$$\text{Integration into farm output markets} = \frac{\text{Gross farm output sold}}{\text{Total gross farm output}} \tag{2}$$

These two variables were transformed into z scores and then combined additively into a single index, ranging from zero (subsistence farming) to unity (fully commercialized farming). As based on terciles of this index, households were classified into three equal groups, of subsistence, semi-subsistence and commercial. This allowed exploring differences between farming systems at distinct stages of commercialization.

For ordinal variables such as Likert scales, we used the non-parametric Kruskal-Wallis test to test if the relationship to agricultural commercialization was statistically significant. For continuous variables, we used a pairwise t-test and Bonferroni post-hoc test. For categorical variables including binary variables, we used a Chi-square test.

3.3.3 Regression model

Regression analysis was used to identify determinants of pesticide use and to test the hypothesis that agricultural commercialization leads to greater pesticide use. The selected method follows previous studies that have identified determinants of pesticide use (Carlberg, Kostandini, and Dankyi 2012, Gong 2012, Rejesus et al. 2009).

The use of ordinary least squares to regress pesticide quantities on a set of household-level determinants would yield incorrect results for two reasons. First, a substantial proportion of farm households practicing subsistence agriculture have not yet adopted pesticides. Partial adoption at the farm-level results in incidental truncation and, possibly, sample selection bias (Baum 2006). Second, the pesticide use variable for adopters contains excess zeros because some farm households that previously adopted pesticides decided not to use pesticides on certain crops, such as crops used for home consumption (e.g. upland rice and taro), and certain perennial crops that had little pest problems (e.g. coffee and tea). The former problem can be addressed by using a stepwise estimation approach with two sequential equations, the latter by estimating the model at the crop-level. The first equation explains farmers’ choice to apply or not to apply pesticides, while the second equation explains farmers' choice about the quantity of pesticides to apply.

Starting with the second equation, the amount of pesticide use is the dependent variable y and reflects the scale of adoption. The vector of strictly exogenous variables that determines y is denoted as xj, while zj is the vector of strictly exogenous variables that determine pesticide adoption. Finally, βj and γj are the vectors of the parameters to be estimated and uij are household specific error terms.

$$y_i = x_j\beta_j + u_{1j} \qquad [regression\ equation] \tag{3}$$

The dependent variable is not always observed. For observation *j* it is observed if,

$$z_j\gamma_j + u_{2j} > 0 \qquad [selection\ equation] \tag{4}$$

where,

$$u_1 \sim N(0; \sigma); \quad u_2 \sim N(0; 1); \quad corr(u_1; u_2) = \rho \tag{5}$$

Sample selection bias occurs if ρ≠0 and a Heckman correction would then be needed to provide consistent and efficient estimates for all the parameters (Baum 2006). Such procedure would estimate the Inverse Mills Ratio, capturing all observed and unobserved characteristics that affect the probability of pesticide application as well as the choice of pesticide quantity, and then include this in the regression equation (Baum 2006). However, if ρ=0 then it is sufficient to run a separate probit for sample inclusion followed by a linear regression, referred to as the two-part model (Manning, Duan, and Rogers 1987).

The model was estimated at the crop level (n=503) because pesticide decisions are crop-specific. Based on previous studies, e.g. Rahman (2003) and Rejesus et al. (2009), we expected that pesticide use (yi) is determined by the following variables: household size, age, sex and education of the farm manager, years of experience in each crop grow, farm specialization, labor use, plot size, amount of seed used, the perceived level of pest intensity, perceived level of pest risk (Table 1). To this list we added the level of agricultural commercialization. We note that the pesticide variable was not used to construct the commercialization variable; these variables are hence independent.

Table 3.1: An overview of the variables used in the regression analysis

Variable name	Definition	Sample mean	Standard deviation
Hh size	Household size (persons)	4.57	1.94
Age	Farmer age (years)	41.73	12.13
Male	Person managing the crop is male (dummy)	0.63	0.48
Experience	Experience growing the crop (years)	14.22	12.88
Education	Education higher than primary school (dummy)	0.48	0.50
Subsistence crop	Subsistence crops (dummy)	0.53	0.50

Variable name	Definition	Sample mean	Standard deviation
Field crop	Maize or grain legume (dummy)	0.21	0.41
Perennial crop	Perennial crop (dummy)	0.11	0.31
Labor input	Total labor input (person-days/ha/year)	210.42	256.12
Plot size	Area of cultivated land (ha)	1.01	1.14
Seed	Amount of seed and seedling used [a]	1.36	1.98
Med. pest intensity	Medium level of pest intensity (dummy)	0.72	0.45
High. pest intensity	High level of pest intensity (dummy)	0.14	0.34
Pest risk	Perceived level of pest risk [b]	1.52	0.45
Commercialization	Agricultural commercialization index (0 to 1)	0.46	0.32

Notes: [a] Variables for seed and seedlings transformed with cube root and combined; [b] Perceived level of pest risk = level of perceived pest risk (rated by farmers from 1 to 5) / level of perceived risk averaged over all risk sources (rated by farmers from 1 to 5).

3.4 Results

3.4.1 Commercialization

Figure 3.1 plots the level of agricultural commercialization against the relative share of subsistence crops (rice) and cash crops (e.g. vegetables, fruit, flowers). Assuming that we can interpret the commercialization index as a time dimension in our cross-sectional data, it shows that cash crops gradually replace rice at higher levels of commercialization. Yet even highly commercial farms continued to grow rice, which appeared as an important food security strategy for most upland households.

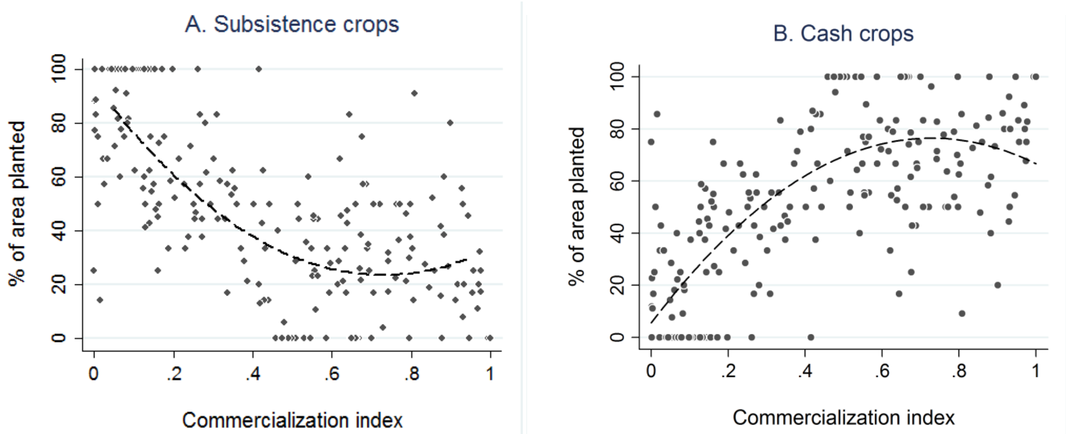

Figure 3.1: Correlation between the level of agricultural commercialization of farm households and their area share of subsistence crops (left diagram) and cash crops (right diagram) in Thai upland agriculture, 2011 (n=240)

3.4.2 Perceptions and management of risk

Commercial and subsistence farmers felt equally exposed to a range of risk factors, including natural disasters, water shortages, credit access, debt repayment, insecure land ownership and livestock diseases and mortality (Table 3.2). Commercial farmers perceived crop pests and diseases, low crop prices as well as the inability to hire labor as more important sources of risk than subsistence farmers did. For subsistence farmers, on the other hand, the risk of a family member falling sick had a greater perceived influence on farm performance. For all sources of risk combined, as shown in the bottom row of Table 3.2, commercialized farmers perceived risk to be more important than subsistence farmers.

Table 3.2: Perceived importance, scaled from 1 (not important) to 5 (very important), of various sources of risk to farm performance by level of commercialization in Thai upland agriculture, 2011

Source of risk [b]	Subsistence (n=80)	Semi-subsistence (n=80)	Commercial (n=80)	p-value [a]
Production risk				
Insufficient water supply	2.34	2.21	2.26	0.76
Natural disaster	2.13	2.11	1.94	0.64
Crop pests and diseases	2.88	2.69	3.05	0.05
Market risk				
Low crop prices	1.40	2.48	3.13	<0.01
Being unable to sell produce	1.28	1.28	1.53	0.13
Being unable to hire labor	1.05	1.14	1.28	0.01
Financial risk				
Being unable to get credit	1.40	1.25	1.43	0.82
Ability to repay debt [c]	1.95	1.79	1.91	0.86
Human and personal risk				
Losing land ownership	1.53	1.43	1.75	0.15
Family member falling sick	3.21	3.06	2.75	0.07
Sick or dead livestock [d]	1.45	1.54	1.47	0.96
Average all sources	1.87	1.92	2.05	0.04

Notes: [a] Kruskal Wallis test. [b] Sources of risk were divided into four categories based on Kahan (2008). The mean values in the table refer to a Likert scale from 1 (not important) to 5 (very important).[c] for farmers having debt. [d] for farmers having livestock.

Table 3.3 lists the strategies used by farmers to manage these sources of risk. For 9 out of the 17 strategies there appeared to be a significant correlation between the share of farmers using them and their level of commercialization. More subsistence farmers chose crop diversification, storage facility and avoiding debt as strategies to reduce their risk. Significantly fewer commercial farmers chose crop diversification and debt avoidance as a risk management strategy. Significantly more commercial farmers chose to apply pesticides to reduce risk, monitored market prices, did contract farming, diversified sales channels, saved money, and selected crops that were profitable. The results therefore show marked differences in risk management strategies by level of agricultural commercialization.

Table 3.3: Choice of risk management strategies by level of agricultural commercialization for Thai upland agriculture, in % of farmers per category using a strategy, 2011

Risk management strategy	Subsistence (n=80)	Semi-subsistence (n=80)	Commercial (n=80)	p-value [a]
Production risk				
Grow more than one crop	53	26	15	0.000
Practice intercropping	45	45	35	0.334
Have a storage facility	93	80	88	0.065
Use pesticides	31	46	80	0.000
Follow GAP/organic standards	3	8	5	0.349
Use non-chemical inputs	3	1	3	0.815
Use new technologies (innovate)	9	11	19	0.146
Market risk				
Diversify sales channels	6	21	41	0.000
Do contract farming	0	10	15	0.002
Monitor market prices	8	19	46	0.000
Financial risk				
Grow highly profitable crop	11	30	41	0.000
Family member earns non-farm income	53	58	63	0.441
Make budget plan	6	13	13	0.327
Avoid debt	53	41	35	0.077
Save money	23	40	44	0.011
Human and personal risk				
Have many children	26	23	20	0.639
Educate children	38	41	34	0.619

Note: [a] Chi2 test.

Farmers were asked to assess the usefulness of each strategy that they adopted to manage the various sources of risk shown in Table 3.4. For 9 out of the 17 strategies there appeared to be a significant correlation between the perceived usefulness and the level of agricultural commercialization. More subsistence farmers than commercial farmers reported that growing more than one crop, having a storage facility and having many children were useful to them. Significantly more commercial farmers perceived the following as useful: Application of pesticides, diversified market channels, contract farming, monitoring market prices, choice of highly profitable crops, and saving money. The results clearly show that farmers' perception of risk management strategies is correlated to the level of agricultural commercialization.

Table 3.4: Perceived usefulness, scaled from 1 (not useful) to 5 (very useful), of various risk management strategies by level of commercialization in Thai upland agriculture, 2011

Risk management strategy	Subsistence (n=80)	Semi-subsistence (n=80)	Commercial (n=80)	p-value[a]
Production risk				
Grow more than one crop	2.05	1.45	1.21	0.000
Practice intercropping	1.85	1.83	1.58	0.641
Have storage facility	3.38	2.96	2.96	0.069
Use pesticides	1.64	2.14	2.98	0.000
Follow GAP/organic standards	1.05	1.16	1.09	0.456
Use non-chemical inputs	1.08	1.04	1.05	0.643
Use new technologies (innovate)	1.16	1.20	1.38	0.156
Market risk				
Diversify sales channels	1.11	1.43	1.86	0.000
Do contract farming	1.00	1.20	1.33	0.048
Monitor market prices	1.15	1.35	1.90	0.000
Financial risk				
Grow highly profitable crops	1.16	1.55	1.76	0.001
Some of family member get non-farm income	2.06	2.10	2.18	0.873
Make budget plan	1.16	1.25	1.21	0.100
Avoid debt	2.56	2.24	2.10	0.151
Save money	1.54	1.84	1.88	0.058
Human and personal risk				
Have many children	1.59	1.55	1.35	0.059
Educate children	1.48	1.51	1.36	0.546

Notes: [a]Chi2 test. The mean values in the table refer to a Likert scale from 1 (not useful) to 5 (very useful).

Higher levels of commercialization are associated with higher levels of income from agriculture, but also with higher levels of farm household debt (Table 3.). The ratio of debt-to-income, which reflects the ability to pay back debt, is also higher for the commercialized farms. The table also shows a very substantial increase in the quantity of pesticide use and the in the share of pesticides in total variable input costs. We will analyze this in the following.

Table 3.5 Pesticide use, agricultural income, pesticide costs and household debt by level of agricultural commercialization for Thai upland agriculture, 2011

	Subsistence (n=80)	Semi-subsistence (n=80)	Commercial (n=80)	Correlation coefficient[a]	p-value[a]
Cash income from agriculture (USD/hh/year)	59	908	3,563	0.37	<0.01
Household debt (USD/hh)	299	432	1,020	0.26	<0.01
Quantity of pesticide use (kg/ha/year)	2.7	2.8	21.5	0.33	<0.01
Share of pesticide cost in total variable cost (%)	3.32	4.18	21.63	0.33	<0.01

Note: [a] Pairwise correlation (t-test); n=240.

3.4.3 Role of pesticides

Agricultural commercialization is associated with an exponential increase in pesticide use (Figure 3.2). Yet there is high level of variation in pesticide quantities, which was analyzed using the regression model.

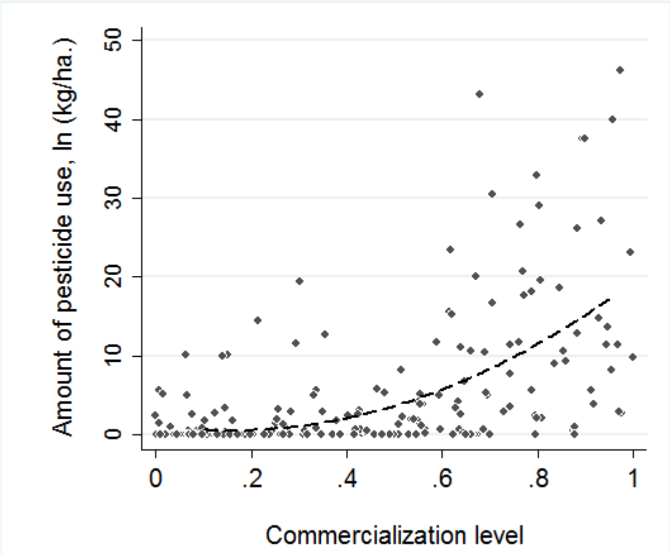

Figure 3.2: Amount of pesticide use by farm household plotted against the level of agricultural commercialization for Thai upland agriculture, 2011

The correlation between the error terms of the equations (1) and (2) was ρ=0.343, but it was not statistically significant (p>|z|=0.576). This suggests that sample selection bias is not an issue in our data. It is therefore not necessary to use a Heckman correction and a simple two-part model is sufficient. Multicollinearity was also not an issue in the regression equations as the variance inflation factor was below 3.5 for all independent variables.

The selection model had a goodness-of-fit of 0.31 (pseudo R2) and the model explaining the quantity of pesticide use had a goodness-of-fit of 0.32 (R2) as shown in Table 3.6. The marginal effects in the probit regression suggest that a switch from subsistence to commercial farming increases the probability of pesticide use by 38%; and the exposure to high pest intensity increases the probability of pesticide use by 23%. The level of perceived pest risk is not a significant determinant of whether or not pesticides are used. The coefficients also show that subsistence and perennial crops are negatively associated with pesticide use while a larger plot size is positively associated with pesticide use.

The right-hand side of the table shows factors that explain the level of pesticide use conditional on households having adopted pesticides on a particular crop. Interpreting the exponentiated coefficient, it can be said that an increase in agricultural commercialization proliferates the quantity of pesticide use by 105% for those households who apply pesticides. The results also show that pesticide risk perception is significantly ($p<0.05$) and positively associated with levels of pesticide use. This confirms that farmers apply greater quantities of pesticides as a strategy to reduce risk.

Contrary to the probit selection model, the OLS regression shows that farmers use a lower application rate if they cultivate larger plots. This is consistent with the idea that smaller plots are cultivated more intensively. The results also show that farmers apply fewer pesticides on subsistence crops than on cash crops. Contrary to the results of the selection equation, a high intensity of pest pressure is associated with a higher application of pesticides. Labor use per hectare has a positive and significant effect on the pesticide application rate, which makes sense because spraying is done manually.

Table 3.6: Determinants of pesticide adoption (left equation) and pesticide application rate (conditional on adoption; right equation) for Thai upland agriculture, 2011

Explanatory variables	Pesticide application (Probit selection equation)			Quantity of pesticide use, ln(kg/ha)		
	Coefficient	SE	p-value	Coefficient	SE	p-value
Hh size (persons, ln[a])	0.222	0.171	0.193	0.041	0.403	0.920
Age (years, ln[a])	-0.053	0.260	0.838	-0.110	0.557	0.843
Male farmer (=1)	0.084	0.145	0.562	-0.203	0.331	0.539
Experience (years, ln[a])	0.009	0.071	0.895	0.123	0.156	0.430
Education (high = 1)	-0.220	0.158	0.164	0.578	0.351	0.101
Subsistence crops (= 1)	-1.248	0.279	0.000	-1.784	0.517	0.001
Maize or grain legume (=1)	-0.470	0.311	0.131	0.545	0.521	0.297

Explanatory variables	Pesticide application (Probit selection equation)			Quantity of pesticide use, ln(kg/ha)		
	Coefficient	SE	p-value	Coefficient	SE	p-value
Perennial crops (=1)	-2.838	0.381	0.000	-0.415	1.081	0.701
Labor input (person-days/ha, ln[a])	-0.129	0.081	0.111	0.434	0.196	0.028
Plot size (ha, ln[a])	0.176	0.096	0.066	-0.417	0.227	0.067
Seed and seedling[b, c]	0.059	0.048	0.221	-0.029	0.074	0.692
Pest intensity (medium = 1)	0.274	0.190	0.150	0.060	0.539	0.912
Pest intensity (high = 1)	0.861	0.286	0.003	0.678	0.625	0.279
Perceived pest risk [d]	0.013	0.150	0.929	0.683	0.344	0.048
Commercialization index (0 to 1)	1.464	0.247	0.000	2.356	0.608	0.000
Constant term	0.806	1.216	0.508	-3.799	2.619	0.148
Observations (n)	503			284		
(Pseudo) R-squared	0.313			0.324		

Notes: [a] Logarithmic transformation was applied for variables with values > 0; [b] Cube root transformation was used for variables with zero values; [c] Variables for seed and seedlings transformed with cube root and combined; [d] Perceived pest risk = level of perceived pest risk (rated by farmers from 1 to 5) / level of perceived risk averaged over all risk sources (rated by farmers from 1 to 5).

It is clear from the above that agricultural commercialization is significantly associated with more widespread use and increasing quantities of pesticides. This trend does not necessarily mean higher levels of pesticide health risks, if farmers are using pesticides in a safe way. However, our results do not show that agricultural commercialization is accompanied by overall improvements in pesticide handling practices (Table 3.7). There was a significant negative correlation (p=0.001) between commercialization and the mixing of pesticides as commercialized farms not only used more pesticides but also combined different pesticide products into a single spray. However, there was a significant positive correlation (p=0.010) between agricultural commercialization and the observance of wind direction during spraying.

Table 3.7: Farmers' pesticide handling practices by level of commercialization in Thai upland agriculture, 2011 (in % of respondents using pesticides, n=159)

Pesticide handling	Subsistence	Semi-subsistence	Commercial	Average	p-value[a]
Follow instructions on the label	56	55	71	62	0.137
Observe wind direction when spraying	63	69	87	75	0.010
Always avoid contact with skin	81	84	90	86	0.192
Take shower immediately after spraying	93	86	81	86	0.251
Don't drink during or soon after spraying	88	88	78	84	0.274
Don't mix different pesticides	88	69	52	67	0.001

Note: [a] Chi2-test.

3.5 Discussion

Agriculture inherently is a risky business. This is especially true for developing countries where government support for agriculture is much weaker than in developed countries, with limited public social security guarantees to fall back onto if farm operations fail. Therefore it is important to better understand the sources of risk to which farm operations are exposed. The contribution of this paper is to show that not all farms are equally exposed to each source of risk and that there is much variation in farm-level decisions on how to manage risk. Most importantly, the study illustrated that risk sources and management are strongly associated with the level of agricultural commercialization.

For farmers who are predominantly subsistence-oriented, personal health is a major source of risk to farm performance, as are factors affecting crop production, such as water supply, natural disasters and crop pests and diseases. Predominantly market-oriented farmers are even more concerned with crop pests and diseases, but also with low crop prices and the ability to hire enough outside labor for their farm. This finding is important for social as well as agricultural policies and shows that a diversity of approaches towards mitigating risks is needed.

To manage risk in subsistence agriculture, farmers use crop diversification and intercropping, try to store enough rice for own consumption on the farm, try to employ household members outside agriculture, and avoid debt. Storing enough food on the farm and employing family members outside agriculture were also important for commercially-oriented farmers. Other key strategies for these farmers included diversification of sales channels, growing crops that are profitable, monitoring market prices, using pesticides and saving money – all of which were only of minor importance to subsistence-oriented farmers. Hence, there are marked differences in risk management by levels of commercialization. Agricultural policies thus need to strengthen farmers' risk management capacities in more than one way. For instance, Thai government agencies could focus on crop diversification in areas where farming is subsistence-oriented, while promoting market diversification in places where commercial farming dominates.

Another key finding of our study is the strong association between agricultural commercialization and the use of pesticides. The average subsistence farm used pesticides at 2.7 kg/ha, while the average commercial farms used 21.5 kg/ha (the global average is about

3.6 kg/ha according to Schreinemachers and Tipraqsa, (2012)). We showed that this increase has not been accompanied by a safer use of these chemicals, potentially increasing health risks. Amplified pesticide health risk tends to be neglected or underappreciated by farmers. As a case in point, such hazards were not mentioned as a major source of risk by the farmers during the focus group discussions that preceded the questionnaire survey. It is well-documented that farmers in lower income countries have limited awareness about the risk of pesticides and therefore do not use enough protection (Ngowi et al. 2007, Oluwole and Cheke 2009, Riwthong et al. 2015, Snelder, Masipiqueña, and de Snoo 2008).

The logical conclusion is that the promotion of cash crops such as vegetables, fruit and flowers needs to be accompanied by greater efforts to support alternative methods of pest management and to raise awareness about the negative health effects of pesticides. Our study also found that farmers growing high-value perennial crops, such as tea and coffee, use much less pesticides than seasonal cash crops (0.14 kg/ha for perennials as compared to 24.5 kg/ha for seasonal cash crops), while having a comparable level of income. However, the production of quality coffee and tea requires particular agro-ecological conditions, and is not equally suitable everywhere in the Thai uplands. Production is furthermore prone to supply gluts on global markets; hence farmers face increased market risks.

The findings of this study are relevant to other developing countries, because land use intensification and agricultural commercialization are global phenomena. More detailed policy-oriented studies would be useful to identify policy options that support farmers in their transition to market-oriented production. This study supports the notion that pathways to sustainable agriculture are location-specific. It highlights the consequent need to strengthen local capacities in agricultural research and extension to deal with the challenges rather than formulating a one size fits all policy for all farmers.

3.6 Conclusion

Thai upland agriculture is transforming from subsistence-based rice farming to the intensive production of high value cash crops. This process has a profound impact on farmers' risk exposure, perceptions of risk and their choice of risk management strategies. With commercialization, market prices and pests and diseases become the most prominent sources of risk to farm performance. Farmers respond by monitoring market prices, diversifying sales channels and applying large quantities of synthetic pesticides. Crop diversification, on the other hand, tends to become a less important risk management strategy for commercial farms, which might further stimulate pesticide use. Average levels of pesticide use on subsistence farms was 2.7 kg/ha, while commercial farms used 21.5 kg/ha. This rapid increase, under conditions of poor pesticide handling practices, exposes farmers to health risks, which they, however, do not fully recognize. There is a need for a diversified approach to agricultural research and extension that captures the different challenges and opportunities of farmers at varying levels of commercialization.

3.7 Acknowledgement

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4 Publication III

Can Public GAP Standards Reduce Agricultural Pesticide Use? The Case of Fruit and Vegetable Farming in Northern Thailand[3]

Pepijn Schreinemachers [a,b], Iven Schad [b,c], Prasnee Tipraqsa [b], Pakakrong M. Williams [b,c], Andreas Neef [d], Suthathip Riwthong [a,b], Walaya Sangchan [b,e], Christian Grovermann [a,b]

[a] Dept. of Land Use Economics in the Tropics and Subtropics, Universität Hohenheim, 70593 Stuttgart, Germany

[b] The Uplands Program, Faculty of Agriculture, Chiang Mai University, Chiang Mai 50200, Thailand

[c] Dept. of Agricultural Communication and Extension, Universität Hohenheim, 70593 Stuttgart, Germany

[d] Graduate School of Global Environmental Studies, Kyoto University, Yoshida-Honmachi, Sakyo-ku, Kyoto, 606-8501, Japan

[e] Biogeophysics Section, Institute of Soil Science and Land Evaluation, Universität Hohenheim, 70593 Stuttgart Germany

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4.1 Abstract

In response to the chronic overuse and misuse of pesticides in agriculture, governments in Southeast Asia have sought to improve food safety by introducing public standards of Good Agricultural Practices (GAP). Using quantitative farm-level data from an intensive horticultural production system in northern Thailand, we test if fruit and vegetable producers who follow the public GAP standard use fewer and less hazardous pesticides than producers who do not adhere to the standard. The results show that this is not the case. By drawing on qualitative data from expert interviews and an action research project with local litchi producers we explain the underlying reasons for the absence of significant differences. The qualitative evidence points at poor implementation of farm auditing related to a program expansion that was too rapid, at a lack of understanding among farmers about the logic of the control points in the standard, and at a lack of alternatives given to farmers to manage their pest problems. We argue that by focusing on the testing of farm produce for pesticide residues, the public GAP program is paying too much attention to the consequences rather than the root cause of the pesticide problem; it needs to balance this by making a greater effort to changing on-farm practices.

Keywords: Certification; food safety; food standards; Good Agricultural Practice; pesticide contamination; Southeast Asia.

4.2 Introduction

Chronic overuse and misuse of agricultural pesticides characterizes crop production in many parts of Southeast Asia as well as in China, exposing farmers, consumers and ecological systems to the risk of pesticides (Xu *et al.* 2008; Schreinemachers *et al.* 2011; Mazlan and Mumford 2005; Van Hoi *et al.* 2009; Lamers *et al.* 2011; Panuwet *et al.* 2008). To address this problem, several countries in the region have recently introduced public standards of Good Agricultural Practices (GAP) aimed at increasing the supply of safe and high quality food by promoting a more sustainable crop production that uses fewer pesticides.

Like many other countries undergoing rapid economic development, Thailand is experiencing a very sharp increase in pesticide use, such that per hectare use of active ingredients grew by 11 percent per annum from 1997 to 2010 (Praneetvatakul *et al.* 2011). The contamination of food with pesticides is a serious problem in Thailand, as has been highlighted by many scholars (*e.g.* Athisook *et al.* 2007, Hongsibsong *et al.* 2007, Posri *et al.* 2006, Tanabe *et al.* 1991). Recent instances of contamination of food exports with pesticide residues and the resulting restrictions imposed by importing countries point to the importance of the issue. At the same time the Thai government is trying to strengthen the country's position as a major exporter of fresh fruit and vegetables.

The first objective of this study is to test whether farm managers using a public GAP standard do indeed apply fewer synthetic pesticides than farmers who do not follow such a standard and whether they select pesticides that are on average less hazardous to human health. The second objective is to understand the reasons why public GAP standards do or do not contribute to reducing agricultural pesticide use. These two objectives are addressed by combining quantitative data from a random sample of farm managers in northern Thailand with qualitative data from interviews with Thai government authorities and an action research project which focuses on a group of farmers using the public GAP standard.

The wider empirical relevance of our study stems from the fact that although many countries in Southeast Asia, such as Indonesia, Malaysia, Philippines, Thailand and Vietnam, have recently introduced public GAP standards, published studies on the impact of these programs remain few in number. This study hence examines the public GAP standard in Thailand as a test case for other countries in the region. Studying pomelo (*Citrus maxima*) growers in the Northeast of Thailand, Amekawa (forthcoming) observed a broad participation of small-scale farmers in the program, while at the same time concluded that their compliance with control points was very poor. He attributed this to a lack of understanding among farmers of the GAP principles and a lack of economic rewards as certification did not give farmers access to higher value markets. Understanding the strengths and weaknesses of public GAP standards is important also because member countries of the Association of South East Asian Nations (ASEAN) are in the process of harmonizing their national public GAP standards in order to promote the mutual acceptance of standards across their borders, and thereby enhance trade opportunities.

Our study is of particular relevance as it helps to understand in how far public standards could be a viable alternative to private standards such as GlobalGAP—a standard developed by a consortium of European retailers, which has become the leading GAP standard globally (Humphrey 2006, Tallontire *et al.* 2011). Although some studies have shown that the use of private standards in developing countries increases farm incomes and lowers pesticide-related health costs (*e.g.* Okello and Swinton 2010), the majority of studies has been rather critical. Some studies have shown that having to comply with private standards acts as a non-tariff trade barrier, which limits the competitiveness of lower income countries (*e.g.* Chen *et al.* 2008; Wilson and Otsuki 2004, Henson and Jaffee 2008). Other studies have raised concerns about the democratic legitimacy of private standards (*e.g.* Busch 2009, Fuchs *et al.* 2011), while others have pointed at the high levels of investment that favor large-scale producers over smallholder farmers (*e.g.* DeLind and Howard 2008, Amekawa 2009). As smallholder farming is the dominant form of agriculture in Southeast Asia, public GAP certification, which is free of charge to farmers, might be a better alternative in the region. Yet we note that a direct comparison between public and private standards is beyond the scope of this study.

The next section begins with an account of the three types of data used in this study: Qualitative data from interviews with government officers, quantitative data from a farm household survey and qualitative data based on action research. The subsequent three sections will present the results of each type of data collected: First, describing the development of GAP standards in Thailand based on interviews with the government officers; second, comparing pest management practices and pesticide use between farmers who do and farmers who do not follow the public GAP guidelines based on quantitative data from structured farm surveys; and third, analyzing the underlying incentives for farmers to comply with the standard as well as potential constraints on compliance based on action research data. The final section reflects upon the results in light of previous studies and draws policy relevant conclusions with respect to improving public standards.

4.3 Methods and data

4.3.1 Combining qualitative with quantitative methods

To better understand the workings of the public GAP certification process in Thailand, we conducted expert interviews with senior government officials in charge of the program. We interviewed the head of the Q-GAP program in Bangkok to determine the objectives of the program, its organization, its size and current challenges. We also interviewed the regional program director in Chiang Mai to better understand how the GAP standard is implemented and how the auditing is being conducted. Lastly, we interviewed an officer at a government laboratory in Chiang Mai to learn how the testing for pesticide residues is being carried out.

Using a structured questionnaire, we further interviewed 295 farm managers in one watershed in northern Thailand who use an intensive horticultural production system, as introduced in the following subsection. The survey involved a twelve month recall period, from April 2009 to March 2010, and recorded detailed information on crop management practices, pesticide use, pesticide handling and household characteristics. It was found that 50 farm managers follow the public GAP guidelines on at least one of their plots, with five also following GlobalGAP. We dropped these latter five from our analysis, as our focus is on the public GAP. The survey data allowed us to quantify factual differences between the farmers and their cropping cycle, which is those using and those not using the public GAP standard. In order to explain these differences and to obtain a more thorough understanding of how public GAP standards change farming practices, we complemented the survey data with qualitative data collected in the same study area, but independently from the survey. Both the quantitative and qualitative data were collected as part of a larger research program with more broadly defined objectives.

The qualitative part of the project employed an action research method in which two researchers supported by two assistants linked a group of about 100 farm managers growing litchis directly to high value markets, and then observed the opportunities and constraints that this situation brought about. Litchi was selected because it is the most important crop by area in the study site and because several authors of this study have been involved in an action-research project on litchi marketing networks in the area, providing direct and unique insights into the reality of the public certification process (see Tremblay and Neef 2009). The high value markets consisted of a British hypermarket chain that aims to buy directly from growers and requires public GAP certification, and of exporters to the European Union, which require GlobalGAP certification. As the emphasis of this paper is on public certification, we will report only on the first marketing channel. The role of the researchers was to facilitate the contact between the group of farmers, the government agencies implementing the public GAP scheme and the agent for the hypermarket chain. Through this role, the researchers were able to collect data from participant observations during farmer meetings. Additional data were gathered from individual interviews that focused on farmers' perceptions of the standard as well as the motivations and constraints they experience in terms of standard compliance. All interviews were recorded and transcribed, and observational data was kept in a standardized form which was analyzed using content analysis, in line with Mayring (2003).

The combination of three data collection methods allows us to look at the public GAP program from different angles. While the quantitative part makes it possible to statistically test for differences in pesticide use, the action-research approach is more useful for explaining possible differences, while the expert interviews help seeing the case study in the wider context of program objectives and their implementation.

4.3.2 Study area

We selected the Mae Sa watershed in Chiang Mai Province in the north of Thailand as the study area for farm-level data collection (Figure 4.1). This watershed is characterized as having a good level of access to input and output markets, and contains intensive upland agriculture. The combination of high levels of pesticide use and a relatively large number of farmers in the public GAP program made it a suitable area to use for the study. The main crops grown in the area are litchis, which are grown on the slopes, and bell peppers, which are grown in greenhouses in the watershed's central valley. Other crops grown include tomatoes and cucumbers—both grown in greenhouses, and chayote (*Sechium edule*), cabbages, lettuce, chrysanthemum and roses.

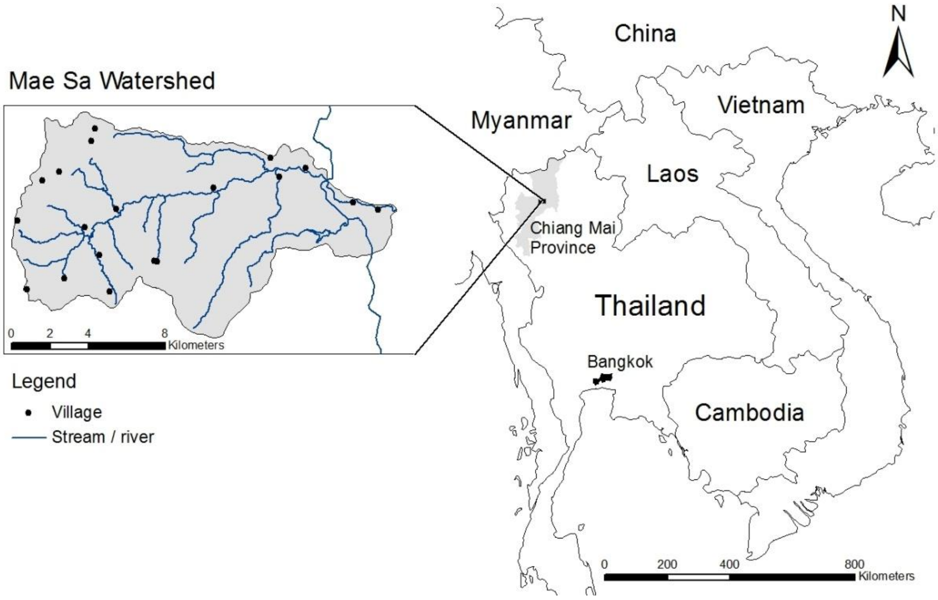

Figure 4.1: Map of the study area location in Thailand

The intensification of agriculture has been accompanied by heightened pest pressure and the development of pest resistance on some crops. For example, farmers growing bell peppers, one of the most profitable crops in the area, struggle to control thrips, viruses and powdery mildew, while fruit borer, shield bugs and downy mildew are major pests with litchis. Added to this, cabbages are frequently infested by webworms, beet armyworms, common cutworms, cabbage loopers and diamondback moths.

Farmers try to protect their market crops from these pests by resorting to a vast array of chemical fungicides and insecticides. Schreinemachers *et al.* (2011) estimated that farmers in the watershed use an average of 13 kg/ha of active ingredients per year, which is high when compared to the average application rate of about 3.6 kg/ha per year for Thailand as a whole (Praneetvatakul *et al.* 2011). The main insecticides used are abamectin and cypermethrin, while mancozeb is the most commonly used fungicide. Farmers prefer to use toxic substances that can quickly eliminate pests.

4.3.3 The development of GAP standards in Thailand

The Thai government declared 2004 to be the 'Year of Food Safety', in order to increase consumer confidence in the Thai food sector through the improvement of food quality and food safety. One measure introduced was a public standard for good agricultural practices, called Q-GAP (with the Q standing for quality). As with other public GAP standards in Southeast

Asia—IndoGAP in Indonesia, VietGAP in Vietnam, PhilGAP in the Philippines and SALM in Malaysia, the Thai standard is fully managed by the government, from standards setting to training, auditing and the issuing of certificates (Sardsud 2007). The National Bureau of Agricultural Commodity and Food Standards (ACFS), established in 2002, is the accreditation body that sets the standards (following ISO/IEC guide 65) and assesses the competence of those organizations doing the auditing and certification (*ibid*.). Table 4.1 gives a chronology of these and other institutional changes linked to food standards in Thailand.

The Q-GAP program has expanded rapidly since its introduction in 2004 and is currently the largest GAP program in Southeast Asia. While the standard is set by the ACFS, the program implementation is managed by two departments of the Ministry of Agriculture and Cooperatives (MoAC): the Department of Agricultural Extension (DoAE), which has overall responsibility for the program, and the Department of Agriculture (DoA), which is in charge of the farm auditing and issuance of GAP certificates. Through the expert interviews, we learned that the MoAC has set clear targets for expanding the number of producers operating within the program and that certification, originally available for 29 crops, has since expanded to cover 128 fresh fruits and vegetables.

Table 4.1: Main institutional changes related to food standards in Thailand

1988	First national GAP scheme introduced
1995	Organic Agriculture Certification Thailand (ACT) established
2000	Ministry of Agriculture and Cooperatives defines organic crop production standards
2002	Establishment of the National Bureau of Agricultural Commodity and Food Standards (ACFS)
2004	Government declares Food Safety Year Start of Q-GAP program (managed by MoAC)
2005	Start of ThaiGAP (private standard)[1]
2006	ASEAN countries agree on AseanGAP standard
2008	Implementation of Globally Harmonized System of Classification and Labelling of Chemicals (GHS), and the Safety Data Sheet (SDS)
2010	ThaiGAP standard was harmonized with GlobalGAP
2012	Q-GAP standard is planned to be harmonized with AseanGAP

Notes: [1] ThaiGAP is a private standard mostly aimed at the EU market. The standard, which started in 2005, is set by the Thai Chamber of Commerce & Board of Trade of Thailand and the auditing is done by a private company (NSF-CMi). Less than ten farms received the ThaiGAP certificate in 2011.

Certificates are issued free of charge to farmers and are valid for one year for seasonal crops and two years for perennial crops. From official documents we found that in 2010, certificates were issued to about 212,000 farmers covering a crop area of 225,000 hectares. Although this area seems large, it represents only 3.7% of the country's farm households and 1.2% of the area of arable and permanent cropland.

The auditing of farms under the Q-GAP program has strained the handling capacity of the DoA, which is the certifying body for the program. For instance, in the northern region there are about 120 DoA auditors but about 140,000 registered farmers, suggesting that each auditor is responsible for processing over 1,000 farmers a year. According to the same DoA officer, there is current nationwide capacity to audit about 10,000 farms a year.

In recent years, auditing has been increasingly carried out by local contractors in a system designed to ensure the expansion of the Q-GAP program. The DoAE provides training in GAP auditing to government officers through a four-day training course, with a refresher course after three to six months. These trained government auditors in turn train a large number of other people who are hired on a temporary basis to conduct GAP audits and are paid per audit. According to a DoA officer in Chiang Mai, about 70 percent of the auditing is currently done by contractors. Privatization of the entire monitoring system is being considered, but a decision on this has been delayed as the costs are unclear. Government laboratories, together with a few accredited private laboratories, do all the residue testing but have been overloaded with samples.

The Q-GAP guidelines are based on eight principles that cover a wide range of farm management issues, such as site selection and management, agrochemical use and water supplies (DoA, 2009). The clear emphasis is, however, on food safety, and more narrowly on the contamination of farm produce with pesticide residues. The Q-GAP auditing reflects this, as the main effort goes into the testing of harvested products for pesticide residues. While Q-GAP guidelines emphasize farm practices that are pre-farm gate, auditing focuses on the final stages of production. The standard requires farmers to record their use of agrochemicals and to use them in a proper way, but farmers are likely to receive a certificate as long as they observe the prescribed pre-harvest spraying interval (that is, a number of days before the harvest during which time farmers are not allowed to spray pesticides). In addition, we observed that official documents recognize Integrated Pest Management (IPM) to be an integral part of Q-GAP, yet guidelines mostly tell farmers how to apply certain chemicals, with little or no mention of alternatives.

The emphasis on pesticide contamination shows the importance of this issue for the Thai food sector. Local media regularly report about high concentrations of chemicals in the blood samples of farmers and consumers, and in 2010, EU customs officials detected pesticide residues on Thai vegetables which exceeded the maximum residue limits (MRLs) by 55 times. In early 2011, Thailand voluntarily suspended exports of sixteen types of vegetables to the EU, after the EU threatened to ban imports of Thai vegetables due to pest and pesticide residues having been found. Thereafter, random sampling in Thailand was increased to cover 50% of vegetable shipments to the EU for a period of six months.

The bulk of Thailand’s fruit and vegetable exports are shipped to other countries in Southeast Asia, with only a relatively small volume shipped to the EU and Japan (Sardsud 2007). Trade in agricultural products within Southeast Asia and with China is likely to continue to increase as the region moves towards a single market in 2015 - the ASEAN Economic Community. To reduce barriers in agricultural trade, ASEAN countries in 2006 agreed to harmonize their national public GAP standards to form a new AseanGAP standard by 2012. The AseanGAP standard is more comprehensive than the Q-GAP standard, as it includes five additional areas including planting materials, soil and substrates, biodiversity, worker welfare and reviewing practices. Unlike the Q-GAP standard, AseanGAP will require using IPM whenever possible (ASEAN, 2008; DoA, 2009).

4.3.4 Comparing the intensity of pesticide use between Q-GAP and non-GAP farmers

Table 4.2 compares pest management practices between farmers from the study area who do and do not follow the Q-GAP guidelines. As can be seen from the table, nearly all farmers use synthetic pesticides, with just four out of 290 farmers only using non-synthetic methods of pest control, and with 84% of the Q-GAP farmers and 77% of the other farmers relying solely on synthetic pesticides to control crop pests (the difference not being significant). Only 14% of the Q-GAP farmers apply non-synthetic methods such as insect traps, bio-pesticides or mechanical control methods.

In terms of pesticide handling, no significant differences were found between farmers who do and do not follow the Q-GAP guidelines. Of those Q-GAP farmers who use synthetic pesticides, 41% spray at regular intervals irrespective of the level of pest infestation. The majority of farmers (78% of the Q-GAP group) determine the dosage by following product labels. When asked an open question as to what climate factors they take into account when spraying pesticides, 88% of the Q-GAP respondents indicated that temperature or radiation (sunshine) are important, but only 27% mentioned wind, wind speed or wind direction. Regarding protective clothing, we found that the majority of farmers cover their mouths, arms and legs during spraying, but much fewer respondents said that they take a shower or change their clothes afterwards. These findings suggest that the majority of farmers in both groups make efforts to reduce the direct risk of pesticide spraying on their health, yet depend heavily on synthetic pesticides in their pest control practices.

Table 4.2: Pest control and pesticide handling by the non-GAP farmers as compared to the Q-GAP farmers, as a percentage of all farmers in the group

Pesticide Handling Aspect	Non-GAP	Q-GAP	t-test[3]
Methods of pest control[1]			
Use synthetic pesticides	96	98	NS
Rely solely on synthetic pesticides to control pests	77	84	NS
Use non-synthetic methods to control pests	21	14	NS
Pesticide handling[2]			
Use pesticides in a preventive way (regular spraying)	41	45	NS
Follow product labelling to decide on the dosage to use	80	78	NS
Take temperature or radiation into account when spraying	86	88	NS
Take wind speed and/or direction into account when spraying	24	27	NS
Cover mouth when spraying	76	81	NS
Cover arms and legs when spraying	86	95	NS
Take a shower and wash clothes after spraying	47	60	NS
Number of farm managers interviewed	245	45	

Notes: 1 Percentage of all farmers in the group. 2 Percentage of farmers using synthetic pesticides. 3 Two-tailed two-sample mean comparison test with unequal variances. *** Significant at 0.01, ** significant at 0.05, * significant at 0.10, NS not significant at 0.10.

We further compared pesticide use between the Q-GAP and non-GAP farmers at the crop level, because certificates are assigned not to farmers but to plot-crop combinations. We had a relatively large number of crop-level observations for bell peppers, cabbages and lettuce, but much fewer observations for other crops. Only for those crops with a minimum of five observations did we carry out a t-test to assess the differences in mean values.

The results in Table 4.3 confirm those seen in Table 4.2 that the majority of farmers rely solely on synthetic pesticides for their pest management. The exception is chayote, which is not significantly affected by pests. In terms of the average quantity of pesticides applied, Q-GAP farmers use smaller quantities on average for all crops mentioned in the table, but as variations in pesticide use are large, these differences are not significant ($p>0.10$) for any crop. We further compared the share of pesticides used that are classified as extremely hazardous (WHO class Ia), highly hazardous (Ib) and moderately hazardous (II) in terms of the total quantity of active ingredients, as the use of these pesticides should be minimized under the Q-GAP standard. Table 4.3 shows that for bell peppers ($p<0.05$), the share of these hazardous chemicals used as a proportion of the total pesticide quantity applied is lower in fields using Q-GAP than in fields not using GAP. However, for lettuce ($p<0.01$) and Chinese cabbage ($p<0.10$) we find the opposite: the share of hazardous chemicals in total pesticide use is greater for Q-GAP. For the four other crops tested we did not find a significant difference.

Table 4.3 Pesticide use by crop—with and without Q-GAP standards applied

Crop	Non-GAP				Q-GAP			
	n	Use Pesticides Only (%)	Active Ingredients (kg/ha) (SD)	WHO 1a, 1b, II (%)[1]	n	Use Pesticides Only (%)	Active Ingredients (kg/ha) (SD)	WHO 1a, 1b, II (%)[1]
Bell peppers	157	79	43.02 (126.04)	39	41	72	23.69 (28.7) NS	27 **
Cabbage (white/pointed)	131	87	4.60 (22.83)	62	21	89	1.20 (1.33) NS	59 NS
Carrots/ potatoes	33	85	4.78 (11.35)	16	6	78	0.56 (0.53) NS	25 NS
Chayote	86	20	1.32 (6.54)	66	4	0	0.00 (0) †	0 †
Chinese cabbage	123	87	4.31 (8.82)	38	21	98	1.53 (2.18) NS	55 *
Lettuce (various)	50	72	1.88 (3.27)	26	22	95	1.29 (2.29) NS	78 ***
Litchis	121	43	4.50 (42.05)	33	9	89	3.38 (5.93) NS	17 NS
Tomatoes	18	78	21.02 (28.3)	32	10	100	20.61 (18.01) NS	30 NS

Notes: n is the number of crop cycles observed. [1] Share of active ingredients of WHO hazard classes Ia, Ib and II in the total quantity of active ingredients used. Two-tailed two-sample mean comparison test with unequal variances. *** Significant at 0.01, ** significant at 0.05, * significant at 0.10, NS not significant at 0.10. † No t-test was performed for chayote ($n<5$).

4.3.5 Farm level constraints and incentives regarding GAP compliance

Having shown that Q-GAP certification has no significant effect on pesticide handling or the amount of pesticides used and only significantly reduces the use of highly hazardous pesticides for one out of eight crops, we now turn to the qualitative data to understand the underlying reasons.

The Q-GAP guidelines for litchi are extensive, with nearly a hundred control points laid down over three field manuals. Control points are organized in four areas as listed in Table 4.4. For the main control points, we compared the required practices with the actual practices of the farmers, and observed how each control point is inspected by the Q-GAP auditor.

Table 4.4: Prescribed and actual practices/monitoring in the Q-GAP certification of litchi

	Control Points[1]	Actual Practice	Q-GAP Audit
A	*Orchard management*		
-	A statement of plot size and location must be submitted	Farmers record the information on the application form	Random checks with land registration office
-	Sources of irrigation water (wells, lakes, rivers, etc.) and location must be identified	Farmers record the information on the application form	On-spot inspections
-	Potentially hazardous factors with regard to water quality must be identified	Only stated if really obvious and might be detected during the field audit	Auditor takes a few randomized water samples
-	Orchard should look neat and clean	Farmers clean- up their orchard before the audit, but most do not pay attention to it afterwards.	Auditor has a one-time, quick look at the orchard
B	*Equipment storage and management*		
-	Tools must be stored in a sheltered location	Tools are stored in makeshift huts in the orchard or in wooden boxes	Auditor checks the storage
-	Broken or unused equipment must be disposed of outside the orchard	Hardly implemented	Not monitored
C	*Handling and use of chemicals*		
-	Nationally banned chemicals may not be used	Most farmers comply; however, one farmer used banned chemicals	Random residue analysis - seldom more than once a year
-	All chemicals must be stored in a secure and protected place.	As required	Checked by auditor
-	Recommendations for handling are not binding	No changes recorded; conventional practices broadly maintained, in parts strongly deviating from recommendations	Not monitored
-	Chemical leftovers and containers must be removed from the plot and disposed of appropriately	No major changes recorded; sloppy disposal - the same as carried out previously	Not monitored
-	Spraying is only allowed during predefined periods. Application must stop 15 days before harvest.	No significant change to conventional practices	Not monitored except for random residue analysis
D	*Record keeping*		
-	Each working step must be recorded in a standardized field diary	As required	Field diary checked during audit. Missing information may cause exclusion from Q-GAP
-	Chemical names, amounts and the time of spraying must be recorded	Mostly done as required	One-time check during audit

Note: [1] Based on the field manuals.

According to the Q-GAP guidelines, farmers registered in the Q-GAP program should receive technical assistance from the DoAE about IPM, integrated crop management and organic compost making. In reality, no technical assistance was provided to any of the farmers. Although farmers are supposed to reduce their synthetic pesticide use, there was hence no training provided and also the field manuals gave no information on how to replace synthetic pesticides with alternative methods of pest control.

According to the Q-GAP guidelines, first-time certification should involve three audits, to take place without advance notification in terms of the date and time. In reality, the farmers had been visited only once and were informed about the date and time of the audit in advance. Auditing of the litchi orchards was done by relatively young and inexperienced government auditors who spent as little as five minutes with each farmer and largely avoided walking into the orchard because of the limited time available. Perhaps because of the large age difference between the auditor and the farmers, critical remarks towards the farmers were mostly avoided during the audit, reflecting a society in which hierarchy and respect for seniors are very important. The friendly style of the auditing suggested that farmers were unlikely to fail.

The farmers said that categories A (orchard management) and B (equipment storage and management) of the standard are relatively unproblematic in terms of implementation. Submitting basic plot information and making the orchard look “neat and clean” before the auditor’s visit is perceived as an easy task. Farmers said that category C (handling and use of chemicals) is a bit more difficult, as they need to find out what chemicals can be used, place them in a storage and change their chemical handling processes as well as the timing of pesticide applications. However, the required changes are minor as compared to conventional practices, and are therefore feasible to adopt. Moreover, these changes do not require additional labor or other costs, and the spraying schedule defined in the field manual is largely the same as what the farmers were used to before, except for the prescribed pre-harvest interval, as farmers used to spray right up until harvesting. While all the farmers stated during the interviews that they comply with the pre-harvest intervals, field observations showed that several farmers do spray right up to the harvest. However, the farmers know that only a few fruit samples will be collected for residue analysis and that the risk of getting caught by the audit is therefore low, whereas the risk of losing a part of the harvest due to pests is high. The most difficult standard to follow is record keeping (category D), because farmers are unfamiliar with this and a few of the older farmers we spoke to possess a low level of literacy.

In most cases farmers do not understand the underlying rationale for these guidelines and therefore do not feel intrinsically motivated to follow them, but rather perceive the guidelines as requirements that need to be fulfilled explicitly and exclusively for the audit. As a result, most guidelines are only implemented immediately prior to the audit. Since auditing involves a one-time visit and very few samples for pesticide residue analysis, the incentive for long-term compliance is low. In addition, there is a lot of leeway allowing farmers to bypass certain guidelines such as those about the handling and appropriate disposal of pesticide containers and leftovers. Not long after the audit, we observed that some of the farmers returned to their conventional practice of randomly disposing leftover pesticides and empty containers in their orchards.

Despite the lack of real changes in pest management practices, the farmers acknowledged that they have become more concerned about the impacts of pesticide use, mostly on human health, as an indirect effect of Q-GAP introduction. One farmer mentioned in the interview: “Since some chemicals had been banned following Q-GAP, we had to go around and look for alternatives […] Therefore, we had a chance to get into contact with new pesticides suppliers who provided us with additional information on how to handle them safely and prevent them from affecting our health.” Farmers also mentioned that they have developed a greater awareness about those substances that are legally banned, and learned the reasons for their being banned.

At an information sharing meeting on GlobalGAP organized by a lecturer from a local university, the participants agreed that Q-GAP has given them a basic understanding that quality goes beyond mere product appearance—such as the color and size of the fruit, and that they would feel motivated to adopt the stricter GlobalGAP standard in the future if there were a market for certified litchis.

4.4 Discussion and conclusion

It is impossible to generalize our findings from studying a small group of farmers following the Q-GAP standard to the entire public GAP program. We interviewed less than 0.1% of farmers in northern Thailand and less than 0.1% of Q-GAP certified farmers in Thailand. Levels of pesticide use in our study area are also much above the Thai average, and therefore not representative of Thai agriculture. Yet our findings are strikingly similar to those of Amekawa (forthcoming) for pomelo growers in the Northeast of Thailand, who also found a lack of standard compliance due to a low motivation of farmers and a lack of understanding of control points among farmers. The information we obtained from the expert interviews also broadly confirms our field observations, which suggests that our results are valid.

The main strength of public GAP certification in Thailand is that it comes at no charge to the farmers, which lowers the hurdle for smallholders to participate as is demonstrated by the large overall number of farmers that are Q-GAP certified. Our study gives evidence, however, that the quality of certification is poor as program resources for training and auditing are spread too sparingly over the large group of participating farmers. The Q-GAP standard, as implemented at present, is therefore no real alternative for more stringent private standards to guarantee food safety. We note that data collected in the Q-GAP program through standardized field diaries, residue testing and farm audits are not currently used to manage the program. However, these data can provide valuable feedback and could, for instance, be used to optimize training and auditing efforts.

Our study shows that in the case of litchis, of the long list of control points set by the standards, maximum residue limits are perhaps the only control point systematically audited, although statistically the auditing frequency is only once every ten years. Yet during the interviews held with the farmers, they mentioned that even when spraying during the pre-harvest intervals, they believe that simply rinsing the produce allows them to stay within MRLs, which points at the lack of intrinsic motivation among farmers to change their pest management practices. However, our study showed that farmers were interested to learn about the risk of pesticides and that they also had a reasonable level of knowledge about how to reduce their own exposure to pesticide risk. Creating more awareness about the risk of pesticide, including the risk of pesticide residues to consumers and the environment, would improve farmers' understanding of control points and give them a stronger motivation to comply with these.

Another problem with the focus on pesticide residue testing is that it merely gives a snapshot of the final stages of the farm production process and does not adequately address the root causes of the pesticide problem. The Q-GAP program does not provide farmers with suitable alternatives to their current practices. In line with this, our study shows that farmers almost entirely depend on synthetic pest control, with non-synthetic alternatives rarely being used. Although the concept of IPM frequently appears in connection with Q-GAP in policy documents, farmers did not receive IPM training, nor did the Q-GAP field manuals make concrete suggestions for farmers' voluntary use of IPM techniques. Instead, they only noted how to improve spraying practices.

To more effectively reduce pesticide use, the Q-GAP program therefore needs to pay more attention to on-farm practices and ensure that farmers have suitable alternatives to synthetic pesticides when managing pests. Q-GAP auditors, having received a two-day training only and spending as little as five minutes auditing a field in practice, are not qualified for this and it is also not part of their auditing task. The DoAE needs to complement the Q-GAP program by providing standardized IPM methods for each crop and providing training to farmers on how to use these. It is illustrative that none of the litchi farmers participating in the Q-GAP program had received technical assistance or training from the DoAE.

The findings of our study raise the question as to whether the Q-GAP program in its present form is the best policy response to the pesticide problem in the Thai agricultural sector. The strong focus on food safety—narrowly defined as the monitoring of pesticide residues on fruits and vegetables—suggests that the government is more concerned with limiting the consequences of pesticide overuse and misuse, presumably to avoid negative repercussions on food export opportunities, rather than addressing the root cause of the problem. With 41 percent of the Thai labor force working in agriculture, and hence having direct contact with pesticides, the task is indeed daunting. Yet re-orienting the focus of the Q-GAP program to give greater attention to changing on-farm practices would benefit farmers and consumers alike.

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5 Publication IV

'Smart' policies to reduce pesticide use and avoid income trade-offs: An agent-based model applied to Thai agriculture[4]

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

[4] Paper submitted to Ecological Economics on 30 June 2015.

5.1 Abstract

Agricultural pesticide use is rapidly increasing in many developing countries, often stimulated by policies that directly or indirectly promote their use. Policy makers need better evidence of how changes in pesticide regulation would affect pesticide reduction as well as farm incomes but there are only few modeling tools that can provide such information. The present study uses an agent-based modeling approach built on the software MPMAS with the objective to assess *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 pesticide use. Simulation results suggest that a pesticide tax alone has little effect on pesticide use. However, if a pesticide tax is combined with the promotion of integrated pest management methods then this could lead to a very substantial reduction in pesticide use. Using the right combination of measures, it is possible to reduce pesticide use by up to 34% over current levels without adverse effects on farm income.

Keywords: Multi-agent systems, ex-ante assessment, pesticide policy, integrated pest management, developing countries

5.2 Introduction

The intensification of crop production in many low and middle income countries is accompanied by a rapid increase in agricultural pesticide use, often leading to overuse and misuse (Ecobichon, 2001; Schreinemachers and Tipraqsa, 2012). This not only harms human health, but also threatens the resilience and long-term productivity of agro-ecosystems as beneficial organisms disappear and pests become resistant (Cowan and Gunby, 1996). Despite high internal as well as external costs, farmers continue using pesticides due to the perceived high withdrawal costs (Wilson and Tisdell, 2001). Developing countries often do not adequately address pesticide risks, 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 that give farmers direct or indirect incentives to use more pesticides. Uncertainty over the impacts of alternative policies is a major obstacle to policy change.

There is thus a need to support policy-making with sound data about the potential economic and environmental 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. First, 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 impacts. Second, 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 not lead to income losses as long as integrated farming techniques were widely adopted. Third, Skevas et al. (2012) conducted an econometric study of the effects of pesticide use reduction policies on Dutch cash crop producers. Their study revealed that even extremely high taxes and penalties result in only small reductions in pesticide use. The authors also pointed out 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 agricultural pesticides use has increased dramatically – exposing ecosystems and millions of farmers and consumers to the risk of pesticides.

This paper addresses the lack of sound evidence on which to base policy recommendations by developing a modeling tool to *ex-ante* assess a range of pesticide reduction strategies. It employs a bio-economic simulation model with several novel aspects as compared to the above-mentioned studies: (a) the study combines a simulation model with econometrically estimated production functions with damage control specifications for pesticides; (b) the study simulates the diffusion of integrated pest management (IPM) as based on the theory of innovation diffusion (Rogers, 2003); and (c) the study uses an agent-based framework rather than a representative farm model to avoid aggregation bias, which might occur in using a representative farm- or sector-level model.

The model was built using the agent-based simulation software MPMAS, 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). We apply it to agricultural production systems in the mountainous north of Thailand, which have experienced rapid land use intensification through the adoption of high-value cash crops (Riwthong et al., 2015). The extent and adverse effects of heavy pesticide use in this area are increasingly becoming apparent (Praneetvatakul et al., 2013; Sangchan et al., 2013; Schreinemachers et al., 2011).

The paper starts by giving the relevant background information on the study area, which is important to understand the choice of model features described in the methods section. The latter focuses on how the substitution between different pesticides was captured in the model and how the model simulated the diffusion of integrated pest management (IPM) under alternative pesticide policy options. 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.

5.3 Materials

5.3.1 Study area and data collection

This study was part of the Uplands Program, a long-term research program on sustainable land use and rural livelihoods in mountainous regions of Southeast Asia (Heidhues and Pape, 2007). One of the research sites was the Mae Sa watershed in northern Thailand representing a highly intensive horticultural production system and thus being well suited for pesticide-related policy analysis. The watershed covers an area of 140 km^2, with altitudes ranging from 400 m to 1,600 m above sea level (masl). Farmers have been able to increase their incomes from agriculture by adopting high value crops, which production is however accompanied by heightened pest pressure and heavy pesticide use (Schreinemachers et al., 2011). The build-up of pest resistance leads farmers to increase pesticide use over time (Praneetvatakul et al., 2013; Schreinemachers et al., 2011; Xu et al., 2008) .

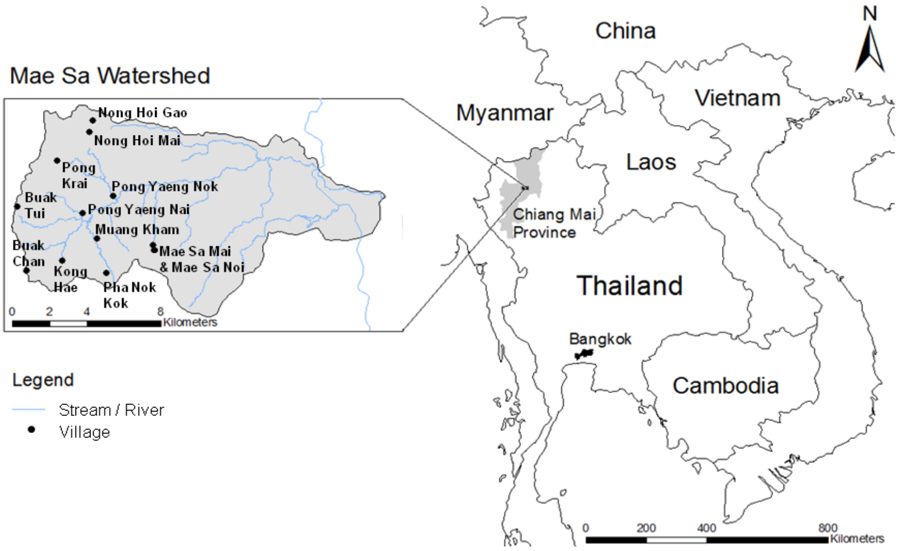

Figure 5.1: Location of the study area

Farm-level data were collected using a structured questionnaire survey in all twelve villages of the watershed where agriculture is practiced. From each village, 20% of the farm households were randomly selected, which gave a sample of 295 households. The questionnaire used a one-year recall period, from April 2009 to March 2010. Data were collected about household characteristics, land-use and cultivation practices. For each plot and each crop, respondents were asked about output and inputs used and the encountered pest problems and their control. Respondents enumerated for all pesticide products used and provided the common name for each product, the number of sprays, the quantity of undiluted chemicals as well as the price and volume per container. Data on the active ingredients contained in the pesticide product were then collected from traders, shops and producers.

5.3.2 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. This results in a diverse agricultural land use, 58 crops being recorded in the survey. 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 planting 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.

The left diagram in Figure 5.2 describes the relationship between profitability and pesticide use for each category, which shows that farmers tend to use greater quantities of pesticides on crops that give a higher profit. The risk of losing valuable crops to pests triggers preventive as well as curative pesticide applications, which are high for greenhouse vegetables and flowers in particular. Many farmers are indebted and so especially afraid of pest damage. There are clear signs of growing pest resistance and resurgence problems as farmers mentioned that certain pesticide products are no longer effective.

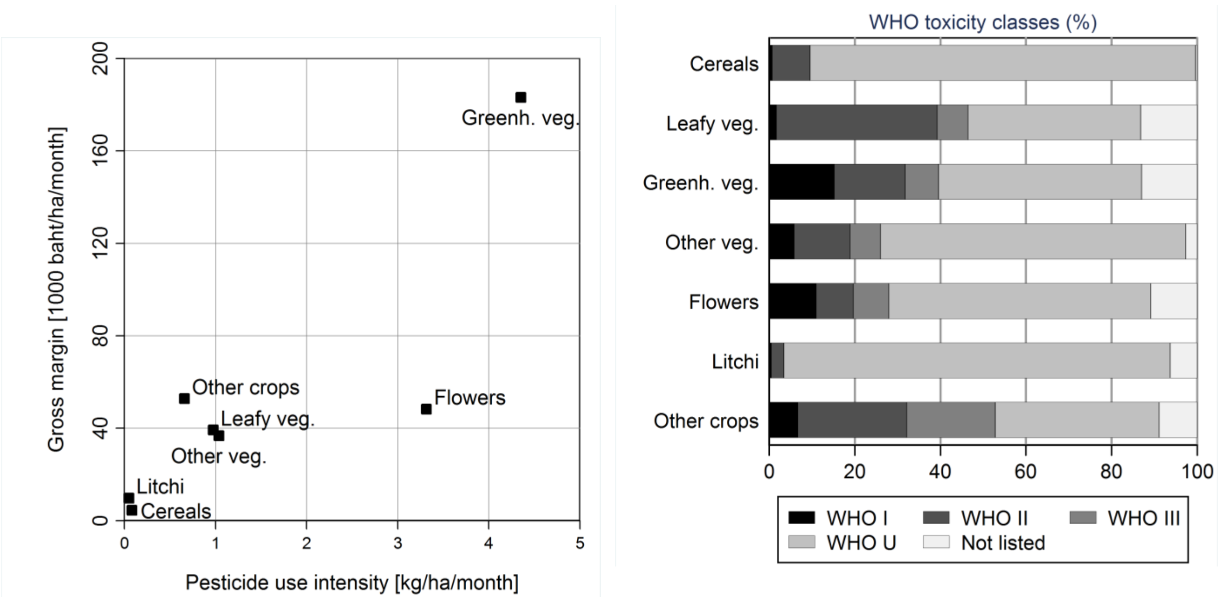

Figure 5.2: Pesticide use vs. profitability (left diagram) and relative toxicity of pesticides applied (right diagram) per category of crops for the Mae Sa watershed, Thailand 2009/10

Insecticides and fungicides are the most commonly applied pesticides in the study area, apart from cereals and fruit trees, in which relatively more herbicides are applied. The main insecticides used are Abamectin and Cypermethrin, while Mancozeb is the most common fungicide. Farmers resort to highly toxic substances to quickly eliminate pests. The widely used WHO toxicity classification allows differentiating pesticides by their potential to do harm to humans (WHO, 2009), which also gives an indication of the risks to other organisms. Pesticides ranked as WHO I (a & b) are extremely hazardous, those ranked as WHO II are considered moderately toxic, WHO III means slightly toxic and WHO U is used for pesticides that are unlikely to cause harm under normal use. The right diagram in Figure 5.2 shows that the relative share of WHO I pesticide is high in greenhouse vegetables and flowers, while relatively much WHO II pesticides are applied on leafy vegetables.

Table 5.1 shows that land holdings in the study area are on average small, ranging from 0.7 ha in the central part of the watershed to 2 ha and above in the other parts of watershed. A high population density and small farm sizes in the central part come along with more intensive production including greenhouses and flower cultivation. In the surrounding parts, many farmers are advised by the Royal Project and certification with the public standard for good agricultural practices (GAP) is more widespread. The majority of the farmers there need to grow their crops on steep slopes and litchi orchards are an important land use type.

Table 5.1: 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/m/hh)	51.8	50.1	81.6	75.9	94.4
Off-farm labor use (md/m/hh)	21.3	15.6	22.3	11.6	18.2
Hired labor (md/m/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 more than 1 crop (%)	56	69	78	62	100
Royal Project member (%)	9	14	58	33	64

Notes: n=295. hh = household, md = mandays, m = months, y. = years

5.3.3 Integrated pest management

IPM here refers to an agro-ecological approach to pest management that incorporates factors such as the preservation of healthy soils, diverse cropping patterns and beneficial insects. Farmers need profound knowledge of the agro-ecosystem and regularly monitor their crops. Cultural, biological, mechanical methods and pesticides are combined in a way that guarantees the long term environmental and economic viability of the farming system, avoiding harm to farmers’ and consumers’ health. In reality, pest control practices are often labeled as IPM, even if only a few of the above aspects are observed.

In the uplands of northern Thailand the practice of IPM has remained rather insignificant. Lack of data on IPM practices in the Mae Sa watershed, required us to use data from another location. The Doi Angkhang IPM program, managed by the Royal Project, exemplifies the agro-ecological intensification of vegetable production through IPM. There, the Royal Project has supported farmers to practice IPM in leafy vegetables for several years. Farmers combine rotations to break the pest cycle and soil conservation with high levels of agro-biodiversity, including many natural predators, traps and well-monitored biopesticide applications. The climate and terrain at Doi Angkhang, located at 1400 masl, is similar to that of the Mae Sa watershed. The land-use and the pest complex are also comparable.

One third (n=34) of the IPM farmers in Doi Angkhang were interviewed using a structured questionnaire to record their input use, yield and farm gate selling prices. Since production is very homogenous among farmers and strictly controlled, a small number of observations was sufficient. Average yields for the selected crops were slightly lower than in the Mae Sa watershed, and labor use was higher, but input costs were lower and prices were higher and more uniform. Table 5.2 shows data for three typical rotations of the three main leafy vegetables grown in Doi Angkhang: cabbages, lettuce and spinach. Each crop is managed according to a recommended cultivation plan, with specified quantities of biopesticides, developed and monitored by the Royal Project. For cabbages, this involves the application of manure after planting, the spraying of a diluted organic fertilizer and the application of biopesticides. Adjustments are made when pest pressure crosses a particular threshold. Farmers closely observe their crops and also use insect traps and hand-picking.

Table 5.2: Input and output data for three IPM vegetable rotations as practiced by farmers (n=34) at Doi Angkhang, Thailand, 2012

Production parameters	**Rotation option 1:** *Cool season: cabbage* *Hot season: lettuce* *Rainy season: spinach*	**Rotation option 2:** *Cool season: lettuce* *Hot season: spinach* *Rainy season: cabbage*	**Rotation option 3:** *Cool season: spinach* *Hot season: lettuce* *Rainy season: cabbage*
Growing length (months/crop)	2.3	2.3	2.3
Labour use (mandays/ha/m)	693	407	334
Biopesticide use and costs			
Bacillus turingh.(kg/ha/m)	11.2	6.5	10.6
Bacillus subtilis (kg/ha/m)	4.0	11.2	6.5
Trichoderma (kg/ha/m)	4.0	4.0	5.2
Azadirachtin (kg/ha/m)	0.8	4.0	5.2
Metazan (kg/ha/m)	1.2	0.8	0.0
Costs (1000 baht/ha/m)	7.3	7.3	5.5
Other variable costs (1000 baht/ha/m)	18.4	21.1	14.5
Sales revenues (1000 baht/ha/m)	202.5	114.5	82.9

5.4 Methods

5.4.1 Mathematical Programming-based Multi-Agent Systems

Multi-agent systems in agricultural economics are useful in situations where model complexity leads to analytical intractability, so that equilibrium conditions either cannot be identified or solved (Nolan et al., 2009). MPMAS is an agent-based software package that was designed to understand how agricultural technology, market dynamics, environmental change, and policy intervention affect a heterogeneous population of farm households and the agro-ecological resources these households command (Schreinemachers and Berger, 2011). MPMAS belongs to a category of models referred to as agent-based models of land-use and land-cover change (ABM/LUCC). The interactions of autonomous individuals with each other and with a cellular component, representing the physical landscape make them effective at analyzing resource management problems and add to the capabilities of standard bio-economic models (Berger et al., 2006).

Schreinemachers and Berger (2011) provide a detailed description of the MPMAS architecture and model equations based on the ODD protocol (2011). The full implementation details of this particular application are explained in Grovermann (Grovermann, 2015). Here we give a brief overview of the model and focus on the main novelties regarding pesticide use decisions and IPM adoption.

For the present application a subset of available MPMAS features was used. Figure 5.3 illustrates how the various model components are connected. Agent decision-making depends on market prices, the availability of resources (cash, land and assets), the access to innovations, and past information about crop yields, which are endogenous in the model. The model is recursive, meaning that agent resources are carried over in each simulation year and agent expectations of market prices and crop yields are updated.

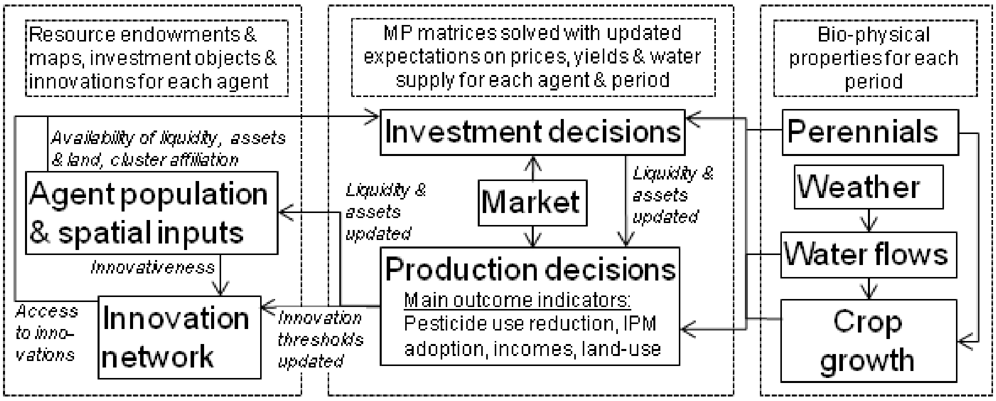

Figure 5.3: Dynamics of the MPMAS Mae Sa watershed model

Agents form expectations about crop yields, water supply and market prices based on past experience, following the theory of adaptive expectations. Agents revise expectations annually in proportion to the difference between actual and expected values as described in Schreinemachers and Berger (2011). The simulation period was set to five years, which we judged as a realistic time frame for pesticide reduction strategies to make an impact. The same buying prices for inputs and farm-gate selling prices for the harvested produce were assumed for all agents and were kept constant over time. Due to the small share of the Mae Sa watershed in overall horticulture in northern Thailand, it was assumed that changes in production did not affect prices. Mathematically, the individual agent decision problem can be described as follows:

$$\text{Maximize} f(X) = \sum_{i=1}^{n} p_i x_i \tag{1}$$

$$\text{Subject to} \sum_{i=1}^{n} \sum_{j=1}^{m} b_{ij} x_i \leq y_j \tag{2}$$

$$\sum_{i=1}^{n} x_i \geq 0 \tag{3}$$

Expected net household income of each agent is represented by f(x), which is a linear function of farm and non-farm activities x_i and their corresponding *i*th expected return per unit p_i. The coefficients b_{ij} indicate the *j*th resource use constraint per *i*th activity, such as the amount of labor, pesticide quantity and other variable inputs per hectare of crop production. The MP algorithm finds values for x_i that give the maximum net household income (Eq.1), while ensuring that the total use of resources does not exceed the resources actually available (y_j) (Eq.2) and selecting only positive values for activities (Eq.3). The coefficients y_j, also denoted as right-hand-side (RHS) values, determine each agent’s resource endowments, such as the available amount of labor, liquidity (cash) and land. Based on these three equations, agents can make their decisions, such as choosing a crop mix with different inputs and outputs, investing in greenhouses or adopting a new technology. Technical coefficients in the decision-matrix, such as on expected yields, available resources or access to particular technologies, are adjusted for each agent and time step. The individual optimization problem is updated for each agent in each simulation period and repeatedly solved.

The total population of farm households in the study area is 1,491, but data were collected only for a sample of 295 households. As described in Berger and Schreinemachers (2006), MPMAS uses a Monte Carlo technique to generate a complete population of unique agents that is statistically similar to the sample population, meaning that the population of agents has the same mean and standard deviation as the sample and that correlations between variables are maintained. To do this, the sample was divided into 15 clusters as based on location and farm size, which was the variable most strongly correlated to any other variable.

5.4.2 Pesticide use decisions

The survey recorded over 100 different pesticide products. Unlike fertilizers, which can be summed in terms of key nutrients, there are a multitude of active ingredients, many of which are substitutes. Also unlike fertilizers, pesticides do not have a straightforward relationship to crop yields as plants do not require them to grow. Simulating farmers' pesticide use decisions is challenging because of these issues, which explains the general lack of such models. The most straightforward approach would be to include all observed input-output combinations inside the MP matrix by specifying a separate resource constraint for each pesticide product. However, observed input-output combinations have measurement errors, which we would then replicate in the model.

We addressed this by estimating production functions with a damage abatement term for pesticides on the data and using a confidence interval to determine which observations are realistic and which are not. Because of insufficient observations for each of the selected major crops, the production functions were estimated on groups of crops that were similar in pest management, input levels and growing lengths: leafy vegetables (open field system), greenhouse vegetables (closed system) and onions and beans (open field system).

We applied a Cobb-Douglas production function with an exponential damage control specification for pesticides (Lichtenberg and Zilberman, 1986; Praneetvatakul et al., 2003):

$$\ln Y = \alpha + \sum_i \gamma_i C_i + \sum_j \beta_j \ln Z_j + \ln[1 - \exp(-\lambda X)] + \varepsilon \qquad (4)$$

in which Y is the output level, C_i are indicator variables of farm and crop characteristics (including location and crop dummies crop and location dummies capturing differences in crop management and agro-ecological conditions), Z_j are growth-stimulating inputs and X is the value of pesticides applied. Estimated coefficients include constant α, coefficients γ_i, β_j and the damage control coefficient λ. Results were previously published as (Grovermann et al., 2013).

Figure 5.4 shows for the example of lettuce, which was one of the leafy vegetables, the 99% confidence interval around the estimated abatement function. Only observations lying within the confidence interval were included in the estimation procedure while all other observations were considered as outliers. This procedure was applied to 8 crops.

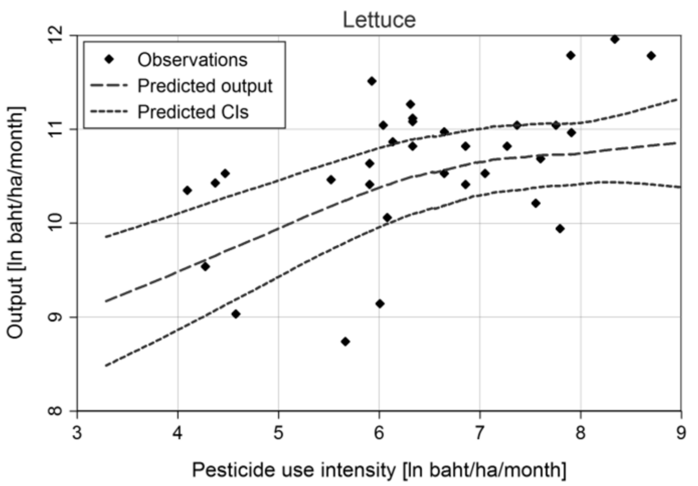

Figure 5.4: Relationship between pesticide use and crop output for lettuce estimated with a Cobb-Douglas production function with pesticide abatement term, northern Thailand, 2009/10

For maize, rice, chayote and chrysanthemums there were too few observations to reliably estimate a production function while there were no other similar crops with which they could be grouped together. For these crops we calculated the mean quantity of pesticide use and included all observations ± one standard deviation of the mean. For litchi, cluster analysis was used to generate three management options with different input-output levels, while for roses we specified only average management option because of the limited number of observations that were available.

This approach gave 417 crop activities, for which 82 active ingredients were used, plus fallow and IPM activities. Each active ingredient was included as a separate constraint in the MP matrix and a separate buying activity. This made it possible to simulate the effect of a price change of a particular pesticide or of a regulatory ban on a pesticide. All other variable inputs (seeds, fertilizers, planting materials, hormones, etc.) were aggregated and expressed as costs per hectare. Summary statistics for the selected crop activities are shown in Table 5.3. The complete MP matrix had 1,129 columns (activities) and 862 rows (constraints).

Table 5.3: Number of conventional crop activities (without IPM and fallow) in the model and average crop output and input requirements per activity, Mae Sa watershed, Thailand, 2009/10.

Crop	Activities per crop	Growing length	Yield	Labour	Pesticide Use	Other variable inputs	Area irrigated
		months	*tons/ha*	*mandays/ha*	*kg/ha*	*1000 baht/ha*	*%*
Upland rice	9	5.7	1.68	15.61	0.20	2.04	0
Maize	11	4.7	2.24	9.79	0.07	0.59	9
White cabbage	66	3.4	25.64	95.19	1.58	30.55	26
Chinese cabbage	66	2.5	23.66	97.84	2.09	21.17	56
Chinese kale	23	2.3	5.93	211.83	1.62	15.91	96
Lettuce	24	2.5	9.45	100.12	0.94	23.68	54
Bell pepper	55	5.6	45.99	247.02	29.45	434.08	100
Tomato	15	5.2	68.68	416.18	14.34	591.52	100
Onion	12	4.0	26.30	165.29	8.61	85.72	100
Fresh bean	28	3.0	8.97	152.06	1.59	13.25	89
Chayote	27	6.2	18.67	178.99	0.09	85.76	96
Chrysanthemum	25	4.3	52.12	198.85	12.23	32.91	100
Roses	8	12.0	164.37	133.46	19.44	131.92	100
Litchi	48	12.0	4.05	11.80	0.82	3.32	67

5.4.3 IPM adoption

Giving all model agents immediate and unlimited access to IPM methods would yield unrealistic simulation results. In reality, not all farm households are equally willing to take risk in innovating and many prefer to see others try first before adopting themselves. MPMAS was designed to capture this process and several previous studies have applied this (Berger et al., 2007; Quang et al., 2014; Schreinemachers et al., 2007). MPMAS builds on the theory of innovation diffusion (Rogers, 2003; Valente, 2005) by dividing agents into five groups of innovators, early adopters, early majority, late majority and laggards as shown in Figure 5.5. The group of innovators gets first access to an innovation, while the group of early adopters will wait until 2.5% of the innovators have adopted and so forth.

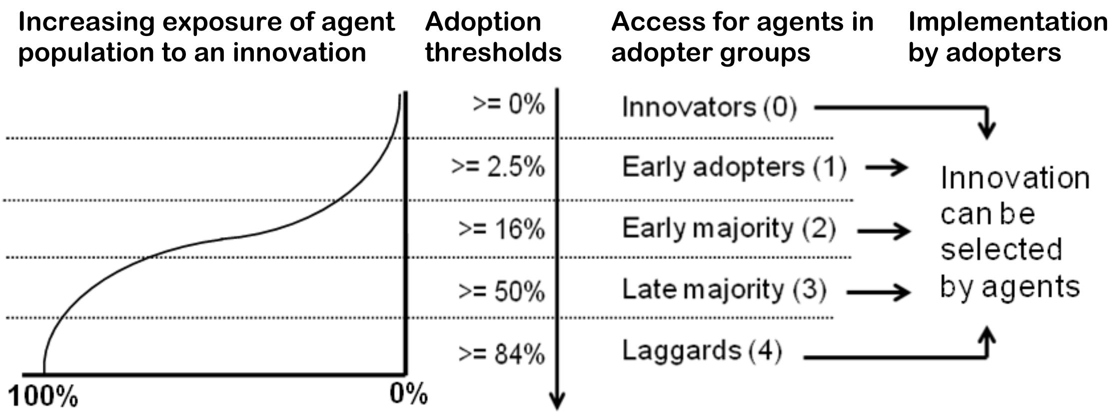

Figure 5.5: Innovation diffusion in MPMAS

Innovativeness is generally seen as a personal characteristic that is difficult to measure directly in a survey (Schreinemachers et al., 2009). To assign agents to one of five adoption categories, we regressed technology adoption decisions of farmers on a set of independent farm and household characteristics using a Probit regression. The predicted values of the dependent variable can be interpreted as the propensity to innovate (*cf.* propensity scores), which is used as our measure of innovativeness. Agents were ranked according to this variable and divided into five groups according to the thresholds values shown in Figure 5.5.

Since there has been no adoption of IPM in the study area we instead used the adoption of the public GAP standard as the dependent variable in the Probit regression. About 20% of the farm households have adopted GAP. As the concept of GAP is closely related to IPM, we can reasonably assume that the innovation attributes and network thresholds related to GAP are also likely to apply for the adoption of IPM. We note, however, that a previous study showed that GAP adoption did not lower pesticide use in the study area and we thus do not consider it is a pesticide reduction strategy in our study (Schreinemachers et al., 2012).

Empirically, we used a two-stage econometric estimation that first explains whether or not farmers know about the GAP standard (selection equation) and secondly whether or not they have actually adopted it (Probit equation). The first stage corresponds to the knowledge and persuasion stage of the adoption process, which is a pre-condition for adoption: If a farmer does not know about GAP then the adoption decision cannot be observed. The likelihood-ratio (LR) test of independent equations was significant (Chi2 = 3.88; Prob. > chi2 = 0.049), indicating that it was necessary to correct for sample selection bias with a Heckman procedure. The analysis was based on a set of explanatory variables, which represent farm characteristics as well as selected network characteristics, such as the links of an individual farm household to those households being aware of the innovation, the ties of an actor with the outside world and the prominence of a person in a network (Valente, 2005). For more detailed regression results we refer to Grovermann (2015).

5.4.4 Investment in IPM

The adoption of IPM requires a long-term commitment of farmers to certain production practices. It is therefore a long-term investment rather than a recurrent production decision. Conveniently, MPMAS separates between such investment decisions, which also include planting trees or buying assets, and recurrent production decisions about variable inputs and choice of seasonal crops. MPMAS simulates these agent decisions by solving two separate MP matrices: one with long-term agent expectations about resources, yields and prices and one with the current expectations about these factors (Berger, 2001). This separation captures the trade-off between short-term income from production and long-term income from investment (Schreinemachers et al., 2010).

Table 5.4 shows how IPM vegetables were implemented in the MP matrix. In the investment stage, agents that have access to IPM through the innovation module can select one of three alternative crop rotations for IPM. Once adopted, it is assumed that agents will continue to practice IPM for at least 6 years before possibly returning to conventional agriculture.

IPM is knowledge intensive and comes with some upfront (acquisition) costs for light terracing, for planting of grass strips and for simple plastic shelters to protect the plants from heavy rainfall. Changing from cash cropping with high external input use to agro-ecological IPM practices can be expected to involve some initial yield losses due to learning on the side of the farmer and restoration of the natural resilience of the agro-ecosystem. This conversion period is taken into account assuming lower yields after the initial adoption: a reduced yield of 30% in year 1, 20% in year 2 and 10% in year 3 and full yields thereafter. This assumption is supported by a comprehensive study of the yield impact of the conversion from conventional to organic practices by Seufert et al. (2012) who found that yields are 5% to 34% lower for organic agriculture. Furthermore, a study by Giovannucci (2006) assessed yield effects of the transition to organic cultivation in China and India and found that yields in the first two years were 20% to 30% lower than pre-conversion yields but matched or even surpassed pre-conversion yields after the third year.

Table 5.4: Simplified representation of implementation of IPM vegetables in the MP matrix

					IPM veg. – rotation 1				IPM veg. – rotation 2							
	Units	Constraints	Sell IPM produce	Buy biopesticides	Invest	Grow	Switch to rotation 2	Idle	Invest	Grow	Switch to rotation 1	Idle	Transf. Land	Transf. labor	Sign	RHS
Units		#	kg	kg	ha	ha	ha	ha	ha	ha	ha	ha	ha	md.		
Activities	#		2	5	12	12	24	12	12	12	24	12	4	1		
Objective function			E (+C)	E (-C)												
Invest land	ha	4			1				1						≤	0
Land	ha	4											1		=	**(+R)**
Labor	md.	1												1	≤	**(+R)**
Monthly water	l/sec	12			(+A)	(+A)	(+A)		(+A)	(+A)	(+A)				≤	**(+R)**
IPM land	ha	12			+1	+1	+1	+1	+1	+1	+1	+1			=	**(+R)**
IPM access	-	1			**(+1)**	**(+1)**	**(+1)**	**(+1)**	**(+1)**	**(+1)**	**(+1)**	**(+1)**			≤	**(+I)**
Capital use	Baht	1			(+A)	(+A)	(+A)		(+A)	(+A)	(+A)				≤	**(+R)**
Sprinkler irrigation	ha	12			+1	+1	+1		+1	+1	+1				≤	**(+R)**
Balance biopesticide	kg	5		-1	+A	+A	+A		+A	+A	+A				≤	0
Bal. monthly land	ha	48			+1	+1	+1		+1	+1	+1			-1	≤	0
Bal. labor IPM	md.	1			(+A)	(+A)	(+A)		(+A)	(+A)	(+A)			-1	≤	0
Balance yield IPM	kg	6	+1			**E(-Y)**	**E(-Y)**			**E(-Y)**	**E(-Y)**				≤	0

Notes: E = Expected values, C = Price coefficients, Y = Crop Yields, A = Technical coefficients, R = Available resources, I = Available innovations. Values in round brackets are adjusted inside the model. Bold values are agent-specific. md.= mandays

5.4.5 Resource constraints

Water is an important production constraint during the dry season when rainfall shows high variability. Following a previous application of MPMAS to the same watershed (Schreinemachers et al., 2009; Schreinemachers et al., 2010), this study integrated the CropWat model (Allen, 1998; Doorenbos et al., 1979) to simulate the crop yield response to variations in the water supply. Monthly water requirements are specified for each cropping activity while the monthly water supply is controlled by a spatial routing module in MPMAS. Weather data from the Royal Project station plus the CropWat software were used to calculate effective monthly rainfall, which was assumed constant for each year of the simulation.

Cash is an important constraint in agricultural production yet available amounts of cash vary widely over the year and cannot be observed through a survey. We therefore calculated for each farm household the total expenditures on crop inputs and depreciation on investment and assumed that this was the amount of cash that a household has available. Like other assets such as land, labor, greenhouses and orchards, we endowed each agent with cash at the start of the simulation. A cash constraint was included in the MP matrix and values were updated at each simulation period. Agents had access to short-term credit at a 9% annual interest rate or could deposit cash at a 2% interest rate. These interest rates were assumed constant over time. Agents can choose, to a limited extend, to perform off-farm labor (at 70 baht per manday) and have access to hired labor (at 96 baht per manday). They can resort to both according to their individual allocations.

5.4.6 Pesticide use reduction strategies

The baseline simulation resembles the actual situation as observed in the farm household survey. The alternative scenarios A-D make changes to the baseline assumptions. The focus of this study is on financial instruments and the adoption of IPM, assessing the impact of the following strategies to reduce pesticide use:

A. Introduction of IPM: IPM is not available and not adopted by agents in the baseline simulation. As part of the scenario analysis, access to IPM, being a complete innovation, is granted to the innovator segment and can consequently diffuse through the network.

B. Progressive pesticide tax based on toxicity: In a range of scenarios, a sales tax on pesticides is introduced with the rate increasing with toxicity following the WHO classification system. The alternative rates are shown in Table 5.5 and follow the logic of economic disincentives, which offer the prospect of reducing pollution beyond set pollution limits and of encouraging polluters with lower abatement costs to reduce their environmental impacts, more so than polluters with higher abatement costs (Jaeger, 2005). The rates were set to levels that were reasonable from a policy implementation perspective. Owing to the increasing tax burden with increasing pollution levels, farmers are likely to oppose pesticide taxes. Yet, a tax policy is said to be more acceptable to farmers if the tax revenues are redistributed to the farmers in the form of lump sum payments (Buchanan and Tullock, 1975). To maintain effectiveness of the tax (dis)incentive, the level of the reimbursement must be decoupled from the level of the tax (i.e. big polluters should not receive a higher reimbursement). This study therefore distributed the reimbursement based on farm size (i.e. payments per hectare) as this variable is easy to observe and relatively static.

C. Price premium for IPM produce: Rather than redistributing tax revenues through lump sum payments, they could be used as an incentive to encourage more sustainable production of safer agricultural produce. Simulation experiments tested the effect of a price premium for IPM produce of 2, 5 and 10%, respectively.

D. Biopesticide subsidy: As for the price premiums, the biopesticide subsidy was picked as a pesticide use reduction strategy due to its practicability and implementation potential. Prices of biopesticides were lowered by 20, 40 and 60% in the simulation experiments.

The scenarios applied combinations of the above strategies as shown in Table 5.5. Several intervention levels, denoted as low, medium and high, were used to evaluate the effect of the policies. Outcome indicators were compared between the baseline scenarios and the alternative scenarios to assess the impact on:

- Overall pesticide use: All chemical pesticides applied in the study area.
- Use of highly toxic pesticides: Pesticides applied in the study area belonging to WHO toxicity classes Ia, Ib and II.
- Farm income: Money earned by farm households.
- Cost-effectiveness: Costs of the respective policy, e.g. biopesticide subsidy, divided by the average change in highly toxic pesticide use.

- Adoption of IPM: Diffusion of IPM in the agent population and area under IPM.

Table 5.5: Pesticide reduction strategies evaluated with the model

Strategy	Scenario			
	Baseline	Low (1)	Medium (2)	High (3)
A. Introduction of IPM	No IPM	---------- IPM diffusion ----------		
B. Progressive tax on toxic pesticides (+ compensation payment)				
WHO Ia & Ib	No tax on pesticides	20%	50%	70%
WHO II		15%	40%	50%
WHO III		10%	30%	40%
WHO U & NL		5%	20%	30%
C. Price premium for IPM produce (price increase)	No price premium	2%	5%	10%
D. Biopesticide subsidy (price decrease)	No subsidy	-20%	-40%	-60%

Here, several intervention levels with different intensity of interference, denoted as low, medium and high, are used to evaluate the effect of the policies, being also instrumental in testing the sensitivity of results.

5.5 Model verification and validation

Verification in the context of MPMAS implies checking that the resources allocated to agents are consistent with the observed resources available to farmers. In this study, consistency is tested on six important assets: household size, liquidity, greenhouses owned, area under chrysanthemum cultivation, area under litchi orchards and area under rose cultivation. All of these variables are expressed as per household quantities. Using linear regression without a constant, the regression line is predicted. Slope coefficients and R-squared values close to unity indicate a good fit between the outcome of the asset allocation by the lottery and the asset allocation recorded in the survey. The Monte Carlo technique to generate agent populations has a stochastic element. Therefore, the robustness of the model results to alternative agent populations was tested. Simulation results proved to be robust to the configuration of the agent population.

Validation was based on an iterative calibration process of the model, in which the goodness of fit was tested after each modification of the calibration variables. Three key outcome variables were used for validation: land-use, sales revenues and pesticide use. We note that values for these variables observed from the survey were not used to parameterize the model and can therefore be used for model validation. The goodness of fit between the observed situation from the survey and the model outcomes was determined by regressing observed data on simulated data (again forcing the intercept through the origin) and by then evaluating the slope coefficient o and R-squared. Coefficients ranged between 0.95 and 1.05 and R-squared values ranged between 0.95 and 1, which indicates that the model was able to closely replicate the observed situation for these key variables. Table 5.6 shows that the criteria are met across 19 alternative configurations of the agent population. The model thus gives a robust representation of farming in the study area.

Table 5.6: Validation results for land use, sales revenues and pesticide use

	Land-use		Sales revenues		Pesticide use	
	Coef.	R2	Coef.	R2	Coef.	R2
Obs.	19	19	19	19	19	19
Mean	0.991	0.995	0.960	0.962	0.980	0.981
Std. dev.	0.008	0.001	0.008	0.004	0.001	0.001
Min.	0.976	0.994	0.944	0.951	0.978	0.980
Max.	1.004	0.997	0.973	0.970	0.985	0.982

As the agent population was subdivided into clusters, the model can also be validated at a less aggregate level. For testing goodness of fit at the cluster level, regressions were run for all three outcome variables in each cluster. Coefficients at disaggregate level ranged from 0.805 to 1.040, with standard deviations between 0.075 and 0.207, which we regarded as acceptable. The same applies to the R-squared values.

5.6 Results

5.6.1 Introduction of a progressive tax

Table 5.7 shows that even high taxes have only a moderate impact on pesticide use in our simulations. The highest tax rate gives a pesticide reduction of 7.3%, and reduces net agent income by 6.6%. A comparison of the high progressive tax with and without compensation payments shows that the effect of compensation on pesticide reduction is negligible, but it partially offsets the income loss. With regard to land use change, agents select crops using fewer pesticides, such as chayote, increase in area, whereas pesticide-intensive crops, such as onions or bell peppers, decrease in area.

Table 5.7: Simulation results showing the effect of a pesticide sales tax on income, tax revenues and pesticide use as compared to the baseline scenario without a sales tax

Scenario	Δ income		Tax revenues	Δ pesticide use		Δ highly toxic p. use	
	%	*1000 baht/hh*	*1000 baht/hh*	*%*	*kg/ha*	*%*	*kg/ha*
Low progressive tax	-1.24	-3.17	1.48	-2.06	-0.33	-2.67	-0.07
Medium progressive tax	-3.96	-10.10	4.21	-5.03	-0.86	-6.26	-0.16
High progressive tax	-6.56	-16.71	6.74	-7.34	-1.25	-8.26	-0.21
High progressive tax + compensation	-4.81	-12.28	6.73	-7.47	-1.27	-8.27	-0.22

Note: Averages over all agents and simulation periods.

5.6.2 IPM introduction and promotion

The following simulation experiments aim at promoting the adoption of IPM rather than penalizing pesticides. Price premiums are used as a mechanism to increase the attractiveness of IPM, and subsidies for IPM inputs are introduced as a production support measure.

Crop activities using IPM are profitable compared to the conventional crop activities in the model as they diffuse quickly through the agent population after becoming available. The diffusion of IPM does not differ between the IPM stand-alone scenario, the low and medium price premium as well as all the biopesticide subsidy scenarios. In year 4 agents in the early majority segment can already adopt IPM. For the high price bonus level, access to IPM even becomes available to agents in the late majority segment in year 5. The reduction in pesticide use is also the highest for this scenario, reaching 22% in the fifth year. Compared to the baseline, the income of agents increased in all IPM scenarios.

Even though pesticide use is most reduced through a high price premium for IPM produce, the scenario creates a high cost that far exceeds pesticide tax revenues. In the case of the high progressive tax, as Table 5.7 shows, the government could generate revenues of about 6,000 baht per agent. Put simply, apart from the high price premium scenario, all the other IPM adoption scenarios could be financed with the tax returns. The cost-effectiveness values in Table 5.8 evaluate the policy costs against the reduction in use of highly toxic pesticides. Biopesticide subsidies appear as the most cost-effective.

Land-use changes clearly differ across the scenarios in terms of the reduction of area under leafy and greenhouse vegetables. Compared to the IPM stand-alone scenario, the area under

IPM can only be substantially increased with a high price premium in place. The other interventions, where the diffusion process does not reach the late majority, bring about a comparatively smaller change in the area under IPM.

Table 5.8: Simulation results showing the effect of the introduction of integrated pest management (IPM) on income, tax revenues and pesticide use as compared to the baseline scenario without IPM

Scenario	Δ income		Policy costs	Δ pesticide use		Δ highly toxic pesticide use		Cost-effectiveness
	%	*1000 baht/hh*	*1000 baht/hh*	*Av. %*	*P. 5 %*	*Av. %*	*P. 5 %*	
IPM, stand-alone	10.9	28.3	0.0	-5.5	-9.7	-7.8	-12.9	-
IPM + low price prem.	11.7	30.4	1.5	-5.7	-10.1	-8.3	-13.5	-0.18
IPM + med. price prem.	12.1	31.4	3.9	-6.6	-11.0	-9.3	-14.7	-0.41
IPM + high price prem.	17.0	44.3	10.5	-10.1	-22.2	-13.1	-27.3	-0.80
IPM + low subsidy	11.2	29.0	1.0	-5.9	-10.7	-8.3	-13.6	-0.12
IPM + med subsidy	12.0	31.0	1.9	-6.0	-10.8	-8.6	-14.2	-0.23
IPM + high subsidy	12.1	31.4	3.0	-6.5	-11.8	-9.3	-14.9	-0.32

Notes: Averages over all agents and simulation periods. Except for columns marked as P.5, which show values for period 5. Cost effectiveness = policy costs / av. Δ highly toxic p. Use

From the above scenarios it is possible to derive a series of policy packages, involving the high progressive tax, the introduction of IPM and suitable IPM adoption incentives. The high tax alone achieves only a moderate reduction in pesticide use, but tax revenues can be employed to promote less pesticide-intensive production practices. The results in Table 5.9 show that spending the tax money on IPM promotion rather than redistributing it as lump sum payments to directly compensate agents achieves higher pesticide use reduction rates. Contrary to the tax-compensation scheme, investing in IPM has a clear temporal dimension, since impacts become more significant with increasing adoption.

Table 5.9: Simulation results showing the effect of the introduction of integrated pest management (IPM) and a pesticide sales tax in combination with 3 measures to compensate farmers

Scenario	Δ income	Tax revenues	Policy Costs	Δ pesticide use		Δ highly toxic pesticide use		Innovation access	IPM area
IPM + tax +	Av. %	Av. 1000 baht/hh	Av. 1000 baht/hh	Av. %	P. 5 %	Av. %	P. 5 %	P. 5 Adopter group	P. 5 ha
No other intervention	4.9	6.2	0.0	-12.9	-17.8	-16.3	-21.7	Early majority	215.7
Direct compensation	6.0	6.2	-6.2	-12.8	-17.9	-16.3	-21.8	Early majority	215.9
Price premium 5%	5.7	6.1	-4.1	-14.4	-20.1	-17.9	-24.4	Early majority	237.5
Biopesticide subsidy 60%	5.5	6.1	-3.2	-14.9	-20.1	-17.9	-24.5	Early majority	239.9
Biopesticide subsidy 80%	8.7	5.9	-5.4	-17.4	-29.0	-20.7	-34.3	Late majority	414.5

Notes: Averages over all agents and simulation periods; values represent the difference between the respective scenario and the baseline, for average pesticide use reductions (Av.) and period 5 (P.5), values are reported.

As Table 5.9 shows, a similar reduction of pesticide use is achieved using a 5% price premium, involving average costs of 4,110 baht per household, and a 60% subsidy for biopesticides, for which average costs only lie at 3,170 baht per agent household. As this cost is well below tax revenues, a policy package with an 80% biopesticide subsidy has been tested and results are also shown in Table 5.9. In this scenario costs on average are still covered by tax revenues. As diffusion takes IPM adoption to the late majority, the area under IPM is much larger. Therefore pesticide use in period 5 is reduced by as much as 34%. Figure 5.6 gives an indication of the related shift in the agent land-use pattern.

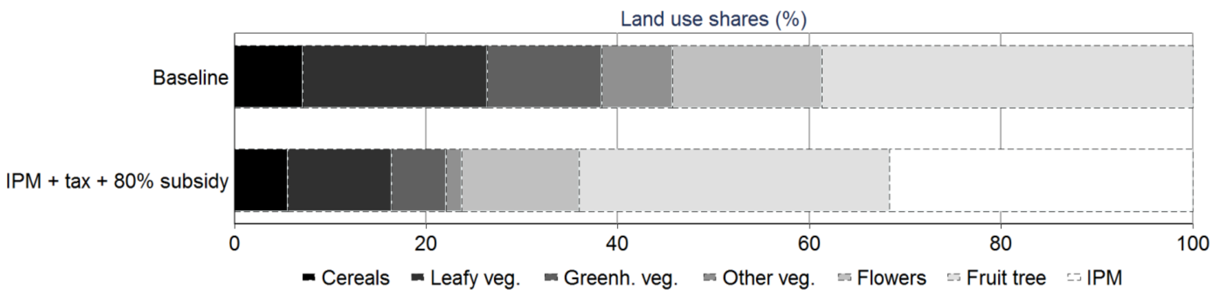

Figure 5.6: Land-use shares in the baseline scenario and the policy package, 80% biopesticide subsidy

It is of interest to examine more closely how much agents gain or lose from the introduction of IPM. Figure 5.7 helps to understand what determines changes in income with regard to the initial income situation, the area under IPM and the innovativeness of the individual agents in the scenario involving a tax and the 80% biopesticide subsidy. The figure shows the 15 clusters into which the agent population is subdivided. The graph on the left demonstrates that gains clearly outweigh the losses in terms of magnitude. The gains occur across the lower and middle ranges of the average baseline income level, while the agents in the wealthiest cluster on average do not benefit from the policy package. The graph in the middle shows that income levels decline for some of the clusters in which agents have adopted IPM only to a minor extend. Lastly, the graph on the right reveals that the innovativeness of agents is a major driver of changes in income and the factor that determines which agents’ benefits from the introduction and promotion of IPM.

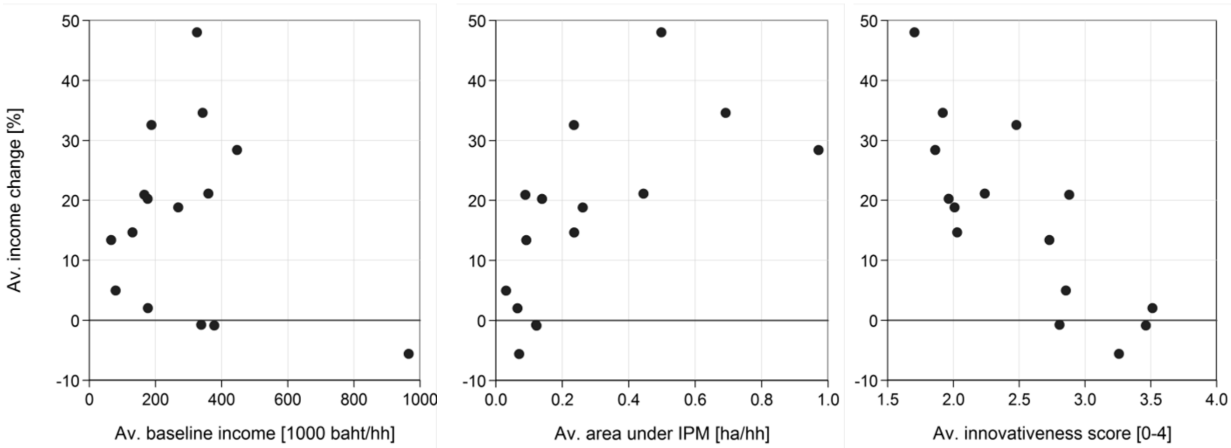

Figure 5.7: Income change related to baseline income, IPM area & innovativeness (15 clusters)

5.7 Discussion

Our review of literature found that there are only few published model applications that evaluated pesticide policies for their potential to reduce pesticide use. Each of these have taken a very different approach, though there are also similarities.

Similar to Falconer (2000) and Jacquet et al (2011), this study used mathematical programming as this approach allows evaluating policies or technologies for which farm-level data cannot be directly observed. Yet different from Falconer (2000) and Jacquet et al (2011), this study did not use a representative farm or aggregate sector model but simulated the effect of policy changes on each individual farm household while aggregation was done only to summarize the results. This approach avoids problems of over-specialization and aggregation bias that are inherent in single farm or sector MP models.

Skevas et al. (2012) used econometric approach to estimate the price elasticity of pesticides and Pina and Forcada (2004) reviewed a range of such econometric studies in order to s simulate, on that basis, the potential effect of a pesticide tax. Such econometrics-based approaches are more straightforward than the MP-based approaches and also easier to replicate. Yet these econometric models make inferences from observed variation in price data and are only valid within the range of observed values. They can also not be used to simulate the effect of new technologies, as these cannot be observed, or the combined effect of a pesticide tax with IPM promotion and subsidies. Rebaudo and Dangles (2013) also applied agent-based modeling for simulation of integrated pest management and show how different types of agent communication might affect speed of dissemination. Their simulation study, however, is based on theoretical insights and not parameterized with empirical data.

Another novelty of our approach was the use of econometrically estimated damage control functions to parameterize the agent decision problems. Damage control functions are widely used to estimate the effect of pesticides on crop yields, but previous studies have used agronomic trial data rather than farm-level data (e.g. Falconer and Hodge 2000; Jacquet et al. 2011). Agronomic data might, however, not be representative of actual on-farm practices. Our study shows that damage control functions can be used to screen farm-level data for realistic combinations of inputs and output. It allowed us to include a wide range of substitution possibilities between hundreds of pesticide product bundles without having to understand the bio-effectiveness of each individual product. The alternative would have been to use expert opinion to specify substitution possibilities, but this again would not represent farmers’ knowledge about pesticides and might thus lead to unrealistic outcomes. We emphasize that our model was intended to show how farmers’ actually behave rather than what is technically possible or optimal.

In terms of empirical results, our study showed that the effect of a stand-alone pesticide tax on pesticide use is low, which means that the pesticide price elasticity is low. This confirms most other studies on this topic. Skevas et al. (2012) found that a 120% pesticide tax led to a 4% reduction in pesticide applications among Dutch potato farmers. Pina and Forcada (2004) report that the literature generally considers the price elasticity is low. Falconer and Hodge

(2000, 2001) also showed that only high taxes can achieve significant pesticide use reductions.

The most important finding of our study is that promotion of IPM and subsidies for biopesticides are much more effective policies for reducing pesticide use than a stand-alone pesticide tax. Yet taxes create government revenues, while subsidies create costs. Our study therefore showed the cost effectiveness of combining pesticide taxes with supportive measures, such as price premiums for safer vegetables and subsidies for biopesticides. The simulation experiments showed that subsidies for biopesticides are the most cost effective policy. A combination of a high progressive tax and a 60% biopesticide subsidy financed by the tax revenues, reduced overall pesticide use after five simulation periods by 18%, and reduced the use of highly toxic pesticides by almost 25%. With additional funds, especially if resources can be shifted from general subsidies for conventional agriculture to targeted financing of sustainable agriculture, it could be possible to sustain an 80% biopesticide subsidy and reduce the use of highly toxic pesticide by almost 35% within five years. These findings confirm Falconer and Hodge (2000) who also found that taxes can be more effective if farmers are provided with pest control alternatives. It also confirms Jacquet et al. (2011) who showed that financially supporting sustainable farming technologies is much more effective at lowering pesticide use than taxes.

The lack of alternatives to synthetic pesticides among farmers has been described as one of the main factors for the high levels of pesticide use observed in Thailand and Vietnam (Lamers et al., 2013; Schreinemachers et al., 2011). Praneetvatakul et al. (2013) concluded that it is best to introduce a package of policies that combines an environmental tax with supportive measures to help farmers change their on-farm practices. This research has substantiated this proposition. Biopesticide subsides are also from a policy implementation perspective practicable, as infrastructure for input subsidies is often in place. With IPM available for crops other than leafy vegetables, in particular bell peppers and tomato, it can be assumed that even substantially higher pesticide use reductions can be achieved.

5.8 Conclusion

A smart policy package can bring down levels of pesticide significantly without negatively affecting livelihoods at large. This study has contributed to clarifying that a trade-off between environmental protection and farm household incomes can be avoided if policy-makers use the right economic instruments to constrain chemical pesticide use and motivate changes towards more integrated growing practices. In this pesticide policy context, it has been shown how the use of production functions with damage control specifications, the inclusion of adoption and diffusion of pesticide use reduction technologies and the use of an agent-based framework can refine the overall modeling approach.

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6 Final discussion

6.1 Conceptual framework and approaches

This thesis first described and analyzed the relationship between the transformation of agriculture in northern Thailand and changes in the pest management activities carried out in the area, highlighting in particular the trend among farmers to exclusively and heavily rely on chemical pesticides. Second, the thesis provided evidence on possible policy options aimed at reducing the currently high levels of pesticide use, evaluated the GAP certification process and its effect on on-farm pesticide handling and use, and ultimately assessed through an agent-based simulation model pesticide sales taxes and economic incentives provided to encourage the adoption of IPM techniques.

The study of transformation processes that took place during this research was focused on two related, yet distinct, farm system characteristics: land use intensification and commercialization, both of which reflect a market orientation. Both variables were used in order to understand the differences between three farming systems: subsistence, semi-commercial and commercial. Using two variables helped to address the key research questions outlined in the first chapter. The land-use intensity index was used to measure the differences to be found among farming systems in terms of the pest problems experienced, pest management methods used and health problems suffered due to the use of pesticides. Furthermore, the commercialization index was used to improve the level of understanding of how the perceptions of risk among farmers and the risk management strategies they use have changed over time.

One limitation here is that it was not possible to use time-series data to observe the changes taking place within the farming systems, due to time and budgetary limitations, so cross-sectional data was used. This thesis is based on data drawn from the highlands of northern Thailand, where agricultural systems offer an ideal setting for collecting cross-sectional data, as differences in road infrastructure conditions and distances to urban centers create a wide variety of agriculture systems within small geographical areas. However, during the survey it was difficult to fully capture changes in the level of pest and disease knowledge among farmers, as well as changes in the roles of men and women with regard to pest and plant disease management. It was also difficult to take into account the minor crops grown only for home consumption when detailing the diversity of crop species grown, the crop areas used and output quantities produced. It should also be noted that the survey gathered information is based on farmers' memories, and this may have resulted in the capture of partially inaccurate information. A generally one-sided bias was not observed however, when collecting the data. Also, prior to individual interviews, general information about each relevant village was captured during focus group discussions to help develop a general level of understanding of the situation in the area prior to conducting interviews, as well as of the village context and the villagers' daily activities.

This thesis demonstrates that increased commercialization and land use intensity has shifted farm households away from subsistence farming towards more intensive forms of farming, those which entail producing large quantities of high value crops based on the principle of profit maximization. The agricultural systems themselves have also changed, characterized as they are now by the increased use of new technologies such as new crop varieties, growth hormones, fertilizers, machinery and chemical pesticides. Pesticides – including herbicides, insecticides and fungicides – play a major role in the pest management activities employed in modern forms of agriculture, much more so than traditional pest management practices. Chemical inputs have become part of modern farmers' lives, with high yields and good looking products being the main benefits derived from their use. However, while pesticides can control pest populations effectively during their initial application, over time pests can develop resistance to the chemicals used, and at such times pest populations can increase suddenly, necessitating the even greater use of pesticides. Over the long run, it is inevitable that such farmers will not be able to avoid both crop losses and incurring higher costs, which together can lead to agricultural failure. Intensive pesticide applications not only influence agricultural production; the residues left can be found in the air, in food, soil and water sources, causing a number of negative side-effects. Furthermore, the use of such chemicals can damage agricultural land by harming beneficial insect species and reducing concentrations of essential plant nutrients in the soil, as well as cause severe health problems for local people. In response to the chronic overuse and misuse of pesticides in agriculture, there is a need to improve the understanding of the effects of the implementation of good agricultural practices. This thesis also provides an evaluation of the effectiveness of the Thai Q-GAP standard, with the results showing that farmers who follow the public GAP standards use pesticides in the same way as those who do not, due to a lack of farm auditing, an overly rapid introduction and expansion of the program, a lack of understanding of the purpose of the program among farmers, and a lack of alternative pest management methods being available. This thesis also sheds lights on the introduction of a range of pesticide use reduction strategies, such as an environmental tax and incentives for the adoption of IPM. The results show that IPM needs to be promoted in a policy package, if it is to achieve the desired reduction in pesticide use. The following paragraphs highlight some of the constraints on pesticide use reduction in Thailand, and also the opportunities available to introduce sustainable farming in the highland areas of the country.

6.2 Land use change and pest management methods

The results of this study, as well as that of Schreinemachers (2013), show that agriculture in Thailand has over recent decades shifted from the use of farming systems based on swidden agriculture, to the more intensive use of land based on shorter fallow periods, as well as the use of permanent fields, irrigation and agro-chemicals. Industrialization has had a significant influence on agricultural production in the country in terms of creating a shortage of rural labour, which in turn has increased the use of chemicals and other labour-productivity enhancing inputs. Also the demand for Thai agricultural products has become global creating additional pressure on land use. This thesis illustrates clearly that rice has been replaced by a number of cash crops. New crops based on market demand, such as strawberries, tomatoes and Japanese spring onions, have been introduced. Due to the need to increase productivity, the use of variable inputs as well as fixed costs has risen constantly. Irrigation periods have also been extended. As many farmers have started to grow high profit crops in response to market demand rather than based on land capacity, so investment in land improvement initiatives has become highly significant, in order to match high agricultural yield expectations. This thesis has also provided evidence that land use intensification across the whole region has led to a reduction in the variety of pest management methods used. Pesticides have been progressively and more generously applied as land use intensity levels have increased, and as farmers have given up their traditional pest management practices such as pulling-out weeds, and trapping or handpicking insects. Due to farmers' lack of skills in terms of cash crop cultivation and the pressure brought-about by pest infestations, farmers in the region have had to increasingly rely on the use of synthetic pesticides. They reported to be generally satisfied with the level of crop protection offered by pesticides. The results of this research show that there is a strong correlation between gross margins, land use intensity and pesticide application levels. Farmers with high levels of land use intensity tend to rely solely on pesticides, especially insecticides and fungicides, to control pests. Such farmers also apply 16 times the amount of pesticides than those who farm at lower levels of intensity, believing that using more chemicals will enhance profits. However, this thesis has found that there are also other factors that may influence pesticide use levels. For example, the availability of pesticides on the market has an influence, as does private sector marketing activities carried out by middlemen, the labor savings that can be made, a reduction in the risk of crop losses – those that directly affect farmers' credit repayment ability, and a lack of information regarding IPM being made available. All these influences render pesticides the only pest control choice for farmers (Atreya, 2007; Castella et al., 1999; Grovermann et al., 2013; Pedlowski et al., 2012). This thesis demonstrates that land use intensification was not associated with a safer use of pesticides, pesticide handling practices do not improve in accordance with land use intensity, and the number of farmers who mix the pesticides before spraying is even higher when land use intensity is high. The lack of awareness about the risks associated with pesticide use and the incorrect assessment of pesticides' benefits incentivize farmers to use more of the chemicals, and this has an adverse impact on human health (Lamers et al., 2013; Ngowi et al., 2007; Thapinta and Hudak, 2000). This thesis has revealed that many farmers in the study area experience dizziness, nausea and vomiting after handling pesticides, 47% of the applicators reported they regularly felt dizzy and 25% that they regularly experienced nausea or vomited. Similar studies carried out in northern Tanzania found that 68% of farmers feel sick after spraying pesticides, with the most common symptoms including dizziness, headaches and nausea (Ngowi et al., 2007). A study in Sri Lanka also found that farmers mentioned suffering negative side-effects from pesticide use, including headaches, dizziness and fainting (Van Der Hoek et al., 1998). However, pesticides not only harm farm workers, but also those who live in local communities, consumers and local wildlife.

6.3 Commercialization and risk management

Commercialization has been accompanied by changes in the types of crop grown. In the past, the key crops grown in the upland areas of Thailand used to be upland rice, maize and legumes, often intercropped with various types of vegetable which were grown for home consumption. These subsistence activities were eventually replaced by the commercial growing of vegetables, fruit, flowers, coffee and tea. However, farmers' exposure to risk and their risk management approach as part of this commercialization process – moving from subsistence to market-oriented production systems. The results of this thesis show that the sources of risk for subsistence farms are mainly related to production activities, such as threats to water supplies, natural disasters, and crop pests and disease, as well as the loss of family labor. For commercial farming, the sources of risk are more diverse, being related to weather conditions, crop pests and diseases, plus market prices for agricultural products, input prices and credit access levels. In fact, market prices, pests and diseases become the dominant sources of risk to farm performance in the process of agricultural commercialization. Since different risks require different responses, farmers must adapt their farming practices to suit the risks they face. As a result, commercial farmers choose to monitor market prices, carry out contract farming, use diversified market channels, save money and choose the most profitable crops in order to minimize market risk. With regard to pests, commercial farmers tend to rely more on agrochemicals and pesticides, and their use has become a common strategy among such farmers. The results of this thesis clearly show that agricultural commercialization is associated with a rapid adoption of synthetic pesticides and an exponential growth in the quantity of pesticides applied per hectare. Also, with increasing commercialization levels, pesticide use is perceived as more useful. Commercialized farmers focus on the use of pesticides to reduce the risks posed by pests, subsistence farmers meanwhile, choose different strategies to manage risk; for example, through crop diversification, by improving storage facilities and by avoiding debt. This research also demonstrates that the level of commercialization helps determine whether pesticides are used or not, as well as the quantity of pesticides used. Furthermore, farmers' perceptions of the level of risk posed by pests also determine the amounts of pesticide used. The pest management strategies used by commercial farmers are also influenced by the crop types grown. For example, in the study area, it is clear that the percentage of farmers using pesticides, and the amount of pesticides used, is much higher among farmers who grow strawberries, chilies, Chinese cabbages, tomatoes and white cabbages when compared to those who grow subsistence crops such as rice and taro. The increase in cash cropping activities in the highlands of northern Thailand has provided farmers with higher incomes, but the internal costs of chemical pesticide use have also increased alongside this commercialization process, as have the external costs, and these latter costs have tended to be ignored by academic studies, which have tended to focus thus far on pest control and pesticide efficacy (Beach and Carlson, 1993; Burrows, 1983; Pingali and Carlson, 1985). The underestimation of the total costs of pesticide use has led to farmers using more pesticides than necessary and also to mishandling them. This thesis has shown that pesticide handling has not improved with increased commercialization in northern Thailand. On average, around 38% of farmers who use pesticides said they do not follow the instructions given on the product labels, 25% said they do not take into account the direction of the wind while spraying, and 48% of commercial farmers said they mix pesticides before spraying (the same figure being 12% among subsistence farmers). These results are similar to those of Atreya (2007), who also found that many farmers do not take note of the wind direction before and during spraying, nor do they read the pesticide labels.

As the Thai population continues to increase and the demand for food rises, it cannot be denied that farmers in the country will need to adapt their farming practices in order to increase crop production levels. The loss of crops due to pests is a serious problem for all farmers, and especially commercially-focused farmers, as pests can cause crop failures and have an adverse impact on farm incomes. As a result, it is likely that pesticides will continue to be used widely as a key part of farmers' pest management programs (Ruberson et al., 1998). Although the benefits of using pesticides are real, they may provide higher incomes and alleviate poverty in the short term (Cooper and Dobson, 2007); however, at the same time they also cause a number of problems. Farmers need to be made aware of the negative impacts their practices will have on the environment and on theirs' and others' health over the longer term, as well the economic sustainability of using pesticides.

6.4 Pesticide use reduction strategies

The change-over from using pesticides to practicing sustainable agriculture requires farmers to accumulate a lot of knowledge in order to combat pests and diseases. For example, they must improve their pest and disease observation and prevention skills, plus must try to reduce the amount of pesticides they use, and where they do use them, do so safely and wisely (Somers, 1997). Traditional pest control practices should not be completely ignored as part of such a move. The practices were designed by farmers over many generations. Farmers inherit this knowledge from within the family, and the practices display significant ingenuity and generally control pests quite efficiently. Traditional knowledge is quite rich (Altieri, 1984; Gliessman et al., 1981; Morales and Perfecto, 2000; Oldfield and Alcorn, 1987); therefore, farmers should adapt it based upon their own experimentations, experience and new information they receive. Traditional pest control practices represent a viable alternative to modern practices, and may be suited to sustainable agriculture in terms of reducing crop losses while at the same time minimizing any adverse environmental impacts (Kiruba et al., 2006). To adopt traditional pest control practices, it is necessary to understand farmers' traditional agricultural knowledge in relation to technical and cultural aspects, plus it is important to understand the ecological mechanisms which form the basis of such practices, so they can be adjusted to new situations (Gliessman et al., 1981; Morales and Perfecto, 2000).

IPM programs can help farmers in this regard, as they can enhance farmers' knowledge about natural enemies, pest control practices and reducing pesticide use. As part of food safety initiatives, IPM has received increased attention among Thai policymakers in recent years, but information on possible interventions is scarce and pesticide tax policies have had little effect on pesticide use in the country thus far. There are only a few tools able to model how changes in pesticide regulation affect pesticide reduction. Praneetvatakul et al. (2013) concluded that the combination of an environmental tax and additional, supportive measures is the best way to encourage farmers to change their farming practices. The MPMAS simulation results that are part of this thesis support the above proposition, and show that a trade-off between environmental protection and farm household incomes can be avoided if policymakers use the right economic instruments to constrain chemical pesticide use and motivate changes towards more integrated growing practices. A range of simulation experiments assess the effect of pesticide price increases through a tax without and with the introduction of integrated pest management methods and various other interventions that give farmers an incentive to switch to more sustainable methods of agricultural production. The simulation results have shown that pesticide taxes and subsidies given for using bio-pesticides, combined with the promotion of integrated pest management methods, are the most effective ways to reduce pesticide use. A tax alone has little effect on pesticide use, but the effect is substantial if combined with IPM. The right policy package can reduce average levels of pesticide use by up to 34%. Therefore, from a policy implementation perspective, bio-pesticide subsides can be introduced, as the infrastructure needed for input subsidies to be given is often in place. Also, promoting IPM among crops such as bell peppers and tomatoes may achieve factually higher pesticide use reductions. Also, in Thailand there is often disconnect between the commitments given and plans developed by policymakers, and actual practice. For example, not enough practical support comes from the government in relation to ecologically sound production methods, nor in relation to Thai products being sold on the domestic market (Kasem and Thapa, 2012). If there was a policy in place which allowed IPM innovations to take root among local communities, through support for IPM educational programs, maybe producers' low rate of IPM adoption would be tackled positively (McNamara et al., 1991). If this were to occur, sustainable pest control methods might be more widely adopted and implemented in Thailand. The introduction of public standards in relation to good agricultural practices (GAP) at the farm level might be an interesting alternative when wishing to address food safety among consumers and minimizing any negative impacts experienced by growers and the environment. Such best practices would also have significant potential in the development of agricultural sustainability if farmers understood correctly the role of the national GAP program. Some important issues with regard to implementing a national GAP program would also need to be addressed; for example, the need to clarify the roles and responsibilities of government agencies and the private sector, developing follow-up plans, and providing GAP training programs for farmers (Wannamolee, 2008).

6.5 Constraints on pesticide use reduction in the Thai highlands

Reducing farmers' level of reliance on pesticides has become an important issue in Thailand, as it has in many other countries which have experienced a rapid growth in pesticide use, and where the negative health and other impacts of this are having an adverse impact on society (Jungbluth, 1996). In Thailand, according to Agenda 21[5] and the Sufficiency Economy philosophy introduced in 1997 by His Majesty King Bhumibol, the country should pursue and pay attention to sustainable agricultural development policies. Many policies and projects aimed at sustainable agriculture have since that time been introduced, but have had little or no effect. The reason for this is that while supporting and promoting sustainable agriculture, the Thai government has at the same time supported conventional agriculture also. Likewise, there has been a lack of support given for the promotion for pesticide free or organic products on the Thai domestic market, as well as few policies introduced to influence customers to buy such products (Kasem and Thapa, 2012). Good agricultural practices were originally designed to be an effective tool introduced in response to pesticide overuse and misuse in the Thai agricultural sector. However, the findings of this thesis show that the fruit and

[5] Non-binding, voluntarily United Nations action plan on sustainable development.

vegetables grown under the public GAP standard do not use less hazardous pesticides than those grown outside the standards. The reasons for this include farmers' lack of understanding of the logic behind of the program, as well their lack of motivation to follow the guidelines, plus that the Q-GAP program does not recommend any alternative practices that are suitable for farmers, especially in relation to pest management. Farmers almost entirely depend on synthetic pest control. This thesis has also found evidence that the quality of GAP certification is poor as program resources for training and auditing are spread too sparingly over the large group of participating farmers. Likewise the strong focus on food safety suggests that the government is mostly concerned with limiting the consequences of pesticide overuse and misuse rather than addressing the root cause of the problem. There is also a problem of overlap between Q-GAP and IPM. IPM as a concept is linked to Q-GAP in the policy documents, but most farmers never receive IPM training or concrete suggestions as to how to use the techniques therein. Q-GAP and IPM implementation challenges can be assessed on two levels. First, at the producer level there are several challenges, such as a lack of understanding, low motivation levels, insufficient awareness about food safety issues and labor shortages. Second, at the institutional level there is a lack of collaboration between researchers and extension services, and farmers are generally not involved in the research process. Also, there are insufficient training programs run, plus government auditors tend to be inexperienced (Morales and Perfecto, 2000; Wannamolee, 2008).

As mentioned above, a major problem faced when wishing to promote sustainable agriculture and food safety among farmers is that they do not fully understand the underlying rationale behind such programs, nor the guidelines used, and this prevents them from being motivated to adapt or follow such practices. Even though policies are an important driver of change in agricultural systems, farmers themselves still need to learn about and become more aware of the impacts of their behavior. Many studies ascribe the mishandling of pesticides to a lack of knowledge, as many farmers are under trained and even illiterate (Hashemi et al., 2012; Ibitayo, 2006; Mokhele, 2011; Palis et al., 2006). The results of this thesis show that farmers with more experience in the agricultural sector are less likely to use pesticides. Farmers' education and knowledge levels have an important impact at every stage of the decision making process, so are important in determining agricultural performance, that which ensures the best economic outcomes for their farms, while minimizing ecosystem damage. In general; however, farmers in the rural areas of South and Southeast Asia have a lower level of education than those in other sectors (Sanne et al., 2004). This research found that 53% of highland farmers have no education certificates, and that 30% have completed only to primary school level. In general, farmers in such rural areas do not have the most up-to-date information on how to manage farms efficiently and economically; therefore, education is needed to help them keep abreast of fast-moving developments in agricultural technology and business management, as well as improve their agricultural skills. Another constraint faced by a large number of farmers in the rural areas of less developed and developing countries is insecure land tenure, which was however not examined in depth by this research. In Thailand, the Department of Land previously produced a 20-year plan that finished in 2004, and this included a Land Titling Program (LTP). The aim of this program was to extend land rights to a larger proportion of the population, helping to address rural poverty, increase land tenure security, and improve access to credit among land title holders. The program had a positive effect on regional economic growth, as it brought greater social stability, and facilitated sustainable resource management practices. However, the project did not complete its key task, as there are still 12 million people living in the country‘s uplands and forests, including ‘hill tribes’ and other communities, which live under communal forms of tenure which have no legal basis. A significant number of these people have not benefited from the government’s land titling activity (Bowman, 2004; Burns, 2004; USAID, 2011). This thesis confirms that in the study areas, the percentage of highland farmers who hold secure land title is rather low, at only 16%, while 76% of farmers have no title to the land under cultivation. It also found that 8% of farmers hold insecure land title documents such as the STG and SPG. This may explain why it is difficult to incentivize Thai highland farmers to make their agricultural activities more sustainable. As farmers who have insecure land rights are unlikely to make an effort at improving their management of the land over the longer term (Deininger, 2004; Feder and Onchan, 1987).

6.6 Opportunities for sustainable farming within Thai highland agriculture

The appropriate use of pesticides requires, not only an understanding of their proper use and their impacts, but also responsibility on the part of governments, the pesticide industry, pesticide users and also consumers. At the national level in Thailand, stricter pesticide regulations, the removal of pesticide subsidies and the introduction of an environmental tax on pesticides need to be implemented; however, even these actions will not be enough to address the problem of high pesticide demand. This thesis demonstrates that the most effective solution to this problem is to introduce pesticide reduction policies while at the same time encouraging farmers to change their farm practices; for example, by promoting integrated pest management activities through introducing ‘Farmer Field Schools’ or government considers establishing special schools in highland areas at which farmers can acquire farming knowledge. Policymakers, researchers and farmers need to work together in order to encourage the use of sustainable pest management activities. More detailed policy-oriented studies are needed to identify policy options to support farmers in their transition to market-oriented production. Policy makers should support scientists with their research, as well as support the dissemination of traditional pest management knowledge, promote locally available resources and adapt any pest management approaches to the more intensive production context. They should also promote soil health as a part of a conservation agriculture approach, support farmers in their use of good seeds – because a healthy plant can better resist pest attacks – and pass knowledge on to farmers regarding the negative impacts of chemical product use, as well as offer training at the local level on how to use pesticides wisely. Meanwhile, agricultural research should try to adjust traditional methods to the current conditions experienced by commercial farms, and so facilitate the re-adoption of such methods. Researchers should also introduce alternative crops suitable for the Thai highland climate. However, the challenges faced not only exist on the producers’ side. Consumer demand is also an indispensable factor in helping to achieve agricultural sustainability, and has a strong effect on the agricultural market. Consumers want the highest quality at the lowest costs, but for them to figure out what the best quality is tricky. The provision of information alone may not resolve this problem, as information can be ignored, misinterpreted or simply create confusion (Grunert, 2005). To understand the role of a consumer need to be clarified by further research. Therefore, to achieve sustainable agriculture is a complex challenge, requiring cooperation among all relevant sectors as well as a true understanding of the problems and limitations that exist. Most importantly, the level of social responsibility held by farmers, consumers, the pesticide industry and the government is an integral part of this development.

6.7 References

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