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The declining profitability of litchi orchards in northern Thailand: Can innovations reverse the trend?

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Abstract

Litchi is an important crop in the mountainous part of northern Thailand yet its profitability has declined during the last 15 years. The replacement of litchi fruit orchards for seasonal flowers and vegetables has external costs related to increased levels of erosion, pesticide use, and irrigation water use. Using a combination of financial analysis and agent-based modeling, the paper *ex-ante* assesses the impact of four technologies—artificial flower induction, small-scale cooperative fruit drying, post-harvest treatments to extend the shelf-life of fresh fruits, and greater irrigation efficiency—in terms of profits, farm incomes, litchi acreage, erosion, and pesticide use. The model was calibrated to one watershed in Chiang Mai province where economic development has been rapid. Although each technology substantially increases the profitability of litchi growing, scenario analysis shows that this is not enough to stem the decline in litchi orchards in the study area. To achieve this, the innovations would have to be combined with an increase in the fresh fruit price at the farm gate from about 9 baht/kg at present to at least 12 baht/kg.

Keywords: ex-ante technology assessment, innovation adoption, agent-based modeling, bio-economic models

Introduction

China, Taiwan, India, Thailand, and Vietnam are the world's largest producers of litchi (*Litchi chinensis* Sonn.). Production in Thailand is concentrated in the northern uplands and is mostly produced by Thai farmers of Hmong and Karen ethnic origin.¹ During the last decade, the area of litchi orchards has more than doubled in northern Thailand (Office of Agricultural Economics, 2008). Average farmgate prices have, however, declined at the same time (**Figure 1**). Domestic overproduction is probably the main cause of this decline and is exacerbated by the fact that the fruit harvest in northern Thailand is concentrated in only a short period from the end of May till the end of June.

Low and declining litchi prices have lowered profits to farmers, who in some regions have reduced orchard management, and in some cases have cut down trees. This trend can be seen as a logical and perhaps necessary adjustment in response to relative price changes: the litchi area expands in more remote areas that are opening up to markets (i.e., Withrow-Robinson *et al.* 1999), while it shrinks in economically well-developed areas with more profitable alternatives. Yet, the loss of fruit trees in some areas has raised environmental concerns as those more profitable alternatives, such as flowers and vegetables, could worsen current problems of soil erosion, rapid runoff and risk of flooding, environmental contamination with pesticides, and loss of biodiversity.

Responding to these concerns, scientists have been developing technological innovations to boost the relative profitability of litchi cultivation. The objective of this paper is to *ex-ante* assess

¹ The northern region accounted for 85 percent of the Thai litchi output and 87 percent of the planted area in 2007 (Office of Agricultural Economics, 2008).

four of these innovations: off-season fruit production, small-scale cooperative fruit drying, improved irrigation management, and fruit preservation methods to extend shelf-life. The *ex-ante* assessment is performed in terms of profitability, farm household incomes, area under litchi orchards, irrigation water use, and levels of soil erosion and pesticide use. Profitability is assessed using a financial analysis of each innovation while the other indicators are assessed at a farm household and landscape level for which we use an integrated model of one watershed in northern Thailand. An agent-based modeling approach was selected to capture the heterogeneity of farm households in terms of opportunity costs and economic constraints.

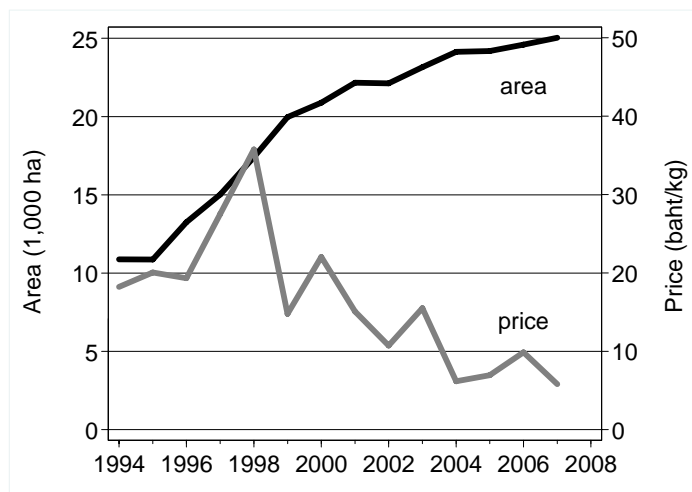


Figure 1 Farmgate price and planted area of litchi in northern Thailand, 1994-2007

Source: Office of Agricultural Economics, 2008

The paper proceeds in the next section with a description of the four innovations studied. This is followed by an account of the used methodology. A subsequent section shows the results, after which we reach a conclusion.

Theoretical background

The cyclical oversupply of agricultural products has been subject of considerable debate in agricultural economics (Cochrane 2003, Levins and Cochrane 1996, Binswanger and von Braun 1991, Marion and Wills 1990, Cochrane 1985). Technological progress stimulates productivity growth in agriculture, yet because the demand for primary commodities tends to be inelastic, the increase in demand does not keep up with the increase in output, thereby creating a downward pressure on the price. Farmers as a results need to adopt cost-saving or yield increasing technologies just to stay at the same level of profit. Willard Cochrane theorized this insight in the 1950s when trying to explain why farm incomes in the United States were persistently low in spite of the rapid technological progress of the time (Cochrane 1958).

Technological innovations that raise crop yields are usually popular with farmers and can bring short-term profits to those who are relatively quick to adopt. But as the innovation spreads, the long-run gains will be captured not by farmers in the form of higher profits but by consumers in the form of lower food prices. From the producer side, it is virtually impossible to organize producers to collectively control the volume of farm output, as for each individual farmer, the marginal revenue from selling one more unit of output outweighs the marginal cost of producing it. Some authors have argued that agricultural oversupply is not necessary a bad thing as declining food prices benefit consumers and keep the agricultural sector competitive internationally, while farmers can keep up profits through crop substitution or diversification (Binswanger and von Braun 1991).

We note that attempts at controlling oversupply, have mostly been through institutional rather than technological innovations. In European countries governments, for instance, have enacted quota on dairy production, while in viniculture there is large range of measures including quality

control and labeling, yield limits by wine growing associations, bans on new planting of vines, and government subsidies for grubbing-up existing vineyards. For tropical commodities, price controls through International Commodity Agreements and government-controlled marketing boards were common in the 1970s and 80s for coffee, cocoa, rubber, and sugar. These programs largely disappeared during the 1990s when the focus shifted to economic liberalization and structural adjustment. Although the innovations studied in this paper are all technological innovations, none of them aims at increasing litchi yields as such. Yield increasing innovations, such as planting litchi trees more densely, were not considered in this study.

Proposed agricultural innovations

Scientists from Chiang Mai University and Mae Jo University in Thailand in collaboration with scientists from Hohenheim University in Germany have been developing four technologies that could improve the profitability of litchi in northern Thailand. These technologies, shown in **Table 1**, are elaborated in the following.

- *Artificial flower induction.* In 1998, scientists found that the application of potassium chlorate (KClO_3) can artificially induce flowering in longan (Manochai *et al.* 1999). This invention allowed farmers to spread the fruit harvest more evenly throughout the year. Litchi and longan are closely related species and scientists hope to develop a similar method for artificial flower induction in litchi.
- *Small-scale cooperative fruit drying.* Litchi fruits must be picked when ripe as the fruit does not ripen off the tree. Yet farmers cannot store the fresh fruit as it has a vulnerable rind that is susceptible to decay (Jiang *et al.* 2006). Farmers must therefore sell the fruits immediately and have little negotiating power if markets are over-supplied. Drying of fresh litchi fruits in

a village cooperative could improve profit margins for farmers. Gas dryer machines are relatively easy to operate, yet the main challenge lies in organizing the community to manage the drying process. Another challenge is that both harvesting and processing need to be conducted in parallel and compete for scarce household labor.

- *Extended shelf-life of fresh litchi.* Though, Thailand is one of the world's largest exporters of fresh and processed litchi, only a quarter of the litchi output is exported (The Thai Customs Department 2008). Low quality of fresh litchi and a short shelf-life are the main constraints to increasing this export (Neidhart *et al.* 2007). Chemical treatment of fresh litchi to extend the shelf-life could therefore widen export opportunities.
- *More efficient irrigation.* Commercial litchi orchards in northern Thailand require irrigation. During the fruit setting and fruit development stage from January to May, the trees should receive water every 2-4 weeks for optimal growth (Menzel and Waite 2005). Conventional sprinklers are the most common type of irrigation in northern Thai litchi orchards but micro sprinklers or drip irrigation could save water.

Table 1 Four innovations to improve the profitability of litchi growing

Innovation	Type innovation ¹	Stage of development	Main advantage	Main disadvantage
Artificial flower induction	Agronomic	Research stage	Could improve average selling prices	Benefits might be short-lived if the litchi area expands
On-farm fruit drying	Mechanical	In use in some villages	Improves profit margins for fruit growers	Unattractive if fresh fruit prices are high
Shelf-life extension	Chemical	Research stage	Great price premium on high quality fruits	Benefits could accrue to traders rather than farmers
Drip irrigation	Mechanical	Available	Could reduce the competition for water	Benefits depend on the relative scarcity of water

Note: ¹ Based on the classifications proposed by Sunding and Zilberman 2001

Methodology

Profitability is a necessary but insufficient condition for farm level adoption. Resource constraints (land, labor, cash, and water), opportunity costs, and knowledge about the innovations also affect adoption. Because these aspects vary between farm households as well as over time, the adoption by farm households is neither instantaneous nor simultaneous. We therefore used a combination of financial analysis to estimate the profitability of each innovation and integrated modeling to simulate potential levels of farm level adoption and its economic and environmental impact in a heterogeneous population of farm households.

In agricultural economics, whole farm programming models are commonly used to identify possible resource constraints and to *ex-ante* assess the impact of agricultural innovations. As these models are linear in the equations, the outcomes tend to be sensitive to small changes in the resource constraints. Though abrupt changes can be a realistic outcome for technology adoption at the level of an individual farm, such abrupt changes are only rarely observed at a population level.

Berger (2001) and Schreinemachers *et al.* (2007) overcame this drawback of representative MP models by using an agent-based modeling approach. In such an approach, each real-world farm household can be individually represented as a computational agent. Though each agent can experience an abrupt change in its land use, the aggregate response of a heterogeneous population of agents tends to be smooth. Berger and Schreinemachers (2006) and Robinson *et al.* (2007) showed that a population of agents can be statistically estimated from farm household survey data.

This study used an approach called mathematical programming-based multi-agent systems (MP-MAS). It is a freeware software application developed at Hohenheim University.² The MP-MAS software sequentially calibrates an MP tableau to each individual farm household in a population keeps track of dynamics, and estimates technical coefficients using various biophysical models. As plot-specific data are organized in spatial layers, the model can be used to analyze spatial changes in land use and land cover. Table A1 shows a concise outline of the MP tableau. Farm households were assumed to maximize the expected net farm and non-farm income. Though the model runs at an annual time step, it includes monthly land, labour, and water constraints to capture multiple cropping, peak labour needs, and monthly variations in the irrigation water supply.

The four litchi-related innovations were included as separate activities in the tableau. Each agent was given an initial amount of litchi orchards corresponding to the observed area in the farm household survey. The fruit yield depends on the intensity of management and the age of the orchard. Each orchard was given a random age between 5 and 30 years to initialize the model.

Neef *et al.* (2000) observed that farmers in the Mae Sa watershed do not normally cut their orchards, even if unproductive. Most of the agricultural land is located inside the boundaries of the Doi Suthep-Pui National Park and the land could be claimed by the park authorities if it looks unused. Keeping the land covered with fruit trees is therefore more secure. The felling of orchards was therefore not included as an activity in the tableau; only after reaching the maximum lifespan can an orchard be felled.

² The software plus user manual can be downloaded from <https://mp-mas.uni-hohenheim.de/>

For each year in the simulation, two MP problems were solved for each agent, simulating investment and production decisions, respectively (**Figure 2**). Investments included the acquisition of new technologies and assets, such as the expansion of litchi fruit orchards and the purchase of a fruit drying machine. For the investment problem, which was solved first at the beginning of each simulation period, the agent optimized the expected net returns averaged over the lifespan of each asset, using an annuity cost approach. For the following production problem, new investments were then added to the available resources of the agent while the purchase price was subtracted from the agent's liquidity. This second MP problem optimized the annual production decision: the allocation of cash, land, labour, and water to a monthly cropping plan (Schreinemachers and Berger, 2006). Although the model integrated various biophysical aspects such as pesticide toxicity, soil loss, and precipitation, it did not include any feedback effects in the biophysical system.

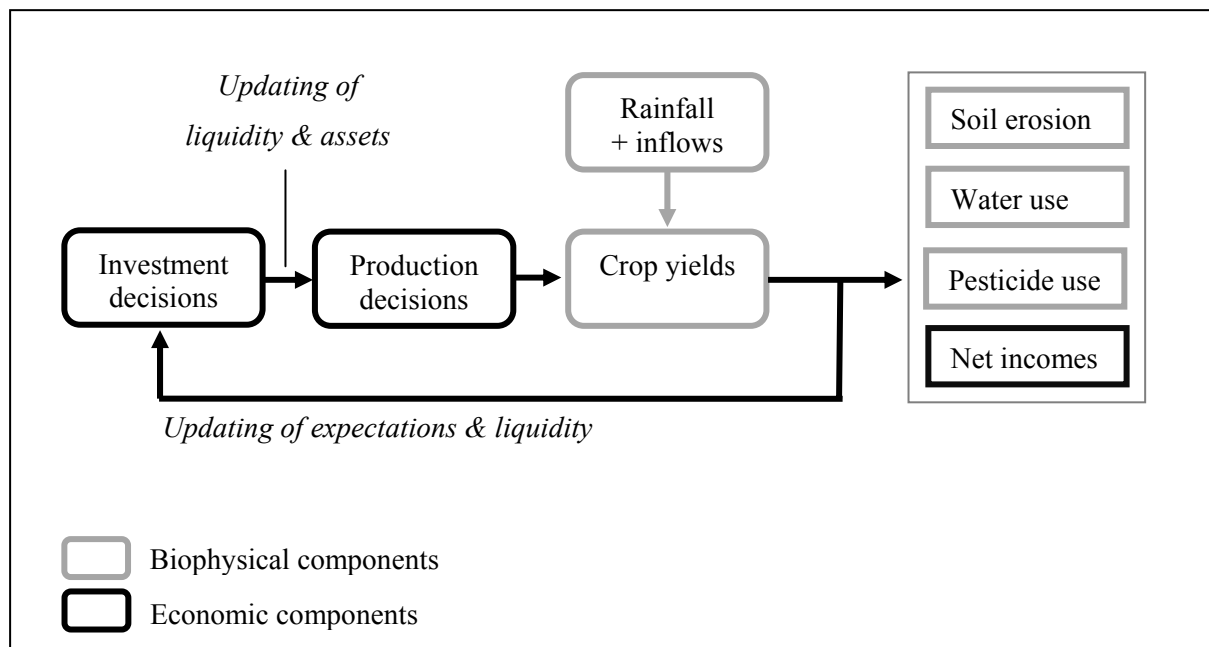


Figure 2 Dynamics of the agent-based decision model

A balance equation was used to update the amount of liquid means (LIQ) between periods:

$$LIQ_t = LIQ_{t-1} + [REV_t - VAR_t - FIX_t] - CONS_t - DEBT_t \quad (1)$$

in which the household revenues (REV) minus the variable costs (VAR) minus the investment costs (FIX) equals the total gross margin of the MP matrix.³ The profit that is not consumed (CONS) and is not used to repay loans (DEBT), is then added to the liquid means and is available to farm production in the next period.

Agents used adaptive expectations for investment and production decisions; this implies that the agents formed expectations about what will happen in the future based on what happened in the past. Following the implementation of adaptive expectations of Berger (2001), agents revise their expectations in each period in proportion to the difference between actual (X_{t-1}) and expected values (X^*_{t-1}) as:

$$X_t^* = X_{t-1}^* + \lambda * [X_{t-1} - X_{t-1}^*], 0 < \lambda \leq 1, \quad (2)$$

in which λ is the coefficient of expectations. This model of expectation formation is applied to prices, water supply, and crop yields. The assumption of adaptive expectations is only realistic if there is no systematic trend, as real farm household would otherwise develop foresight. After agents decided on investment and production, the solution vector of the MP matrix was recalculated for each agent using actual values.

³ Note that the amount of cash not used for investments (FIX) or the purchase of variable inputs (VAR) equals the amount of short-term deposits (DEP): $LIQ_{t-1} - FIX_t - VAR_t = DEP_t$. Another way of writing equation (2) is therefore: $LIQ_t = DEP_t + [REV_t - CONS_t - DEBT_t]$, that is liquid means at the end of the period equals deposits plus new savings.

Crop yields were modeled following the FAO CropWat model (Smith 1992, Clarke *et al.* 1998).

The crop-water requirement (CWR) for crop c in month m is the product of a crop coefficient (KC), the potential evapotranspiration (ETO), and the planted area ($Area$):

$$CWR_{cm} = KC_{cm} * ETO_m * Area_{cm} \quad (3)$$

The CWR could either be met through irrigation (IRR) or rainfall, which was converted into effective rainfall (ER) to capture the share of rainfall actually available to the crop, depending on its growth stage. The amount of water actually supplied (CWS) was then as follows:

$$CWS_{cm} = ER_{cm} + IRR_{cm} \quad (4)$$

For lack of detailed data from the study region, the quotient of crop water supplied and the crop water requirement were simply averaged over all months with non-zero crop water requirements:

$$Kr_c = (1/m * \sum(CWS_{cm} / CWR_{cm}) \quad | \quad CWR_{cm} > 0) \quad (5)$$

The crop growth model assumed that the crop yield was lost if the average Kr fell below 0.5, while for Kr values greater than or equal to 0.5 the Kr value was multiplied by the crop yield potential (YPOT) to simulate the actual crop yield (Y_c):

$$Y_c = \begin{cases} Kr_c * YPOT_c & \text{if } Kr_c \geq 0.5 \\ 0 & \text{if } Kr_c < 0.5 \end{cases} \quad (6)$$

Rainfall, groundwater, and surface water were the sources of crop water supply in the model. Daily rainfall data were generated following Yaoming *et al.* (2004). Agents, as their real-world analogues, derived irrigation water from either groundwater or streams (surface water). Groundwater was assumed to give an unlimited water supply but only to those agents that had already access (about 11 percent in the central valley, as identified from the survey). Surface water needed to be shared among agents in the same village. The irrigation water supply (IRR)

was approximated using a backward calculation on observed pattern of land use, irrigation methods, irrigation sources, and effective rainfall. Let $IEFF_{jck}$ be the efficiency of irrigation method j used on crop c by a household k . The irrigation water use of household k was then calculated by summing the irrigation water use over all months and crops as:

$$IRR_k = \sum_m \sum_c (CWR_{ckm} - ER_m - GR_{mc}) * IEFF_{jck} \quad (7)$$

in which GR was the groundwater use. The sum over all households in an area that shared a common water source thereby approximated the total volume of the surface water for irrigation.

Outcome indicators

Four outcome indicators were used to analyze the simulation results:

- *Area under litchi fruit orchards*, an increase of which is the basic objective of the proposed innovations.
- *Net farm household incomes*, calculated as the sum of farm and non-farm income.
- *Pesticide loads* were quantified using the Environmental Impact Quotient (EIQ) method (Kovach *et al.* 2008). Following this method, an average field use rating, which was a proxy for toxicity, was calculated for each crop.
- *Erosion soil loss* was quantified using the Revised Universal Soil Loss Equation (RUSLE) in which the amount of soil loss is a function of the steepness and length of the slopes, rainfall erosivity, soil erodibility, crop choice and crop management, and erosion control measures.

Study area and data collection

The study was conducted in the Mae Sa watershed area. This watershed, 140 km² in size that lies about 40 km northwest of Chiang Mai city, has an elevation ranging from 300 to 1700 meters

a.s.l. There are an estimated 1,309 farm households with a permanent residence in the watershed and 313 of these grow litchi (24 percent). Most of the litchi is grown in the upper parts of the watershed at elevations above 1000 meters by Thai citizens of Hmong ethnic origin. In the seven Hmong villages in the watershed, 39 percent of the agricultural land area is occupied by litchi trees.

Because of the proximity of the watershed to Chiang Mai city and other urbanized areas, the opportunity costs to litchi growing are high. Especially with low litchi prices, many households choose not to manage their litchis but to perform non-farm work or intensify field crop production, sometimes by cutting down orchards. The main alternative crops for upland farmers are cabbage, potato, carrot and cut flowers like rose and gerbera. The research area is therefore not representative for agricultural in northern Thailand, yet if the study would show that the innovations make litchi growing competitive in the Mae Sa watershed then it would certainly be competitive in most of northern Thailand.

Data about each of the four innovations were collected from secondary sources, such as publications, and through interviews with scientists developing these technologies. As some technologies are not available at this moment, the financial assessment uses assumptions on the costs and benefits and tests the results for alternative assumptions. To calibrate the land use model, farm household data were collected using a structured questionnaire survey on a random sample of 303 farm households from October to November 2006. Secondary data were used in addition to calibrate the model, such as crop water requirements and precipitation data. All pesticides used in the watershed were converted to EIQ values based on their active ingredients and application rates.

Results

Average profitability of litchi growing in the Mae Sa watershed

Average fruit yields of litchi orchards in the Mae Sa watershed area are about 3.1 tons/ha. At an average selling price of 9 baht per kilogram this creates revenues of about 28 thousand baht/ha. Since the variable input use is relatively low, the profitability of litchi is mostly a function of the price of fresh litchi and the valuation of labor, as shown in **Figure 3**. At a current wage rate of 100-140 baht per man-day and a litchi price varying between 6 and 12 baht/kg, profits range from -7 to 15 thousand baht/ha. At an average wage rate of 120 baht, the break-even-point for litchi growing is 7.7 baht/kg.

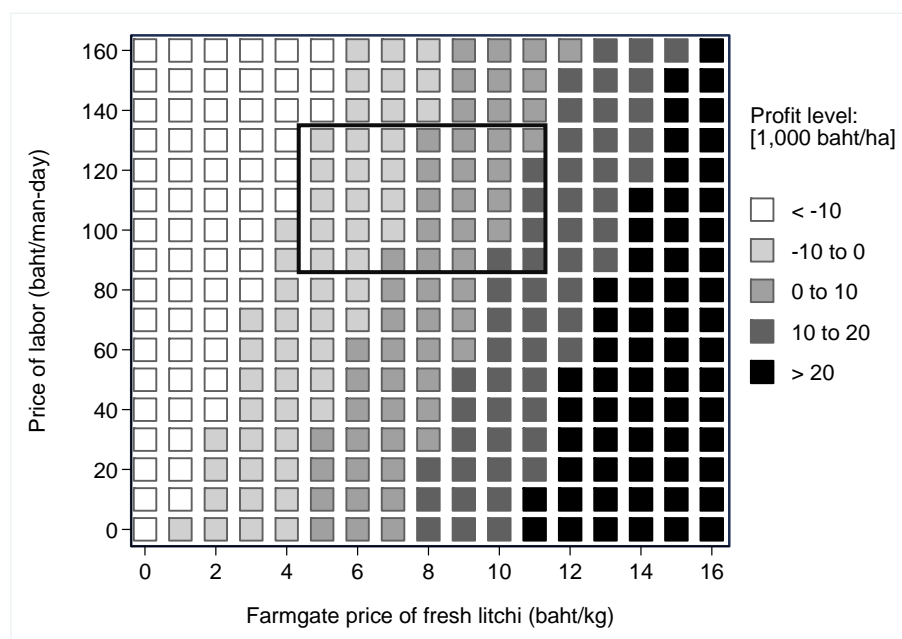


Figure 3 Profitability of litchi growing by levels of selling price and wage rate

Source: Own estimates from 2006 farm household survey

Note: The rectangle indicates the current range of profits

Figure 4 compares the profitability of litchi and off-season litchi with that of various other crops grown in the watershed, excluding the cost of labor, water, and land. Because of the great differences in altitudes within the study area, not all crops are substitutes. Though, the graph might suggest a certain pessimism about litchi growing in the watershed, whether farm households will grow it not only depends on the relative profitability but also on land, labor, water and cash constraints which are scrutinized in the integrated analysis.

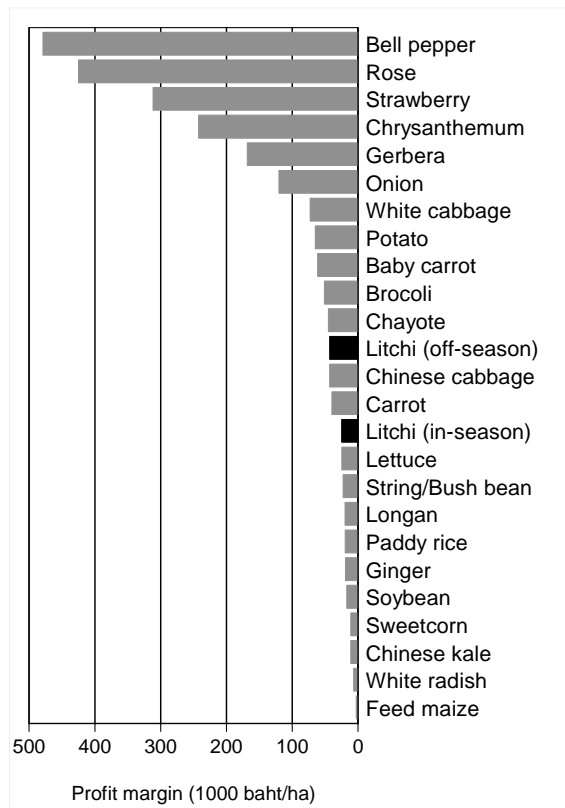


Figure 4 Profitability of litchi compared to other crops

Note: Calculations excludes all labor costs and the cost of irrigation infrastructure except for bell pepper.

Average profitability of the innovations

The costs and returns of artificial flower induction were based on the experience in off-season longan production. Artificial flower induction in longan has been widely adopted since its

introduction in 1998, during the so-called “longan mania” the planted area increased 7 percent annually from 1998 to 2007. **Figure 5** shows the average monthly price for longan fruits. The average in-season fruit price from July to August was 12.3 baht/kg (sd=5.6) while the average off-season price was 21.7 baht/kg (sd=6.1), which suggests an average premium of about 9.4 baht/kg (76 percent) yet average fresh fruit prices declined during this period. Based this experience, a price premium of 40-60 percent can be expected for off-season litchi. At a fruit price of 9 baht/kg and an average labor price of 120 baht/man-day, this would translate into an average increase in profits from about 7.57 thousand baht/ha for in-season harvesting to 21.06 thousand baht/ha for off-season harvesting (**Table 2**).

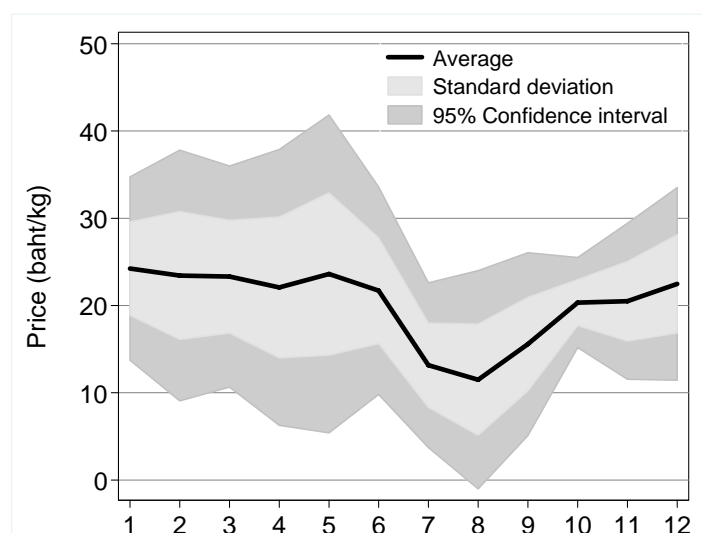


Figure 5 Average monthly farmgate price of longan in northern Thailand, 2001-2008

Source: Office of Agricultural Economics, 2008

The break-even-point of litchi dryer was estimated to lie at a fresh fruit price of 8.24 baht/kg. At fresh fruit price above this price, selling the fresh fruits brings a greater profit than drying. Because fruit drying is labor intensive, the profits are substantially higher if own household labor is not accounted for. Excluding own labor costs, the fruit drying is attractive also at higher fresh

fruit prices. The possibility of compensating low litchi prices with fruit drying is an attractive option as it increases profits but does not increase the fresh fruit supply and does therefore not suppress fresh litchi prices.

Table 2 Average profitability of litchi growing and four innovations under alternative assumptions about household labor and farmgate prices, in thousand baht/ha

Innovation	Including the cost of household labor			Excluding the cost of household labor		
	6 bt/kg	9 bt/kg	12 bt/kg	6 bt/kg	9 bt/kg	12 bt/kg
Current litchi orchards (=baseline) ¹	-5.19	4.18	13.56	3.40	12.77	22.15
Artificial flower induction ²	6.06	21.06	36.06	14.65	29.65	44.65
Cooperative fruit drying ³	1.80	1.80	1.80	34.12	34.12	34.12
Improved shelf-life / fruit quality ⁴	11.49	29.21	46.93	20.08	37.80	55.52
Greater irrigation efficiency	-5.51	3.86	13.24	3.08	12.45	21.83

Notes: ¹ Average yield=3,125 kg/ha. Average cost=20.56 thousand baht/ha, with labor costs valued at 120 baht/man-day. ² Farmgate price premium 60%. ³ Profits per kg fresh fruit were multiplied by the average yield. This profit is irrespective of the fresh litchi price as the fresh litchi input was valued at the production cost and not at the selling price ⁴ Assumed price premium of 89%.

Figure 6 shows average farmgate selling prices for five grades of fresh litchi in 2007. While the average farmgate price of fresh litchi was 5.8 baht/kg in 2007, the price of graded litchi 10.8 baht/kg, which is 89 percent higher. This suggests that improving fruit quality could dramatically improve litchi prices for farmers. Shelf-life extension methods could contribute to this, but it is unclear at what stage in the market chain these benefits would accrue: to litchi growers, traders, or exporters? Also unclear at the moment is what the costs of the chemical preservatives would be, so the profitability of shelf-life extension methods cannot be answered with certainty. In the integrated analysis later on, we therefore ask what the price premium for farmers should be to reverse the decline in litchi orchards.

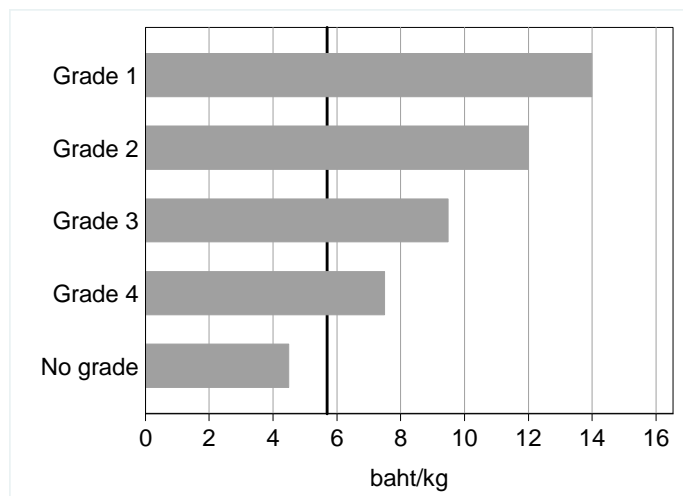


Figure 6 Farm gate litchi price by grade, 2007

Source: Office of Agricultural Economics, 2008

The irrigation efficiency of sprinklers is about 70 percent, while that of micro sprinklers is about 80 percent. Although the price of a micro sprinkler head is about double that of a conventional sprinkler head, the main cost of the irrigation infrastructure is PVC pipes rather than sprinkler heads. As a result, the total per hectare cost of micro sprinklers is only about 4 percent greater than for conventional sprinkler. As irrigation water has no direct cost, the attractiveness of micro sprinklers depends on the relative scarcity of this resource.

In summary, the results of the financial analysis showed that the profitability of the innovations crucially depends not only on the fresh fruit prices but also on the valuation of household labor and irrigation water. These resources have no direct monetary cost but have a scarcity value and an opportunity cost that varies between households. To include these in the analysis, we turn to the integrated assessment.

Results of the integrated assessment

The objective of the integrated analysis is to put the profitability of each single innovation into the context of the whole farm and farming system while capturing the heterogeneity in resource conditions between households.

The model fit was quantified with a regression line through the origin of predicted versus observed land use. For details we refer to Schreinemachers *et al.* (2009). The Parameter coefficient equaled unity at the watershed (1.00), was close to unity at the village level (0.83) but was low at the farm household level (0.23). This suggests that although each agent in the model does not exactly represent a real-world farm household, at a watershed or village level, agents on average are a good representation of reality.

The impact of the innovations was assessed by comparing a baseline scenario, which represents current conditions without the innovations, with alternative scenarios with the innovations. The simulation was run for a period of 15 years from 2006 to 2020. Although the MP-MAS model can simulate the communication of innovations among agents (e.g. Berger 2001), the scenarios here assume that all agents have simultaneous access to the innovations in order to assess the maximum impact the innovations could have.

In the baseline scenario, the model simulates an average decline in litchi orchards of 2.30 percent annually. **Table 3** shows that the four innovations are able to reduce this decline but not to reverse it. Artificial flower induction, assuming a price premium of 60 percent, and fruit drying have the strongest positive effect on the litchi area, lowering the decline to 1.92 and 1.82 percent, respectively. If simultaneously introducing all three innovations then the litchi area declines with 1.42 percent annually between 2006 and 2020. The simulation results also suggest that the

innovations would have a positive but small effect on pesticide loads and soil erosion in the watershed, though no significant effect on average farm incomes (**Table 3**).

Table 3 Simulated effect of the three innovations, 2006-2020

Scenario	Annual % growth in litchi area ¹	Index numbers (baseline=100)			
		Litchi area	Household income	Pesticide use	Erosion soil loss
1. Baseline scenario	-2.30	100	100	100	100
2a. Off-season, 40% price premium	-2.03	105	100	98	99
2b. Off-season, 60% price premium	-1.92	107	100	98	99
3. Cooperative fruit drying	-1.82	108	100	99	98
4. Improved irrigation	-2.27	101	100	100	99
5. All innovations	-1.42	117	99	96	97

Note: ¹ Growth rates were calculated by fitting a linear regression line through the annual average values over the period 2005-2020, in which 2005 represents the initial conditions which is the same for all scenarios.

The decline in litchi orchards occurs, in spite of a rapid adoption of the innovations as shown in **Figure 7**. After 15 years, the adoption rate is 89 percent for artificial flower induction, 36 percent for on-farm fruit drying, and 57 percent for improved irrigation equipment.

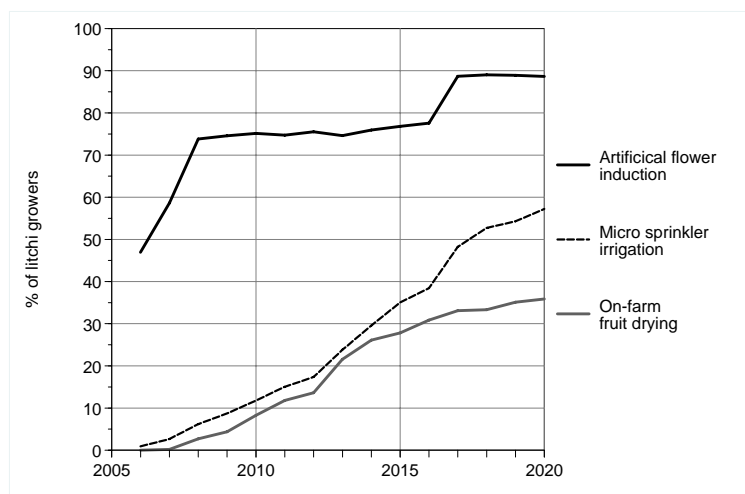


Figure 7 Simulated diffusion of innovations, 2006-2020

Note: This is based on the “All innovations scenario” in Table 3

Table 4 Results for alternative fresh fruit prices, with and without innovations, average values 2006-2020 expressed as index numbers (baseline scenario=100).

Fresh litchi price	Litchi orchard area		Household income		Pesticide loads		Erosion soil loss	
	with	without	with	without	with	without	with	without
6 bt/kg	98	94	100	100	100	101	101	101
9 bt/kg	106	100*	100	100*	97	100*	98	100*
12 bt/kg	124	111	99	99	94	98	94	97
15 bt/kg	140	122	98	98	90	94	89	92
18 bt/kg	148	132	101	98	86	92	87	89
21 bt/kg	153	139	104	99	85	90	86	86
24 bt/kg	156	145	108	102	84	89	85	85

Note: * Baseline scenario (same as in Table 4).

The impact of innovations to improve the fresh fruit quality could not be assessed because of uncertainty about the costs and benefits at the farm level. We therefore analyzed what level of fresh litchi prices would be needed to reverse the decline in litchi orchards. Fourteen scenarios were analyzed to answer this question with fresh fruit prices ranging from 6 to 24 baht per kilogram, as shown in **Table 4** and **Figure 8**. Without innovations, the area stabilizes at about 15 baht/kg, but if all innovations would be available then there would be a moderate growth in litchi orchards at a price of 12 baht/kg. As it takes about five years for newly planted litchi trees to give a first fruit yield, the effect on current incomes is small; yet the effect of higher prices on pesticide use and soil erosion would be substantial.

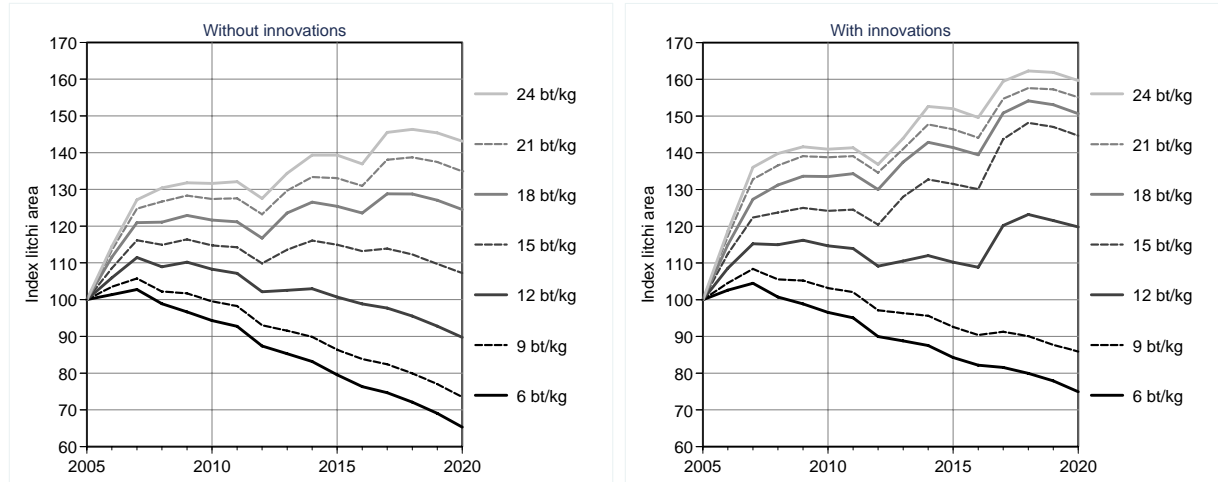


Figure 8 Simulated area under litchi orchards under alternative price scenarios, index 2005=100

Conclusion

Artificial flower induction, on-farm fruit drying, and methods to extend the shelf-life of fresh fruits increase the profitability of litchi growing, which is currently low, ranging from -7 to 15 thousand baht/ha. The profitability is, however, sensitive to the price of water, household labor, and land which have no direct monetary cost but only have an opportunity cost. The profitability of the innovations is a necessary but an insufficient condition for stemming the decline in litchi orchards. Simulation results of the agent-based watershed model showed rapid adoption rates of the innovation but no reversal in the downward trend in litchi areas. The results furthermore showed that the innovations would yield a moderate reduction in the growth of pesticide use and erosion soil loss. To reverse the decline of litchi orchards, the innovations would have to be combined with a fresh fruit price of at least 12 baht/kg.

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Table A1 Part of the MP model showing the decision-making about litchi-related activities in simplified matrix format

Constraint	Annuals (ha)		Invest in fruit dryer	Invest/produce litchi (ha)					Hire labor in/out	Sell crops (kg)	Dry litchi (kg)		Sell litchi (kg)		Buy inputs (baht)	Right- hand- side
	Rain- fed	Irri- gated		high input	low input	h. input + drip	h. input + off- season	h. input + drip + off.			in season	off- season	in season	off- season		
<i>Objective function</i>			-C						±E(C)+E(C)		+E(C)	+E(C)	+E(C)	+E(C)	-E(C)	
<i>Resources (monthly)</i>																
Land (ha)	+1	+1		+1	(+1)											≤ (R)
Labor (man-days)	+A	+A		(+A)	(+A)	(+A)	(+A)	(+A)	±1		(+A)	(+A)				≤ (R)
Sprinkler irr. (lit/sec)		+A		+A	+A		+A									≤ (R)
Drip irr. (lit/sec)		(+1)						+A								≤ (R)
<i>Resources (annual)</i>																
Cash (baht), annual															+1	≤ (R)
Variable inputs (baht)	+A	+A		(+A)	(+A)	(+A)	(+A)	(+A)				(+A)			-1	≤ 0
Fruit dryer capacity			-A								+1	+1				≤ (R)
Litchi orchards (ha)				±1	±1	±1	±1	±1								≤ (R)
<i>Crop yields (tons)</i>																
Annual crops	E(-Y)	E(-Y)								+1						≤ 0
Litchi in-season				E(-Y)	E(-Y)	E(-Y)					+1		+1			≤ 0
Litchi off-season							E(-Y)	E(-Y)				+1		+1		≤ 0

Notes: C=Price coefficients, A=Technical coefficients, Y=Crop yields, R=Available resources, I=Available innovations, E=Expected values. Values in brackets are adjusted inside the model, of which values in bold are agent-specific.