Trade-offs between the Economic, Social and Environmental Objectives in Optimal Resource Management in the Fang Watershed, Chiang Mai Province, Thailand

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ABSTRACT

The objective of this study was to find the relationships and trade-offs between the citrus farms and the natural resource management at the watershed level. Data collection were done among 149 households in Chai Prakan, Fang and Mae Ai districts, Chiang Mai, Thailand. A weighted multi-goal programming was employed with eight model objectives/goals covering economic, social and environmental aspects. These were maximization of annual equivalent value (AEV) of cropping systems, employment and revenue from non-timber forest products and minimization of revenue variance, dependence from external inputs, expenditure on pesticides, nitrogen use, soil erosion. This study looked at trade-offs between decisions at the farm and watershed level, economic and environmental objectives, economic and social objectives, and social and environmental objectives. If decisions on optimal land use were done at the farm level, farm land in the watershed would be allocated to mixed fruit trees and annual crops while if they were done at the watershed level, land would be planted to fruit trees and some forests and not so much annual crops. Trade-off analysis between different objectives revealed that expenditure on pesticides or nitrogen use as well as soil erosion could be substantially reduced for only a relatively small decrease in the annual equivalent value and employment. On the other hand, employment could not be much reduced without scarifying farmers’ income. Nevertheless, further reductions in the environmental goals would lead to rapid rates of reduction in employment and the annual equivalent value.

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Keywords: Trade-off, optimal and use, multiple goal Linear programming, environmental protection, cropping systems

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1. Introduction

The Fang watershed is located in the north of Chiang Mai province, Thailand, covering a total area of 1,948.5 square kilometers in the three districts of Chai Prakan, Fang and Mae Ai. This area is surrounded by mountains and is abundant with natural resources with most of the area belonging to national parks. Its cold weather is conducive to growing fruit trees, especially citrus. It is a major citrus producing area providing year-round produce through the stimulation of branch initiation to obtain continuous production and generating higher income for farmers (Junreanma et al. 2005). As a result, the demand for citrus planting areas has continually increased since 2000. Nevertheless, problems of air and water pollution from chemical use as well as conflicts over water for citrus production have emerged and raised concerns among nearby residents and the Chiang Mai population (Chowprayoon, 2005). A planted area of 6,400 hectares can have an estimated chemical usage of more than 600 tons per year distributed by heavy spraying (PCD, 2004; Junreanma et al. 2005).

The production of citrus was in response to market demand. This increased commercialization led to further excessive chemical use which affected the local population’s health as well as the environment. Citrus orchards in the watershed are located on sloping areas which are prone to soil erosion and soil degradation. The residues from the high chemical and fertilizer usage left in the soil were leached and contaminated the stream water. Consequently, this affected the soil acidity and the soil nutrient balance because of the high phosphorus and exchangeable potassium in the soil. In addition, there was reportedly an accumulation of diseases and pests in this area. These have resulted in a decrease in the citrus yield as well as product quality, which when combined with high input costs and low prices for the crop, resulted in a reduction in net returns and have caused a decrease in the citrus plantation area in the watershed for the last few years (Santassup and Verunrat, 2011). The citrus-based farming system in the highland watershed landscapes mentioned above revealed a conflict of interests in terms of income generation for farmers and maintaining sustainable resources and the environment of the watershed. Such scenarios require further study to determine the sustainability of the farming system when compared with the natural resource system. The objective of this study was to examine the relationships and trade-offs between the economic and environmental objectives, the social and environmental objectives and the economic and social objectives.

2. Research methods

There are many stakeholders involved for the use of watershed areas such as the Agricultural Office, National Parks, NGOs as well as farmers. The objectives of watershed land use are varied depending upon their own points of views. A model of watershed land use is constructed in this study to facilitate balancing of these objectives.

2.1. Selecting the goals for the watershed level

For this model, eight goals are chosen related to economic, social and environmental factors. The goals were selected to cover system properties, namely, productivity, social contribution, autonomy, stability, resilience. The selected goals of watershed management are: (1) annual equivalent value (AEV). AEV of cropping systems is a net income value in a year of the cropping systems in question by converting net present value of long term investment of a tree crop into a yearly income. If the cropping systems are annual crops, then gross margin is used; (2) revenue variation (RV). RV is the standard deviation of the average net revenue from 2009 to 2011; (3) employment (EMP). EMP is defined as labor use in crop production; (4) dependence on external inputs (ExIn). ExIn is measured by the value of external production inputs used; (5) nitrogen use (N). N is measured by quantity of nitrogen fertilizer use; (6) expenditure on pesticide (PEST). PEST is measured by the total expenditure spent on pesticide; (7) soil erosion (SOIL). SOIL is measured by tons of soil eroded from the land use; (8) revenue from non-timber forest products (NTFP). NTFP is measured by the value of income obtained from non-timber forest products.

The goals were given a score by the participating stakeholders which was then evaluated though the Analytic Hierarchy Process (AHP) method. The AHP is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s (Saaty, 2010) and has been extensively studied and refined since then. This study employed the AHP method to determine weights for the indicators at the farm scale by a participatory method from stakeholders in each farm type. Using this method and a software program called Ror Tor Sor developed by Ekasingh et al (2006, 2007), the weights of the goals
evaluated were then obtained (Table 1).

<table>
<thead>
<tr>
<th>Aspects</th>
<th>Category</th>
<th>Objective variables</th>
<th>Unit</th>
<th>Weight</th>
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<td>baht/rai</td>
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<tr>
<td>Social</td>
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<td>Maximization of employment</td>
<td>man-days</td>
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<td>Environmental</td>
<td>Autonomy</td>
<td>Minimization of dependence on external inputs</td>
<td>baht/rai</td>
<td>6.49</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>Minimization of revenue variance</td>
<td>baht/rai</td>
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<tr>
<td></td>
<td></td>
<td>Minimization of expenditure on pesticides</td>
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<tr>
<td></td>
<td></td>
<td>Minimization of nitrogen use</td>
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<tr>
<td></td>
<td></td>
<td>Minimization of soil erosion</td>
<td>ton/rai</td>
<td>13.39</td>
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<tr>
<td>Resilience</td>
<td></td>
<td>Maximization of revenue from non-timber forest products</td>
<td>baht</td>
<td>22.67</td>
</tr>
</tbody>
</table>

2.2. Optimization models

Models of land use were constructed as a representative for the watershed as a whole in order that the goals at each level could be optimized. They were analyzed using Multiple Goal Linear Programming (MGLP) which has been widely used to generate farm household and watershed land-use systems using land-use activities as building blocks (Lu et al. 2004, 2005; Roetter et al. 2007; Nidumolu et al. 2007; Nikkami et al. 2009; Sadeghi et al. 2009; Acosta-Alba et al. 2011). In this study, MGLP models used the goals value from current and constraint functions for the optimization of land use at the watershed level. In MGLP models, one main goal is defined by an objective function and others are described by constraint functions (Janssen and van Ittersum, 2007; Sittisak and Ekasingh, 2014). In this study, the analysis was conducted using the software program “Interactive Multiple Goal Linear Programming” (IMGLP), developed by Ekasingh et al., (2011).

The objective function for the MGLP model at the watershed scale is the minimization of the total deviations from the goals as follows:

$$\min \sum (w_w d_{w1}^- + w_{w2} d_{w2}^- - w_{w3} d_{w3}^+ - w_{w4} d_{w4}^+ - w_{w5} d_{w5}^+ - w_{w6} d_{w6}^+ - w_{w7} d_{w7}^+ + w_{w8} d_{w8}^+)$$

(1)

Where $w_w$ represents the weight of the $w$th goal and $d_{w}^-$ and $d_{w}^+$ are the negative and positive deviations of the $w$th goal. The set of goals determined the goal constraints. MxAEV and MxEMP are the achievable goal level to increase the annual equivalent value and employment in the watershed. MnExtln is the achievable goal level to decrease dependence on external inputs. MnRV, MnPEST, MnN and MnSOIL are the achievable goal levels to decrease revenue variance, expenditure on pesticides, nitrate use and soil erosion respectively. MxNTFP is the achievable goal level for revenue from non-timber forest products.

The model at the watershed level contains 84 decision variables consisting of cropping systems and off-farm work, employment and capital transfer per month, revenue from crop production, loans and repayments, food consumption, net annual revenue and deviations. There are 67 constraints consisting of goal constraints, land units (irrigated upland, rainfed upland, irrigated lowland and rainfed lowland), household labor and employment, loans and repayments (village funds, agricultural co-operatives, the Bank for Agriculture and Agricultural Co-Operatives (BAAC) and commercial banks), capital constraints, revenue from crops production, household consumption and net annual revenue.

2.3. Trade-Off Analysis

The trade-off analysis is expressed as the inter-relationship between two objectives using opportunity cost theory. The situation involves losing one quality of one aspect in return for gains in another. If one thing increases, something else must change, for example, an increase in citrus production could lead to an increase in soil erosion. The results will provide the decision maker with a deeper understanding into the relationship between the indicators, such as if we increase the farmers’ income, how will it affect other resource use? In this study, the trade-off analysis was obtained by the IMGLP-LPlan program mentioned earlier. The IMGP-LPlan gives optimal results over repeated runs using the methods involving use of restriction value for one objective as against another objective as presented by Lu et al. (2004).
3. Results

3.1. Trade-off between the farm and watershed levels

Sittisak and Ekasingh (2014) compared the optimal land use for the analysis at the watershed level with that where optimal farm level results were extrapolated to watershed level. It was found that the optimal resource use had vastly different patterns of land use as the results depend on whose points of view was being considered. Farm-level models recommended an optimal land use for the economic objective which was composed of mixed fruit trees (58% of the land use) and annual crops (42% of the land use). This was in contrast to the watershed model which recommended an optimal land use plan which was environmentally-friendly by planting fruit trees and forest. This reflects the differences in the objectives and their relative importance to each group of stakeholders. If the farmers are making the decisions, they are more concerned about economic income and employment than the environmental objectives. If the Fang watershed is managed and optimized with more priority given to the environmental objectives as opposed to the economic and social ones, we will see that it should be left largely as forest with a small proportion of fruit trees. The fruit trees planted in the Fang watershed should be those friendly to the environment rather than citrus e.g. coffee, tea or lychee. One cannot ignore the reality in the field as the farmers are the ones who make the decisions on land use. Their objectives and interests should also be recognized and some balance between the economic and the environmental objectives should be met. These results can be used as a basis for discussion between the farmers and the watershed officials so that some changes to land use can be achieved in order that the economic, social and environmental objectives can be more balanced.

3.2. Trade-off between the economic and the environmental objectives

The trade-off between the annual equivalent value and the expenditure on pesticides showed that when the expenditure on pesticides was reduced by 40 per cent, there was only a 9 per cent reduction in the annual equivalent value and a 90 per cent reduction in pesticides led to a 35 per cent reduction in the annual equivalent value. If soil erosion was reduced by 70 per cent, the annual equivalent value was reduced by 19 per cent. This means that a substantial reduction in the expenditure on pesticides or soil erosion will be needed before it has a serious negative effect on the annual equivalent value (Fig. 1 (a) and (c)). For the trade-off analysis between the goals of the annual equivalent value and nitrogen use, the comparable figures were a 40 per cent reduction in nitrogen use led to a 7 per cent reduction in the in annual equivalent value but after a 40 per cent reduction in nitrogen use, it would have a proportionally larger negative effect on the annual equivalent value (Fig. 1(b)).
3.3. Trade-off between the social and the environmental objectives

The trade-off between employment and the expenditure on pesticides, and that between employment and soil erosion gave similar results. When the expenditure on pesticides or soil erosion was decreased by 30 per cent, there was a 12 per cent reduction in employment. If it was reduced by more than 30 per cent, it would have a proportionally larger effect on employment. This result mirrored the actual situation in the watershed where farmers employed labor for the activities of chemical spraying and fertilizer (nitrogen use) as the citrus crop must be sprayed frequently (Fig. 2 (a) and (b)). The trade-off between employment and nitrogen use found that if nitrogen use decreased by 30 per cent, there was an 8 per cent reduction in employment with a constant decline until 70 per cent. This shows that a decrease in nitrogen use would not have a significant impact on employment (Fig. 2 c).
Fig. 2. Trade-off between social and environmental objectives (a) total employment in the watershed and total expenditure on pesticides (b) total annual employment in the watershed and total nitrogen used (c) total employment in the watershed and total soil erosion

3.4. Trade-off between the economic and the social objectives

Here, the minimization of the revenue variance (economic objective) is examined against the maximization of employment (social objective). The results found that when the revenue variance was reduced by 20 per cent, there was a 10 per cent reduction in employment with a constant decline until an 80 per cent reduction in the revenue variance gave a 47 per cent reduction in employment. This means that there can be a substantial reduction in the revenue variance before it has a significant impact on employment (Fig. 3).
4. Discussions and conclusions

The results show that if there is a reduction to a certain degree in some environmental the expenditure on pesticides, nitrogen use and soil erosion, it would not have a large effect on the annual equivalent value. Some sacrifice of economic objective will much improve several environmental objectives. To reduce expenditure on pesticide and nitrogen will decrease production costs and make farming more environmentally friendly and not much affect farmers’ income. However, if there was a large reduction in these environmental goals by over 40 per cent, it would have a serious negative effect on the annual equivalent value. In the same line, if nitrogen use, soil erosion and the expenditure on pesticides were reduced by up to 30 per cent, it would not have a serious effect on employment in the watershed although a larger reduction would lead to a sharp decline in employment. A high degree of tradeoff was found between employment and revenue variance. A small decrease in employment would have a serious negative effect on revenue variance. If we want to have better achievement rates for the environmental and social objectives, it would be necessary to allow for some decrease in the level of achievement rates for the economic objective. Nevertheless, these results were obtained based on assumption of proportionality in the MGLP model. In the case of strong violation of proportionality assumption, a major modification of the models will be needed.

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References