Optimal Resource Management with Multiple Goals of Citrus-based Farming Systems at Farm and Watershed Levels, Chiang Mai Province

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ABSTRACT: The objective of this study was to find optimal resource management with multiple goals of citrus based farming systems in the Fang watershed, at the farm and watershed levels. The citrus farms in this study were divided into four types of resources management: small farms using chemicals, small farms using chemicals and bioextract, large farms using chemicals and large farms using chemicals and bioextract. A set of questionnaires was designed for data collection covering 149 households in Chai Prakan, Fang and Mae Ai districts, Chiang Mai province. The analysis included seven indicators of objective goals at the farm level as annual equivalent value, hired labor, independence from external inputs loan investment, yield variance, revenue variance and off-farm work. For the watershed level was broken down into eight indicators of objective goals as annual equivalent value, hired labor, revenue variance, independence from external inputs, and expenditure on pesticide, nitrogen use, soil erosion and revenue from non-timber forest products. An analysis with multiple goal programming was conducted in weighted by using analytic hierarchy process (AHP) method. The study made assumption that the economic objective at the farm level was more prominent than social or environment-related objective, while the objective of watershed management was predominantly environment related. The analysis found that all farm types' the goals that were achieved at the highest level of annual equivalent value (GA) followed by off-farm work. The results of the analysis at the watershed level were obtaining lower of annual equivalent value (GAW) and hired labor (GHW). When comparing the analysis at the watershed level with an extrapolated-to-watershed level using farm-level results, it was found that the watershed level analysis recommended an optimal land use plan being all planted in fruit trees, while the extrapolated farm level analysis recommended an optimal land use composed of mixed fruit trees (58% of total land use) and annual crops (42% of total land use). This study showed how different viewpoints, objectives and weighting of goals led to different patterns of optimal land use in the Fang watershed.
Keywords: optimal resource management, multiple goals programming, citrus-based farming systems, farm and watershed levels, Chiang Mai Province

Introduction

Fang watershed is located in the north of Chiang Mai province covering a total area of 1,948.5 square kilometer in three districts i.e. 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 (Chowprayoon, 2005). Besides, it's cold weather is conducive to growing fruit trees especially citrus. At present, Chiang Mai is a major citrus producing area, producing several crops per year by stimulating branch initiation to obtain continuous production and generating higher income for farmers (Jumreanma et al., 2005). As a result, the demand for citrus planting areas has continuously increased since 2000. Nevertheless, problems of air and water pollution from chemical use as well as of water conflict in citrus production have emerged and raised concerns among nearby residents and Chiang Mai population (Chowprayoon, 2005).

Citrus cultivation generates a lot of residue chemicals. For example a planting area of 40,000

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rai can produce the estimated chemicals usage of more than 600 tons per year (PCD, 2004) by heavy spraying (Jumreanma et al., 2005) and the cost of chemicals use was 17.9 % of total production costs, second to the 22.9% of fertilizer (Phratnuwat et al., 1999). The majority of chemicals used are classified by World Health Organization as being extremely hazardous and highly hazardous. As a result of heavy pesticide spraying, it was found that in the 2003-2004, 25.7% of people in the age group of 43-59 years in Fang watershed had symptoms of vertigo and 9.9% out of them had suffered from dizziness, 62.2% suffered from urticaria and 26.9% had skin rashes, with respect to cause of illnesses in 1997-2001, it was found that the first cause of illness was in the respiratory system and other causes were related with musculoskeletal system and connective tissue, digestive system, mouth, skin and subcutaneous tissues. HISO (2005) found that in 2001, farmers who used organophosphate and carbonate like chemicals had caused residual effects on people and it was found that in Fang and Mae Ai district, the affected area was 12.11% and 8.7% of production areas respectively. Furthermore, the chemicals released have polluted air and water of this area not only during cultivation but also during processing of citrus. (e.g. water pollution from plants processing citrus products). In the 2003, the cabinet resolution assigned the Ministry of Natural Resources and Environment to seek cooperation with other agencies by forming participatory committees to manage these problems. These committees had since drafted declaration to protect the environment of Chai Prakan, Fang and Mae Ai district for 5 years between in 2003-2008 (NREMD, 2011). Meanwhile from 2003 to 2008, the planting area of citrus doubled from 43,315 rai to 85,939 rai (Chiang Mai Agricultural Office, 2011), although the area decreased to 29,633 rai in 2012.

Besides, citrus orchards in Fang watershed are located in sloping areas which are proned to soil erosion and soil degradation. Meanwhile, the residuals of the high chemicals and fertilizer usage left in the soil were found leached and contaminated into stream water. Consequently, this affected soil acidity and soil nutrient balance because of high phosphorus and exchangeable potassium in the soil. In addition, there was also accumulation of diseases and pests in this area. These have resulted in the decreasing of citrus yield as well as product quality, altogether with high input costs, low price of yield and net return. These caused the decrease of citrus plantation area in Fang watershed in the last few years (Santasup and Verunrat, 2011).

This citrus-based farming system in the highland watershed landscapes mentioned above revealed conflict of interests in terms of income generation for farmers and maintaining sustainable resources and environment of the watershed. Such scenarios require further study to determine the sustainability of the farming system vis-a-vis natural resource system. Therefore, in this study was objective to find optimal resource management with multiple goals of citrus based farming systems in the Fang watershed, at the farm and watershed levels.

Methodology

In this study, MESMIS methodology (Lopez-Ridaura et al., 2005b) will be used to evaluate multi level sustainability at the farm level and watershed level. At the farm level stakeholders are farmers who have the highest priority in profit or economic aspects while at the watershed level, from many agencies involved such as Agricultural office, Nation parks, NGOs. They have priority for the environment and social aspects as compared with the economic aspect. Therefore, indicators measures the sustainability of these levels is difference and are explained as follows:

1. Scales of analysis and objectives of the stakeholders at different levels.

1.1 The farm household level: as in most agricultural regions of the world, farm households in Fang watershed are the direct managers of land and take the ultimate decisions on resource allocation. Farm households manage their natural and human resource in order to improve their livelihood and satisfy their objective for the generation of income. In this study, the stakeholders at farm level are the farmers of orange orchard. Land resource management will be determined by selecting 2 farm sizes (small farm (SF) and large farm (LF)) in order to evaluate their activities in resource management of orange orchards and the impact of production activities into the environment of watershed.

1.2 The watershed level: the stakeholders much as government, NGOs offices will be interviewed related to co-existing in the orange orchard activities, their perceptions of the system, and their objectives. All of that stakeholder in the watershed level will keep the importance of environment in order to reduce chemical use that cause soil loss, diseases and insects are cumulative in soil, and nitrate combination in water was cause of sewage. While the forest officers in the watershed focus on the increase of forest trees and forest areas to promote wildlife, food stock, revenue from non-timber forest products and steam water in the future.

2. Selecting goals for different level

For multi-level sustainability evaluation, a set of goals for the farm and watershed level will be identified. These goals are related to the performance of the system itself –*productivity and social contribution* – and its ability to cope with changes in its environment, co-existing systems or its internal functioning – *autonomy, stability and resilience.* Which are further broken down into seven goals at the farm level as annual equivalent value, hired labor, independence from external inputs loan investment, yield variance, revenue variance and off-farm work. For the watershed level was broken down into eight indicators of objective goals as annual equivalent value, hired labor, revenue variance independence from external inputs, expenditure on pesticide, nitrogen use, soil erosion and revenue from non-timber forest products.

3. Land-use activities

To evaluate land-use systems the inputs and outputs of each farm size (small farm (SF) 30 rai and large farm (LF) 31 rai) will be quantified by two production technologies; T1: chemical usage (pesticide + fertilizer) and T2: chemical and bioextrect usage (pesticide + fertilizer + bioextrect). Both farm sizes and chemical usage will be classified according to Resource Management Unit (RMU) into 4 RMU type (e.g. RMU type 1 (small farm chemical usage: SFC), RMU type 2 (small farm with chemical and bioextract usage: SFCB)).

4. Optimization models

Models of land use were constructed for representative farms and for the watershed as a whole in order that the goals at each level can be optimized. They will be 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; 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 use the goals value of current and constraint functions for optimization of land use in each RMU type for the farm household level and 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).

The equation formula of for the farm household level: The objective function in MGLP model at the farm household level is minimization of the total deviations from goals as follows:

$$min = (w_{f1}d_{f1}^{-} - w_{f2}d_{f2}^{+} - w_{f3}d_{f3}^{+} - w_{f4}d_{f4}^{+} - w_{f5}d_{f5}^{+} - w_{f6}d_{f6}^{+} + w_{f7}d_{f7}^{-}) \quad \text{...... (1)}$$

Where w_f represents the weight of fth goal, d_f^- and d_f^+ are the negative and positive deviations of fth goal. While GA is the achievable goal level of annual equivalent value from cropping systems. GH is the achievable goal level of hired labors. GI and GL are the achievable goal levels of independence from external inputs and loan investment. GY and GR are the achievable goal levels of yield and revenue respectively. While GO is the achievable goal level dealing with off-farm work. Constraints include:

1. Goals constraints

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(AEV_{crop_{ij}} * Area_{crop_{ij}}) + w_{f1}d_{f1}^{-} = GA \quad \text{...... (2)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(HL_{crop_{ij}} * Area_{crop_{ij}}) - w_{f2}d_{f2}^{+} = GH \quad \text{...... (3)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(IIEI_{crop_{ij}} * Area_{crop_{ij}}) - w_{f3}d_{f3}^{+} = GI \quad \text{...... (4)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(LI_{crop_{ij}} * Area_{crop_{ij}}) - w_{f4}d_{f4}^{+} = GL \quad \text{...... (5)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(YV_{crop_{ij}} * Area_{crop_{ij}}) - w_{f5}d_{f5}^{+} = GY \quad \text{...... (6)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(RV_{crop_{ij}} * Area_{crop_{ij}}) - w_{f6}d_{f6}^{+} = GR \quad \text{...... (7)}$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(OFF_{crop_{ij}} * Area_{crop_{ij}}) + w_{f7}d_{f7}^{-} = GO \quad \text{...... (8)}$$

Where *ith* is cropping systems (i = 1,…,25) from *jth* land use (j = 1,…,4 of upland irrigated, upland rainfed, lowland irrigated and lowland rainfed respectively.

2. Resource Constraints

$$\sum_{i=1}^{n} Land_{crop_{ij}} \leq TotalLnad_{crop_{ij}}$$ …… (9)

$$\sum_{i=1}^{n} FruitTrees_{crop_{ij}} \leq TotalLand_{crop_{ij}}$$ …… (10)

$$\sum_{i=1}^{n} DryCrops_{crop_{ij}} \leq TotalLand_{crop_{ij}} - FruitTrees_{crop_{ij}}$$ …… (11)

$$\sum_{i=1}^{n}\sum_{j=1}^{m} Labor_{crop_{ijk}} - LaborHire_k \leq AvailableLabor_k$$ …… (12)

$$\sum_{k=1}^{12} LaborHire_k \geq 0$$; For every month *kth* (k = 1,…,12) …… (13)

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(CashCost_{crop_{ijk}} * Area_{crop_{ijk}}) + \sum_{k=1}^{12}(Wage_k * Labor_{crop_k}) - \sum_{s=1}^{3} (Interest_s * Loan_s) \leq AvailableLoan$$ …… (13)

$$Loan_s \leq AvailableLoan_s$$; For source of loan s (s = 1,…,3) …… (14)

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(Revenue_{ij} - Cost_{ij}) \geq 0$$ …… (15)

The models at the farm level contain 80 decision variables composing of cropping systems, hired labors, off-farm employment, loans and interest payment. There are 78 constraints consisting of goal constraints, land, family labor, hired labors, capital and interest payment constraints.

The equation formula of watershed scale: The objective function in MGLP model in watershed level is minimization of the total deviations from goals as fallows;

$$\min = (w_{w1}d_{w1}^{-} + w_{w2}d_{w2}^{-} - w_{w3}d_{w3}^{+} - w_{w4}d_{w4}^{+} - w_{w5}d_{w5}^{+} - w_{w6}d_{w6}^{+} - w_{w7}d_{w7}^{+} + w_{w8}d_{w8}^{-})$$ …. (16)

Where represents the weight of *w*th goal, and are the negative and positive deviations of *w*th goal. As for GAW is the achievable goal level of equivalent value of cropping systems. GHW is the achievable goal level of increased employment in the watershed. GIW is the achievable goal level of independence from external inputs. For GRW, GEW, GNW and GSW are the achievable goal level of revenue variance, expenditure on pesticides, nitrate used and soil erosion respectively. GFW is the achievable goal value of revenue from non-timber forest product. Constraints include:

1. Goals constraints

$$\sum_{r=1}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(AEVW_{ijr} * Area_{crop_{ij}}) + w_{w1}d_{w1}^{-} = GAW$$ …… (17)

$$\sum_{r=1}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(HLW_{ijr} * Area_{crop_{ij}}) + w_{w2}d_{w2}^{-} = GHW$$ …… (18)

$$\sum_{r=1}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(IIEIW_{ij} * Area_{crop_{ij}}) - w_{w3}d_{w3}^{+} = GIW$$ …… (19)

$$\sum_{r=1}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(RVW_{ijr} * Area_{crop_{ij}}) - w_{w4}d_{w4}^{+} = GRW$$ …… (20)

$$\sum_{r=1}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(EPW_{ijr} * Area_{crop_{ij}}) - w_{w5}d_{w5}^{+} = GEW$$ …… (21)

$$\sum_{r=4}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(NW_{ijr} * Area_{crop_{ij}}) - w_{w6}d_{w6}^{+} = GNW$$ …… (22)

$$\sum_{r=4}^{4}\sum_{i=1}^{n}\sum_{j=1}^{m}(SE_{ijr} * Area_{crop_{ij}}) - w_{w7}d_{w7}^{+} = GSW$$ …… (23)

$$\sum_{r=1}^{4}\sum_{l=1}^{n}(Revenue_{NTFP_{lr}} * NTFP_{activities_{l}}) + w_{w8}d_{w8}^{-} = GFW$$ …… (24)

2. Resource Constraints

$$\sum_{i=1}^{n} LandWatershed_{crop_{ij}} \leq TotalLnadWatershed_{crop_{ij}}$$ …… (25)

$$\sum_{i=1}^{n} FruitTreesWatershed_{crop_{ij}} \leq TotalLandWatershed_{crop_{ij}}$$ …… (26)

$$\sum_{i=1}^{n} DryCropsWatershed_{crop_{ij}} \leq TotalLandWatershed_{crop_{ij}} - FruitTreesWatershed_{crop_{ij}}$$ …… (27)

$$\sum_{i=1}^{n}\sum_{j=1}^{m} LaborWatershed_{crop_{ijk}} - LaborHireWatershed_{k} \leq AvailableLaborWatershed_{k}$$ …… (28)

$$\sum_{k=1}^{12} LaborHireWatershed_{k} \geq 0$$; For every month *kth* (*k* = 1,…,12) …… (29)

$$\sum_{k=1}^{12} LaborHireWatershed_k \geq 0$$; For every month *kth* (*k* = 1,…,12) …… (29)

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(CashCostWatershed_{crop_{ijk}} * AreaWatershed_{crop_{ijk}}) + \sum_{k=1}^{12}(Wage_k * LaborWaterseed_{crop_k}) - \sum_{s=1}^{4}(Interest_s * LoanWatershed_s) \leq AvailableLaborWatershed$$ …… (30)

$$LoanWatershed_s \leq AvailableLabor_s$$; For source of loan *s* (*s* = 1,…,4) …… (31)

$$\sum_{i=1}^{n}\sum_{j=1}^{m}(RevenueWatershed_{ij} - CostWatershed_{ij}) \geq 0$$ …… (32)

The model at the watershed level contains 82 decision variables consisting of cropping systems, off-farm employment, hired labors, capital and interest payment. There are 81 constraints consisting of goal constraints, land, family labor, hired labors, monthly capital requirement and interest payment constraints.

5. Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) (Saaty, 2010) is a process of pairwise weighting of options by stakeholders and is used in this study to determine weights of goals at farm and watershed levels by participatory method of stakeholders in each level. There are very different patterns of goal weights for the farm level and the watershed level. The stakeholders at the farm level gave high priority to reduced yield variance (GY) and revenue variance (GR), while gave lower priority to off- farm work (Figure 1). At the watershed level, stakeholders gave high priority to revenue from non-timber forest product (GFW) and reduced expenditure on pesticide (GEW) followed lower nitrate used (GNW) and soil erosion (GSW) (Figure 2).

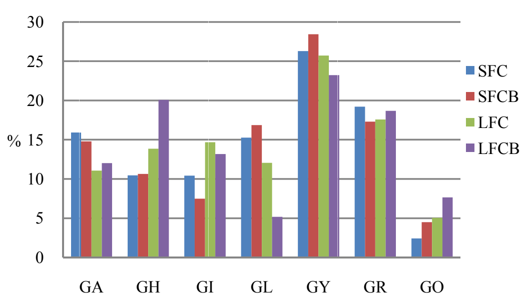

Figure 1 Goal ranking weighted using AHP: farm level

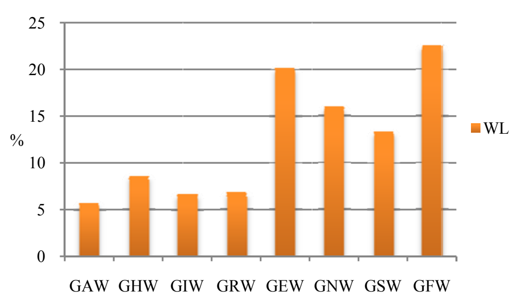

Figure 2 Goal ranking weighted using AHP: watershed level

Data Collection Section

This study employed a sample group of 149 households. It was classified into; SFC was divided 53 households, 49 households were SFCB, LFC was classifying of 25 households and 22 households were LFCB.

Results

To illustrate the performance of optimal resource management with multiple goals of citrus-based farming systems at farm and watershed levels. After that comparing the analysis at the watershed level with an extrapolated-to-watershed level using farm-level results. The study made assumption that the economic objective at the farm level was more prominent than social or environment-related objective, while the objective of watershed management was predominantly environment related.

Optimal resource management at the farm level

The farm-level models were then run to give optimal patterns of land use given the set objectives. The recommended optimal land use in irrigated upland for all farm types was citrus and in rainfed uplands sweet corn-sweet corn. In the irrigated lowlands, the model recommended optimal land use being mostly citrus for large farms but triple cropping of rice-sweet corn-sweet corn for small farms. In the rainfed lowlands, the model recommended only rice as optimal land use.

In terms of goal achievement, there were high achievement rates for all farm types for annual equivalent value, off-farm work but in terms of yield and revenue variations, the goal achievement was low (Figure 3).

Optimal resource management at watershed level

The recommended optimal land use at the watershed level turned out to be mostly forests (73.55% of total land use) and the rest being fruit tree (26.45% of total land use). In irrigated upland, tea was mostly recommended while in rainfed upland, coffee and lychee was recommended. Only in irrigated lowland, citrus was recommended.

In terms of goal achievement, there was high achievement in environmental-related goals (85% achievement rates) e.g. pesticide and nitrate use, soil erosion, revenue non-timber forest product while there were low achievement rates in social-economic-related goals (income and employment).

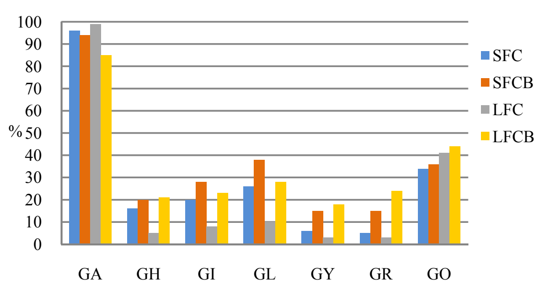

Figure 3 Achievement of goals the farm level

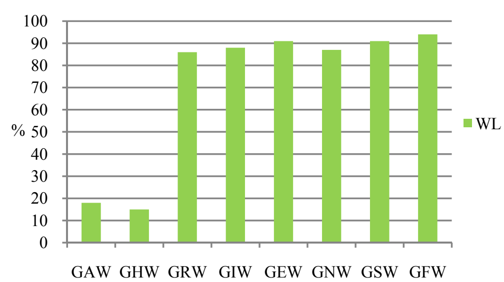

Figure 4 Achievement of goals the watershed level

Extrapolated-to-watershed level using farm-level results

The farm level results of optimal land use were extrapolated to the watershed level based on the proportion of land occupied by each farm type. The results of optimal land use for extrapolated-farm- watershed level are shown in Table 1.

Table 1 Comparative agroecosystems management at the watershed level with extrapolated-to-watershed level using farm-level results

Land unit	Land use	Current use at watershed	Optimal use
Irrigated upland (rai)	Citrus		98,620
	Tea	32,997	
	Sweet corn-sweet corn		8,453
	Forest	74,076	
Rainfed upland (rai)	Coffee	71,544	19,911
	Lychee	12,208	
	Sweet corn-sweet corn		238,930
	Forest	175,089	
Irrigated lowland (rai)	Citrus	22,798	105,780
	Rice-sweet corn-sweet corn		13,797
	Rice-garlic-sweet corn		1,533
	Forest	98,312	
Rainfed lowland (rai)	Rice		40,590
	Forest	40,590	
Total area (rai)		527,614	527,614

Discussion and Conclusion

When comparing the watershed level with an extrapolated-to-watershed level the result found that the watershed level analysis recommended an optimal land use plan being all planted in fruit trees and forest, while the extrapolated farm level analysis recommended an optimal land use composed of mixed fruit trees (58% of total land use) and annual crops (42% of total land use).

It can be seen that optimal resource use results in vastly different patterns of land use in the watershed depending on whose points of views are being considered. Farm-level models as contrast to the watershed model are reflected in differences in objectives and their relative importance. If farmers are making decisions as they are more concerned about economic income, employment as compared to environmental objectives. If Fang watershed is managed and optimized with more priority to environmental objectives as against economic and social ones, we will see that it should be left largely as forests with some small proportion in fruit trees. Even in such situation, the fruit trees that should be planted in Fang watershed should be those friendly to the environment than citrus e.g. coffee, tea or lychee. Nevertheless, one cannot ignore reality in the field as farmers are the ones who make decisions on land use. Their objectives and interests should also be recognized and some balance between economic and environmental objectives should be met. The model results can be used as a basis for discussion between farmers and watershed officials so that some changes to land use can be achieved in order that economic, social and environmental objectives can be more balanced.

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