CHAPTER 6

THE FARM LEVEL MODEL

This chapter deals with the objectives at the farm level and the Analytic Hierarchy Process (AHP) characteristics of the farmer's decision-making with pairwise comparisons for the goal objectives. This will include an explanation of the resource constraints, decision variables, coefficient variables and the formula model used at the farm level.

6.1 Objectives at the farm level

The farm households in the Fang watershed are the direct managers of the land and take the ultimate decisions on resource allocation. Farm households manage their natural and human resources in order to improve their livelihood and satisfy their objective for the generation of income. The study made the assumption that the economic objective at the farm level was more prominent than the social or the environmental objectives. These objectives were broken into 5 attributes and 7 objective goals as follows:

1. The economic objective considered the main criteria to be productivity, autonomy and stability:
   - 1.1 Productivity was measured by the annual equivalent value (baht/rai).
   - 1.2 Autonomy was measured by the independence from external inputs and loan investment (baht/rai).
   - 1.3 Stability was measured by yield variance (ton/rai) and revenue variance (baht/rai).
2. The social objective was judged by the social contribution of the hired labor (man-days).
3. The environmental objective was judged by the resilience in order to evaluate their alternatives for off-farm work (man/days).

6.2 Analytic Hierarchy Process (AHP) at the farm level

The Analytic Hierarchy Process (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. In this study, AHP was used to determine the weights of goals at the farm level by the participatory method of the stakeholders for each farm type. Using this method, the scores for the evaluated weight objective goals were obtained. The process is as follows:

1. Define the problem by using the 7 objective goals at the farm level, namely, Annual Equivalent Value (AEV), hired labor (HL), independence from external inputs (IIEI), loan investment (LI), yield variance (YV), revenue variance (RV) and off-farm work (OFF).
2. Construct a set of pairwise comparison matrices from the objective goals. Based on the principle of comparative judgments, the results are applied to determine the relative importance of the objective goals and the relative preference of the alternatives through pairwise comparisons. The AHP uses a fundamental level of absolute numbers to express individual preferences or judgments. Table 6.1 lists these fundamental level values.
3. Use the participatory method by including ideas from the focus groups and stakeholders who are the farmers from each farm type. Nine stakeholders from the small farms using chemicals and seven stakeholders from the small farms using chemicals and bioextract were included. The focus group was conducted in February, 2013. In addition, there were 6 stakeholders representing the large farms using chemicals and 5 stakeholders from the large farms using chemicals and bioextract. AHP was conducted separately for each group.

   The focus groups started by explaining the background of the study and the objectives of the research. The meaning of each objective goal and how the scores by using pairwise comparisons were explained (Table 6.1). There were many people participating, multiple judgments were combined by taking the geometric means of individual judgments. Pairwise comparison judgments were made based on the best information available and the decision maker's intuition, knowledge and experience.

Table 6.1 Pairwise comparison levels

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the property
3	Moderate importance of one over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An element is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Compromise is needed between the two judgments
Reciprocals of the above numbers		If an activity has one of the above numbers assigned to it when compared with a second activity, then the second activity has the reciprocal value when compared to the first

Source: Saaty, 2010

4. The pairwise comparisons against given objective goals result in a matrix. The numbers in the matrix below are the AHP level values with the definitions in Table 6.1. They correspond to the judgments obtained by comparing the elements in the left-hand column with the elements in the top row. When an element is regarded less favorably than the others, the judgment is a fraction. A pairwise comparison matrix is also reciprocal. The judgments are only needed for the upper triangular part of a matrix. The lower triangular part is their reciprocals. Once a pairwise comparison matrix is generated, the AHP derives the weights vector for the relevant elements from the principal of the matrix. Using this method and a software program called *Ror Tor Sor* developed by Ekasingh et al (2006, 2007) at the Multiple Cropping Center, Chiang Mai University; the weights of the objective goals evaluated were then obtained. The results in each farm type are shown as follows:

4.1 The small farm using chemicals (SFC): the stakeholders were given the pairwise score which was calculated by the software program *Ror Tor Sor*. The results found that the highest weight value of yield variance (YV) was 0.2297 followed by the revenue variance (0.1731) and the lowest was off-farm work (0.0683). The details are shown in Figure 6.1.

	AEV	HL	IIEI	LI	YV	RV	OFF	Weight value
AEV	1	1/2	3	4	1/6	2	4	0.1520
HL	2	1	1/3	6	1/4	1/2	1/4	0.1162
IIEI	1/3	3	1	6	1/4	1/6	4	0.1395
LI	1/4	1/6	1/6	1	4	1/2	3	0.1212
YV	6	4	4	1/4	1	2	2	0.2297
RV	1/2	2	6	2	1/2	1	5	0.1731
OFF	1/4	4	1/4	1/3	1/2	1/5	1	0.0683

Figure 6.1 Weight value for the small farm using chemicals

4.2 The small farm using chemicals and bioextract (SFCB): the results found that the highest weight value was for yield variance (YV) and the annual equivalent value (AEV). The off-farm work (OFF) was lowest at 0.0861 (Figure 6.2)

	AEV	HL	IIEI	LI	YV	RV	OFF	Weight value
AEV	1	6	3	5	1/5	1/6	3	0.1696
HL	1/6	1	1/2	6	2	3	1/6	0.1367
IIEI	1/3	2	1	1/5	1/6	4	5	0.1258
LI	1/5	1/6	5	1	1/4	1/2	3	0.0923
YV	5	1/2	6	4	1	1	5	0.2247
RV	6	1/3	1/4	2	1	1	5	0.1649
OFF	1/3	6	1/5	1/3	1/5	1/5	1	0.0861

Figure 6.2 Weight values for the small farm using chemicals and bioextract

4.3 The large farm using chemicals (LFC): the stakeholders gave more important to yield variance (YV) with a weight value of 0.2085 followed by the revenue variance (RV) of 0.1722. The loan investment (LI) was lowest at 0.1009 (Figure 6.3)

	AEV	HL	IIEI	LI	YV	RV	OFF	Weight value
AEV	1	3	5	4	1/4	1/2	1/6	0.1525
HL	1/3	1	1/4	4	1/4	1/3	7	0.1231
IIEI	1/5	4	1	3	1	1/3	4	0.1404
LI	1/4	1/4	1/3	1	1/3	4	2	0.1009
YV	4	4	1	3	1	1	5	0.2085
RV	2	3	3	1/4	1	1	5	0.1722
OFF	6	1/7	1/4	1/2	1/5	1/5	1	0.1024

Figure 6.3 Weight values for the large farm using chemicals

4.4 The large farm using chemicals and bioextract (LFCB): the yield variance (YV) had the highest weight value at 0.2137 and 0.1877 for the revenue variance (RV). The off-farm work was the lowest at 0.0821 (Figure 6.4)

	AEV	HL	IIEI	LI	YV	RV	OFF	Weight value
AEV	1	6	5	1/2	1/4	1/3	2	0.1542
HL	1/6	1	1/5	9	1/3	1/4	3	0.1214
IIEI	1/5	5	1	7	1/3	1/4	1/3	0.1352
LI	2	1/9	1/7	1	1/3	4	1/3	0.1057
YV	4	3	3	3	1	2	4	0.2137
RV	3	4	4	1/4	1/2	1	6	0.1877
OFF	1/2	1/3	3	3	1/4	1/6	1	0.0821

Figure 6.4 Weight values for the large farm using chemicals and bioextract

6.3 Goal constraints at the farm level

The study determined 7 indicators at the farm level which were taken into account for the analysis by MGLP which were used for goal constraints. The results of the goal constraints were analyzed by linear programming for each goal objective as shown in Table 6.2.

Table 6.2 Goal constraints at the farm level

Goal constraints	SFC	SFCB	LFC	LFCB
Annual equivalent value (GA) (baht)	231,317	206,881	3,390,848	869,430
Hired labor (GH) (man-day)	356	304	70,061	3,740
Independence from external inputs (GI) (baht)	263,172	214,439	40,340,259	2,594,600
Loan investment (GL) (baht)	103,551	66,178	21,562,696	1,292,507
Yield variance (GY) (kg)	22,511	17,747	4,946,961	164,791
Revenue variance (GR) (baht)	463,123	208,330	79,898,769	2,809,008
Off-farm work (GO) (man-day)	18,860	18,416	160,400	38,750

This study will evaluate the optimal resource management by the equal weight and the AHP methods. The equal weigh method determined the weight value of all the goals equally at 0.1428 from 1 (1 divide 7 = 0.142857). The AHP method was given the weight values by participatory stakeholders as mentioned above and the results are shown in Figure 6.1 to Figure 6.4. The goal constraints and the weigh value are relevant to the analysis with MGLP as follows:

- The annual equivalent value goal (GA) was maximized. This aim was to reach the goal constraint that was set for this objective. The linear programming assessed the annual equivalent value and determined the goal constraint for the small farms using chemicals at 231,317 baht. The negative deviation should be equal to the value of 0.1428 from 1 (14.28 percent) by the equal weigh method or 0.1520 from 1 (15.20 percent) by the AHP method (Table 6.1). The optimal resource management would be to minimize the negative deviation of the weight value result from the equal weight or the AHP methods. This means that the optimal resource management for the small farm using chemicals would have an annual equivalent value of 231,317 baht. The small farm using chemicals and bioextract determined the annual equivalent value goal constraint to be 206,881 baht, the large farms using chemicals had an annual equivalent value constraint of 3,390,848 baht and the large farm using chemicals and bioextract had an annual equivalent constraint of 869,430 baht.

- The hired labor goal (GH) was to minimize hired labor and the small farm using chemicals determined a goal constraint of 356 man-days. The optimal resource management would be minimize the positive deviation of the weight value result from the equal weight method at 14.28 percent or the AHP method at 11.62 percent (Table 6.1). This means that the optimal resource management would have hired labor lower than or equal to 356 man-days. The small farm using chemicals and bioextract determined a hired labor goal constraint of 304 man-days, the large farm using chemicals had a hired labor goal constraint of 70,061 man-days and the large farm using chemicals and bioextract had a hired labor goal constraint of 3,740 man-days.

- The independence from external inputs goal (GI) was to minimize the dependence on external inputs and the small farm using chemicals determined a goal constraint of 263,172 baht. The optimal resource management would be to minimize the positive deviation of the weight value result from the equal weight (14.28 percent) or the AHP method (13.96 percent, Table 6.1). This means that the optimal resource management would have independence from external inputs lower than or equal to 263,172 baht. The small farm using chemicals and bioextract determined an independence from external inputs goal constraint of 214,439 baht, the large farm using chemicals determined an independence from external inputs goal constraint of 40,340,259 baht and the large farm using chemicals and bioextract determined an independence from external inputs goal constraint of 2,594,600 baht.

- The loan investment goal (GL) was to minimize loan investment and the small farm using chemicals determined a goal constraint of 103,551 baht. The small farms using chemicals and bioextract determined a loan investment goal constraint of 66,178 baht, the large farm using chemicals determined a loan investment goal constraint of 21,562,696 baht and the large farm using chemicals and bioextract determined a loan investment goal constraint of 1,292,507 baht.

- The yield variance goal (GY) was to minimize the yield variance and the small farm using chemicals determined a yield variance goal constraint of 22,511 kilograms. The small farm using chemicals and bioextract determined a yield variance goal constraint of 17,747 kilograms, the large farm using chemicals determined a yield variance goal constraint of 4,946,961 kilograms and the large farm using chemicals and bioextract determined a yield variance goal constraint of 164,791 kilograms.

- The revenue variance goal (GR) was to minimize the revenue variance and the small farm using chemicals determined a revenue variance goal constraint of 463,123 baht. The small farm using chemicals and bioextract determined a revenue variance goal constraint of 208,330 baht, the large farm using chemicals determined a revenue variance goal constraint of 79,898,769 baht and the large farm using chemicals and bioextract determined a revenue variance goal constraint of 2,809,008 baht.

- The off-farm work goal (GO) was to maximize off-farm work and made the assumption that if off-farm work gave more a revenue than the work on the farm, the farmers should leave on farm. On the other hand, if off-farm work gave a higher wage rate (baht per day) than the hired labor rate, the farmers should work off-farm and instead hire labor for the farm. The small farm using chemicals determined an off-farm work goal constraint of 18,860 baht, the small farm using chemicals and bioextract determined an off-farm work goal constraint of 18,416 baht, the large farm using chemicals determined an off-farm work goal constraint of 208,330 baht and the large farm using chemicals and bioextract determined an off-farm work goal constraint of 38,750 baht.

6.4 Resource constraints at the farm level

The resource constraints at the farm level included land unit, labor, capital and loan constraints. These varied by farm type and the details are as follows:

6.3.1 Land constraints

This study classified land units into four types: irrigated upland, rainfed upland, irrigated lowland and rainfed lowland.

1. The small farms using chemicals have an average agricultural land holding of 15.2 rai. This is divided into 7.8 rai of irrigated upland, 1.23 rai of rainfed upland, irrigated lowland of 5.12 rai and rainfed lowland of 1.05 rai.

2. The small farms using chemicals and bioextract have an average land holding of 13.8 rai. The area is divided into 4.18 rai of irrigated upland, 1.91 rai of rainfed upland, 6.46 rai of rainfed lowland and 1.25 rai of irrigated lowland.

3. The large farms using chemicals have an average agricultural area of 142.5 rai. This is divided into 85.21 rai of irrigated upland, 7.96 rai of rainfed upland, 45.81 rai of irrigated lowland and 3.52 rai of rainfed lowland.

4. The large farms using chemicals and bioextract have an average agricultural land holding of 40.63 rai. This is divided into 16.75 rai of irrigated upland, 2.32 rai of rainfed upland, 16.1 rai of irrigated lowland and 5.46 rai of rainfed lowland. The data is shown in Table 6.3.

Table 6.3 Agricultural land holdings at the farm level

Characteristics	SFC (rai)	SFCB (rai)	LFC (rai)	LFCB (rai)
Irrigated upland	7.80	4.18	85.21	16.75
Rainfed upland	1.23	1.91	7.96	2.32
Irrigated lowland	5.12	6.46	45.81	16.10
Rainfed lowland	1.05	1.25	3.52	5.46
Total area	15.20	13.80	142.50	40.63

Source: survey, 2012

6.3.2 Household labor constraints

In this study, labor days per month were assumed at 25 days per month. This applied equally to external and household labor. Exchanged labor with neighbors was assumed to be equal with household labor because exchanged labor was repaid equally.

1. The small farms using chemicals had an average full-time household labor on the farm of 2.07 people multiplied by 25 days per month. The total household labor therefore equaled 51.75 man-days per month.
2. The small farms using chemicals and bioextract had an average full-time household labor on the farm of 2.04 people multiplied by 25 days per month. The total household labor therefore equaled 51.00 man-days per month.
3. The large farms using chemicals had an average full-time household labor on the farm of 2.08 people multiplied by 25 days per month. The total household labor therefore equaled 52.00 man-days per month.
4. The large farms using chemicals and bioextract had an average full-time household labor on the farm of 1.75 people multiplied by 25 days per month. The total household labor therefore equaled 43.75 man-days per month (Table 6.4).

Table 6.4 Household labor constraints at the farm level

Description	SFC	SFCB	LFC	LFCB
Average household labor (persons)	2.07	2.04	2.08	1.75
Work-days per person per month	25	25	25	25
Total household labor (man-days/month)	51.75	51.00	52.00	43.75

6.3.3 Hired labor constraints

The small farm using chemicals and the small farms using chemicals and bioextract had an average full-time hired labor of 2 people per farm multiplied by 25 days per month. This gives a total hired labor figure of 50 man-days per month. The large farms using chemicals had an average hired labor figure of 30 people and the large farms using chemicals and bioextract had an average of 6 people. When we multiply by 25 days per month, this gives us the figures of 750 and 150 man-days per month respectively (Table 6.5).

Table 6.5 Hired labor constraints at the farm level

Description	SFC	SFCB	LFC	LFCB
Average hired labor (persons)	2.00	2.00	30.00	6.00
Work-days per person per month	25	25	25	25
Total hired labor (man-days/month)	50.00	50.00	750.00	150.00

6.3.4 Capital constraints

The capital constraints were calculated from the net income from crop production and off-farm activities minus loan and interest payments, household consumption and savings. The money which remained was taken for investment in crop production.

In the survey and analysis, the results found that for the small farms using chemicals, the net revenue equaled 276,864 baht while the loan and interest repayments equaled 133,962 baht. The small farms using chemicals and bioextract had a net revenue of 244,752 baht and loan and interest repayments of 114,038 baht. The large farms using chemicals had net revenues of 5,074,544 baht and loan and interest repayments of 2,232,692 baht. The large farms using chemicals and bioextract had a net revenue of 1,103,657 baht and 476,363 baht for loans and interest repayments.

To measure household consumption, the basic needs of food consumption presented by Chaiwinit (2009) were used. This study found that the farmer's basic needs regarding food consumption amounted to 19,569.75 baht per person per year. If we consider inflation using the Consumer Price Index (CPI) from the Bank of Thailand (2014) based on 2010, 3.1 percent was used to adjust this value to 20,176.41 baht per person per year. The adjusted value will be given to the index of food consumption requirements which ranks priorities by age and gender as shown in Table 6.6, Wironsri (1988). Using the index to assess the family size for the weight consumption value, the example of a household which has one male 24 years old, a female, 19 years old and a daughter, 2 years old was used. This gave a weighted family size (WFS) of 1+0.7+0.4 equals 2.1

people. In this study, the adjusted value (20,176.41 baht) for food consumption was given a value of 1 on the weighted family size scale. When the WFS was multiplied by the adjusted value, the food consumption costs for a household could be calculated. The results found that the small farms using chemicals had a basic food consumption of 78,279 baht per year, the small farms using chemicals and bioextract had a food consumption of 79,906 baht, large farms using chemicals and large farms using chemicals and bioextract had costs of 83,404 and 80,719 baht respectively. This study allowed for 10 percent of net income for household savings. They will be able pay the loan and interest repayments and afford their food consumption and still save and have money to invest in crop production. The results are shown in Table 6.7.

Table 6.6 Food consumption requirements index

Age (year)	Male	Female
< 6	0.17	0.18
6 - 10	0.35	0.40
11 -15	0.68	0.60
16 – 20	0.98	0.70
21 – 60	1.00	0.90
> 60	0.43	0.25

Source: Wironsri, 1988

Table 6.7 Capital constraints at the farm level

Description	SFC	SFCB	LFC	LFCB
Net income (baht)	276,864	244,752	5,074,544	1,103,657
Minus loan and interest repayments (baht)	133,962	114,038	2,232,692	476,363
Minus household consumption (baht)	78,279	79,906	83,404	80,719
Minus Savings of 10% (baht)	6,901	5,874	254,523	65,773
Capital for investment (baht)	57,721	44,934	2,503,925	480,800

6.3.5 Loan constraints

There are four sources of loans. The Bank for Agriculture and Agricultural Co-operatives (BAAC) could make the highest personal loans of up to 200,000 baht per year with an average interest rate of 7.5 percent per year. Agricultural Cooperatives could make loans to farmers of up to 20,000 baht per household per year with an average interest rate of 8.5 percent per year. Another favorite source of loans for the small farms was a loan from the village fund averaging 30,000 baht per household per year with an average rate of 12 percent per year. Another source of loans for the large farms are from commercial banks which can make an average personal loans of 5,000,000 baht per with an interest rate of 8 percent per year (Table 6.8).

Table 6.8 Loan constraints at the farm level

Description	SFC	SFCB	LFC	LFCB
BAAC (baht)	200,000	200,000	200,000	200,000
Interest rate (%)	7.50	7.50	7.50	7.50
Agricultural Cooperative (baht)	20,000	20,000	20,000	20,000
Interest rate (%)	8.50	8.50	8.50	8.50
Village fund (baht)	30,000	30,000	-	-
Interest rate (%)	12.00	12.00	-	-
Commercial banks (baht)	-	-	5,000,000	5,000,000
Interest rate (%)	-	-	8.00	8.00

The conclusions from the resource constraints shown above suggest that there are 57 constraints at the farm level. The data is shown in Appendix A. These are shown as follows:

$R_1 – R_4$ Land use constraints classified by irrigated upland, rainfed upland, irrigated lowland and rainfed lowland (rai).

$R_5 – R_{18}$ Household labor constraints per month (man-days)

$R_{17} – R_{28}$ Hired labor constraints per month (man-days)

$R_{29} – R_{40}$ Capital constraints per month (baht)

$R_{41} – R_{43}$ Loan constraints from BAAC, agricultural cooperatives, village fund (the small farms) or commercial banks (the large farms) (baht)

$R_{44} – R_{52}$ Revenue from the cropping systems (baht)

R_{53} Food consumption constraints (baht)

R_{54} Annual revenue from cropping systems (baht)

$R_{55} – R_{57}$ Interest repayments to BAAC, agricultural cooperatives, village funds (the small farms) or commercial banks (the large farms) (baht)

6.4 Decision variables at the farm level

The models at the farm level contain 65 decision variables composing of cropping systems, off-farm employment, hired labor, capital transfers, revenue distribution, loans and interest repayments. The activities are shown as follows;

X_1 Citrus production in the irrigated upland (rai)

X_2 Citrus production in the irrigated lowland (rai)

X_3 Longan production in the irrigated upland (rai)

X_4 Longan production in the irrigated lowland (rai)

X_5 Lychee production in the irrigated upland (rai)

X_6 Lychee production in the rainfed upland (rai)

X_7 Lychee production in the irrigated lowland (rai)

X_8 Lychee production in the rainfed lowland (rai)

X_9 Coffee production in the irrigated upland (rai)

X_{10} Coffee production in the rainfed upland (rai)

X_{11} Tea production in the irrigated upland (rai)

X_{12} Tea production in the rainfed upland (rai)

X_{13} Rice production in the rainfed lowland (rai)

X_{14} Sweet corn – sweet corn production in the irrigated upland (rai)

X_{15} Sweet corn - onion production in the irrigated upland (rai)

X_{16} Sweet corn - sweet corn production in the rainfed upland (rai)

X_{17} Sweet corn - onion production in the rainfed upland (rai)

X_{18} Rice - rice production in the irrigated lowland (rai)

X_{19}	Rice - sweet corn production in the irrigated lowland (rai)
X_{20}	Rice - garlic production in the irrigated lowland (rai)
X_{21}	Rice - onion production in the irrigated lowland (rai)
X_{22}	Rice - sweet corn - sweet corn production in the irrigated lowland (rai)
X_{23}	Rice - garlic - sweet corn production in the irrigated lowland (rai)
X_{24}	Rice - onion - sweet corn production in the irrigated lowland (rai)
X_{25}	Off-farm work (man-days)
X_{26} - X_{37}	Hired labor activities during January - December (man-days)
X_{38} - X_{49}	Capital transfers during January – December (baht)
X_{50} - X_{52}	Loan activities from the Bank for Agriculture and Agricultural Co-operatives (BAAC), agricultural cooperatives, village funds for the small farms or commercial banks for the large farms (baht)
X_{53}	Food consumption (baht)
X_{54} - X_{62}	Revenue balance (baht)
X_{63} - X_{65}	Loan and interest repayments to BAAC, agricultural cooperatives, village funds for the small farms or commercial banks for the large farms (baht)
X_{66}	Net revenue (baht)

6.5 Coefficients at the farm level

Agriculture in the Fang watershed is made up from 2 major components, Fruit production and cash crops:

1. The major cash crops grown in the Fang watershed are rice, onion, garlic and sweet corn. Twenty samples from each crop production were collected.
2. A variety of fruit trees such as citrus, longan and lychee are planted in the Fang watershed. These require different resource management depending on the age of the trees. In this study, the growth period of the fruit trees in each type were divided by following the criteria laid down by the Chiang Mai Agricultural Research and Development Center, Fang (2012). Some farmers had fruit trees in each category, especially in the large farms so the samples from each category are not equal.

2.1 Citrus was divided into 4 periods: 1-2 years, 3-5 years, 6-9 years and 10-12 years respectively. The study collected data from the small farms using chemicals from 53 households, 52 households from the small farms using chemicals and bioextract, 26 households from the large farms using chemicals and 22 households from the large farms using chemicals and bioextract.

2.2 Longans were divided into 4 periods: 1-3 years, 4-6 years, 7-10 years and 11-15 years. The data was collected from 20 households.

2.3 Lychees were divided into 4 periods: 1-4 years, 5-7 years, 7-10 years, and 11-15 years. The data was collected from 20 households.

The study considered alternative crops which are environmentally friendly as well as providing yield and revenue equal or greater to the major crops grown in the Fang watershed. The production of these alternative crops would have the additional benefit of not affecting the farmer's health by avoiding chemical use. The alternative crops selected were tea and coffee. The collected data came from Tambon Thepsadej, Doi Saket district, Chiang Mai province, as this area has a climate similar to the Fang watershed. The collected data came from 20 households and the categories of the tea and coffee are as follows:

1. Tea was divided into 1-3 years old and 4-20 years old trees.
2. Coffee was divided into 4 phases: 1-2 years ,3-4 years, 5-10 years and 11-20 years old respectively.

The data was obtained by interviewing the farmers from both the Fang and Tambon Thepsadej areas and the answers were recorded on questionnaires. The information was then edited and coded before being entered into a Microsoft Excel program. The information was divided by general household information and crop production. Crop production were classified by crop production area, price and input factors (seed, manure, fertilizer, chemicals use etc.), household labor, exchange labor, hired labor, wages, yield and sale price. These were analyzed by all the variable coefficients of crop production and took into account every model at the farm level, except for the coefficient variable of the citrus which depended on the farm type.

6.5.1 Labor coefficients

The labor coefficients were analyzed by the time period each crop needed for production per month. These activities included an average of household labor, exchanged labor and hired labor man-days per rai per month. The cropping systems were given the sum of the labor coefficients for each crop in the system and the data is shown in Appendix A Table A1 to Table A4.

6.5.2 Capital coefficients

The capital coefficients of crop production were analyzed by calculating the average of input factor costs to the farmers for the crop production measured in baht per rai per month. The cropping systems were the total sum of the capital coefficients for each crop in the system and the data is shown in Appendix A Table A5 to Table B8.

6.5.3 Revenue coefficients

The revenue coefficients were obtained from the yield multiplied by the sale price. The average monthly income per rai from the individual cash crops in the systems equaled the total sum per rai of the revenue coefficients for each crop in the systems and the data is shown in Appendix A Table A9 to Table B12.

6.6 Goals coefficients at the farm level

In this study, 7 objective goals as described in Chapter 3 were identified. A figure was calculated for each goal averaged per rai for each crop by following the equation no. 3.2 to 3.8 in Chapter 3. These results for each individual crop in each cropping system are then totaled to arrive at an annual figure and this can be used for every farm type. The exception is for citrus which depends on the farm type. The results are shown in Appendix A Table A13 to Table A16.

6.7 The farm level model

The farm level model with the Multiple Goal Linear Programming (MGLP) was used to obtain an optimal resource management of citrus-based farming systems. At this level, the economic objective at the farm level is more prominent than the social or the environmental objectives. These are related to the 7 objective goals and are given equal weighting (EW), and are then weighed by AHP. The objective function in the MGLP model at the farm level is the minimization of the total deviation from the goals as follows:

$$min = (w_{f1}d_{f1}^{-} - w_{f2}d_{f2}^{+} - w_{f3}d_{f3}^{+} - w_{f4}d_{f4}^{+} - w_{f5}d_{f5}^{+} - w_{f6}d_{f6}^{+} + w_{f7}d_{f7}^{-}) \quad .... (6.1)$$

Where: w_f represents the weight of *f*th goal,

d_f^- and d_f^+ are the negative and positive deviations of *f*th goal.

The constraints include:

1. Goals constraints

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(AEV_{cro\,iju} * Area_{crop\,iju}) + w_{f1}d_{f1}^{-} = GA \quad ...... (6.2)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(HL_{crop\,iju} * Area_{crop\,iju}) - w_{f2}d_{f2}^{+} = GH \quad ...... (6.3)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(IIEI_{crop\,iju} * Area_{crop\,iju}) - w_{f3}d_{f3}^{+} = GI \quad ...... (6.4)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(LI_{crop\,iju} * Area_{crop\,iju}) - w_{f4}d_{f4}^{+} = GL \quad ...... (6.5)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(YV_{crop\,iju} * Area_{crop\,iju}) - w_{f5}d_{f5}^{+} = GY \quad ...... (6.6)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(RV_{crop\,iju} * Area_{crop\,iju}) - w_{f6}d_{f6}^{+} = GR \quad ...... (6.7)$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}(OFF_{crop\,iju} * Area_{crop\,iju}) + w_{f7}d_{f7}^{-} = GO \quad ...... (6.8)$$

Where

GA is the achievable goal level of the Annual Equivalent Value (AEV) from the cropping systems.

GH is the achievable goal level of hired labor (HL).

GI and GL	are the achievable goal levels of independence from external inputs (IIEI) and loan investment (LI).
GY and GR	are the achievable goal levels of yield variance (YV) and revenue variance (RV) respectively.
GO	is the achievable goal level dealing with off-farm work (OFF).
*j*th	is the cropping systems and off-farm work (*j* = 1,…,25)
*i*th	is the crop production in the cropping systems (*i* = 1,…,3)
*u*th	is the land unit *u* = 1,…,4 of irrigated upland, rainfed upland, irrigated lowland and rainfed lowland respectively).

2. Resource Constraints

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq IU_f \quad \text{..... (6.9)}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq RU_f \quad \text{.... (6.10)}$$

$$\sum_{j=1}^{n}\sum_{i=1}^{3} X_{ij} \leq IL_f \quad \text{..... (6.11)}$$

$$\sum_{j=1}^{n}\sum_{i=3}^{3} X_{ij} \leq RL_f \quad \text{..... (6.12)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} HH_{miju} X_{ij} \leq THH_f \quad \text{..... (6.13)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} Hired_{miju} X_{ij} \leq THired_f \quad \text{..... (6.14)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} CashIn_{miju} X_{ij} \leq OwnInvest_f \quad \text{..... (6.15)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} Loan_{miju} X_{ij} \leq AvailableLoan_s \quad \text{.....(6.16)}$$

$$RepayLoan_s \geq 0 \quad \text{.....(6.17)}$$

$$FoodCon_f \geq BasicNeed\_HH_f \quad \text{.....(6.18)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3}\sum_{m=1}^{12} Revenue_{miju} X_{ij} \geq 0 \quad \text{..... (6.19)}$$

$$\sum_{u=1}^{4}\sum_{j=1}^{n}\sum_{i=1}^{3} NetAnualRev_{iju} X_{ij} \geq 0 \quad \text{..... (6.20)}$$

Where

IU_f	The total irrigated upland available (rai)
RU_f	The total rainfed upland available (rai)

IL_f	The total irrigated lowland available (rai)
RL_f	The total rainfed lowland available (rai)
X_{ij}	The cropping systems and off-farm work from the *j*th systems of the *i*th crop (*j* = 1,…,25 and i = 1,…,3)
HH_{miju}	The household labor from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit (*m* = 1,…,12 and *u* = 1,…, 4)
THH_f	The household labor available (man-days)
$Hired_{miju}$	The hired labor from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$THired_f$	The hired labor available (man-days)
$CashIn_{miju}$	The cash investment from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$OwnInvest_f$	The total owner capital investment (baht)
$Loan_{miju}$	The loan investment from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$AvailableLoan_s$	Total loan available (baht) from *s*th source (*s* = 1,…,3)
$RepayLoan_s$	Total repayment of loan (baht) to *s*th source (*s* = 1,…,3)
$FoodCon_f$	The food consumption of the household
$BasicNeed\_HH_f$	The basic need of food consumption in the household at the farm level
$Revenue_{miju}$	The revenue (baht) from the *j*th plants of *i*th crop in the *m*th month from the *u*th land unit
$NetAnualRev_{iju}$	The net annual revenue from crop production of the household

The models at the farm level contain 80 decision variables. Cropping systems and off-farm work have 25 variables, hired labor and capital transfers have 24 variables, loans and interest repayments have 6 variables, revenue has 9 variables, food consumption and annual profit have 2 variables and 7 weigh values (Table 6.9).

There are 64 constraints. Variable goal objectives have 7 constraints, land units have 4 constraints, household labor and hired labor have 24 constraints, capital has 12 constraints, loan and interest repayments have 6 constraints, revenue has 9 constraints, food consumption and annual profit have 2 constraints (Table 6.10).

Table 6.9 Decision variables at the farm level model

Decision variables	Number
Cropping systems and off-farm work	25
Hired labor and capital transfers	24
Loans and interest repayments	6
Revenue variables	9
Food consumption and annual profit	2
Deviations	14
Total	80

Table 6.10 Constraints at the farm level model

Constraints.	Number
Goal constraints	7
Land units	4
Household labor and hired labor	24
Capital constraints	12
Loan and interest repayments	6
Revenue constraints	9
Food consumption and annual profit constraints	2
Total	64

This chapter analyzed the weight values, the constraints and the coefficients. The weight value results were used for the analysis by the AHP method. The study analyzed the goal constraints (annual equivalent value, hired labor and yield variance etc.) and the resource constraints (land use, household labor, hired labor and loans etc.). It also analyzed the goal coefficients and the resource coefficients which were taken into account in the model at farm level as shown in Table 6.11.

Table 6.11 Multiple-goal programming at the farm level model

Constraints/Activities			Crop activities	Off-farm work	hired labor	Cash flows	Loan	Food consumption	Revenue from crop production	Repayment of loan	Net annual revenue	Deviation		
			X_1 ... X_{24}	X_{25}	X_{26} ... $X3_7$	X_{38} ... X_{49}	X_{50} ... X_{52}	X_{53}	X_{54} … X_{62}	X_{63} … X_{65}	X_{66}	X_{67} ... X_{80}		
Objective												N1 … P7		
Constraints	Unit	Row											Signal	RHS : B
Land use	rai	R_1 …. R_4	a_{ij} … a_{ie}										<=	b_1 …. b_4
Household labor	man-day	R_5 …. R_{16}	a_{ij} … a_{ie}	1	-1 …. -1								<=	b_5 …. b_{16}
Hired labor	man-day	R_{17} …. R_{28}			1 ….. 1								<=	b_{17} …. b_{28}
Cash flows	baht	R_{29} …. R_{40}	a_{ij} … a_{ie}		[W]	-1 ….. 1	-1 ….. -1		-1 ….. -1				=	b_{29} …. b_{40}
Loan	baht	R_{41} …. R_{43}					1 ….. 1						<=	b_{41} …. b_{43}
Revenue from crop production	baht	R_{45} …. R_{52}	[R]						1 ….. 1				=	b_{42} …. b_{52}
Food consumption	baht	R_{53}						-1					=	b_{53}
Net annual revenue	baht	R_{54}				-1		1		1 ….. 1	1		=	b_{54}
Repayment of loan	baht	R_{55} …. R_{57}					[-1+r]			1 ….. 1			=	b_{55} …. b_{57}
Annual equivalent value	baht	GA	[AVE]									1 ….. -1	<=	C_1
Hired labor	man-day	GH	[HL]									1 ….. -1	<=	C_2
Independence from external inputs	baht	GI	[IIEI]									1 ….. -1	<=	C_3
Loan investment	baht	GL	[LI]									1 ….. -1	<=	C_4
Yield variance	kg	GY	[YV]									1 ….. -1	<=	C_5
Revenue variance	baht	GR	[RV]									1 ….. -1	<=	C_6
Off-farm work	baht	GO		[OFF]								1 ….. -1	<=	C_7

[W] = wage, [R] = revenue from crop production (average yield minus price), [r] = interest rate, C = goal constraints, [AVE] = annual equivalent value, [HL] = hired labor, [IIEI] = independence from external inputs, [LI] = loan investment, [YV] = yield variance, [RV] = revenue variance, [OFF] = off-farm work, N = negative and P = positive