VERSITA DOI: 10.2478/v10295-012-0027-2 AGRICULTURA TROPICA ET SUBTROPICA, 45/3, 166-172, 2012

Original Research Article

The Impact Assessment of Water Resource Management on Farms in the Ping Watershed, Northern Thailand

Yotapakdee Teeka, Bohumil Havrland

Department of Economic Development, Institute of Tropics and Subtropics,
Czech University of Life Sciences Prague

Abstract

The irrational use of water in agriculture is often responsible for several problems concerning the depletion of water resources. Water resources sustainability has crucial for the existence of farming system which is dependent on the cropping pattern practices. This paper concerns the studies of existing water resource management and determines factors affecting decision making about water use and management within different farming systems. In these cases, a multi-criteria decision making model (MCDM) has been determined that aims at allocating efficient water and land resources to farms in the Ping watershed area in northern Thailand by optimizing a set of important socio-economic objectives which depend on sustainable agricultural (rural) development. The solution was found by using two analytical steps as follows: single objective optimization and compromise programming.

These resources include: land, labour, capital, fertilizer, pesticides and irrigation water. Existing cropping pattern included the in-season rice, off season-rice, vegetables (chili, pak choi, cauliflower, long bean, cabbage), soybean and sweet corn. Under the model cropping pattern conditions the in-season rice was produced for the household consumption and specially found in irrigated areas with storage dam. The model recommended that the suitable cropping pattern of the in-season rice followed by chili and long bean increased the gross margin two times. The amount of water used for the irrigation decreased by 6.84 percent from original 1,198,904 m^3 at the existing cropping pattern to 1,116,902 m^3 at the model cropping pattern.

However, in the case of the irrigated areas with water gates the model showed that the suitable cropping pattern was not different from the existing ones. However, the recommended model cropping pattern as the suitable cropping pattern consisting of the in-season rice followed by vegetables, sugar cane and perennial crops such as longan increased the gross margin three times while the water use increased only by 2.25 percent from the existing cropping pattern (from 1,374,655 m^3 to 1,405,582 m^3 at the model cropping pattern).

In the case of the rainfed areas the model cropping pattern recommended to grow the in-season rice, tobacco and longan on farm which increased the gross margin six times. However, the water using increased slightly from the existing on-farm water consumption (101,601.2 m^3) up to 680,869 m^3 as linked to the model cropping pattern.

Keywords: water resource management, multi-criteria decision making, water using, cropping pattern, farming system

INTRODUCTION

Thailand is inhabited by 65.5 million people (NSO, 2011). According to the Thai Statistical Office in 2008 the majority people (73 %) lived in rural areas whereas only 33.3% of them lived in urban areas (ADB, 2009). The Thailand economic structure is composed of two major sectors: agricultural (mostly in rural areas) and industrial (mostly in Bangkok, its vicinity, and industrial areas). In comparison with 2009 the Thailand GDP in 2010 had grown up by 7.8% of which the agricultural sector share fell by 2.2% however the non-agricultural sectors grew by 8.8%.

In Thailand, the yearly demand for water is about 53 billion cubic meters. Out of this volume, almost 90 percent is allocated for agriculture, 6 percent for domestic consumption and the rest is for the use in industries (Sacha et al., 2000). The annual demand for water is estimated at about 70 billion cubic meters annually in the next 10 years (Board of Investment Thailand, 2007).

Thailand has been divided into 25 river basins. The average annual countrywide rainfall is about 1,700 mm. The total volume of water from rainfall in all river basins in Thailand is estimated at 800 billion m^3, 75 percent of which (about 600 billion m^3) is lost through evaporation, and infiltration; the remaining 25 percent or 200 billion m^3 constitutes the runoff that flows in rivers and streams (Sacha et al., 2000). As a result of water scarcity, competition for water thus exists between regions, between different sectors, and even between upstream and downstream users in the same catchments and river basins.

In the Ping watershed in northern Thailand, the catchment areas are 33,898 km^2, average runoff is 7.965 billion m^3, storage capacity 14.107 billion m^3 and irrigation area 310,868 ha. Water requirement includes domestic consumption at 75.26 million m^3, ecological balance 457.27 million m^3, irrigation/agriculture 2.4282 billion m^3 and hydropower 3.623 billion m^3 (Sacha et al., 2000).

The lack of water in agricultural sector pushes farmers to adapt themselves as best as they can to a declining and fluctuating water supply. Several water management strategies at farm level have been applied to prevent water shortage in their farms such as investment in pumping devices and water storage and investment in water distribution technology at farm level. However, farmers are still blamed for that they use water inefficiently because they do not have to pay for the irrigation water and, thus, they are not motivated to conserve water or to use it efficiently on high-value crops. As a result, the irrigation efficiency is under 30% (Francois, 2001). This article reports on a study about existing water resource management within different farming systems in order to get better understanding of the current water use and management in Northern Thailand. It is expected that the research conducted in the Northern Thailand (Ping watershed) will identify a potential of water resources under sustainability development as well as assess the impact of future development on farm activities and farmers' livelihood.

MATERIALS AND METHODS

Hypotheses

The research has been based on two hypotheses on water resource management potential in the Ping watershed:

i. Water resource management plays an important role in sustainable agricultural development.
ii. More efficient use of water resources will improve the farmers' socio-economic situation.

Study area

The study areas are located in the Ping Watershed in Northern Thailand. Chiang Mai Province was selected as a study area based on the water resource and project diversity. There are different types of water resource development projects for irrigation along the Ping watershed in Chiang Mai Province. The projects can be classified into small, medium, and big scale irrigation ones. They are developed and managed by different groups, organizations and agencies. The corresponding data were collected from farmers within different farming systems by interviewing the experts and completing the standard cropping cost-benefit questionnaires.

Overview of Applied Data Set

The indicators are introduced as accounting equations in the simulation models of which indicators are from the vector of crop plans chosen by agricultural producers. The indicators are economic, social and environmental.

The economic indicator is total gross margin which the farmers get as measured in terms of the gross margins obtained through farming activities while the social indicator is the total labour because the degree of employment explains the social importance in the agricultural sector and distribution of this income in each area. The environment indicator is water use which is quantified in terms of crop water requirements on farms. The data used to perform calculations of the above indicators were collected and assessed though their averages per one survey on farmers within different farming systems.

Goal Programming Model

A multi-criteria Mathematical Programming model (MMP) has been developed to support the spatial development planning process. The model achieves the optimum farm plan in the area combining different criteria to a utility function under a set of constraints concerning different categories of land, labour, available capital, etc.

Model specification

Variables

Each farmer has a set of variables X_i (crops). These are the decision variables that can assume any value belonging to the feasible set. The economic values of the crops resulted from the agricultural indicators from the survey data.

Objectives

Four objectives have been specified for the case illustrated here:

i) maximization of gross margin to farmers, operators and family labour;
ii) maximization of hired labour employment;
iii) minimization of risk from price alternations;
iv) minimization of risk from yield alternations.

Formulation of multi-objective problem

Objective 1: Maximization of gross margin to farmers, operators and family labour (FI)

The gross margin to farmers, operators and family labour at different crops is obtained by subtracting total variable costs (hired labour cost, fertilizers, pesticides, irrigation and other costs) from gross revenue (Francisco and Ali, 2006).

$$MaxFI = \sum (R_i - C_i)X_i \ , \qquad i = 1, 2, \ldots, n \qquad (1)$$

Where: FI..…farm income of crop
R_i …. gross margin from crop *i*;
C_i…. total variable costs incurred in the production of crop *i*;
X_i…...the area allocated to production of crop *i*;
i …. the crop index.

Objective 2: Maximization of hired labour employment (HL)

The intensity of production as well as absence of mechanical means to perform most of the operations involved in vegetable production results in a large share of hired labour cost to total variable cost (Francisco and Ali, 2006).

$$MaxHL_i = \sum H_i = \sum (TL_i - FL_i)\, X_i, \quad i = 1, 2, \ldots, n \tag{2}$$

Where: HL_i …. hired labour requirement of crop *i*;
TL_i …. total labour requirement of crop *i*;
FL_i …. family labour available for crop *i*;
X_i....... the area allocated to production of crop *i*;
i ….. the crop index.

Objective 3 and 4: Minimization of risks

An economically feasible production plan must pose a minimum risk to farmers. The minimum risk is due to variable weather conditions, insect, pests and diseases infestations and changes in prices and other market conditions that create conditions of higher variability in farm incomes realized by farmers through their production (Francisco and Ali, 2006). The total income variance of incomes derived in the production of crop *i* with the gross margin, R_i, can be formulated as a quadratic formula given by:

$$V(I) = \sum\sum \sigma_{ij} X_i X_j, \quad i,j = 1, 2, \ldots, n \tag{3}$$

Where: V(I)…total income variance
σ_i ... Variance-covariance matrix of net income derived from the production of crop *i*;
X_i... the column vector of the area allocated to production of crop *i*;
X_j... the row vector of the the area allocated to production of crop *j;*
i ... the crop index in the column vector;
j ... the crop index in the row vector.

Minimization of total income variance can then be expressed as:

$$MinV(I) = Min\sum\sum \sigma_{ij} X_i X_j \quad i,j=1,2, \ldots,n \tag{4}$$

Two sources of the minimum risk include: price induced by the minimum risk and yield induced by the minimum risk on the income. The price induced by the minimum risk is associated with the availability of the product in the market that is observed from year to year. The yield induced by the minimum risk is associated with the stability of yield of the crops from year to year.

The set of objective functions is constrained by availability of resources of vegetable farmers. These resources include: land, capital, labour, fertilizers, pesticides and irrigation water.

Constraints imposed on the model include as follows:

Land: sum of all crop areas is equal to the total available area. The total land used for different crops at any time cannot exceed the total available land. The land allocated to a crop remains unchanged from the time of sowing to time of harvesting (Ranvir Singh et al. 1987).

Labour: amount of family working labour is used as the upper limit of family labour constraints. The family working labour is assumed to be equal in each month. Hired labour is assumed to be unlimitedly available.

Capital: sum of all crops requiring capital is equal to the total available capital, earned incomes through sales of crops and available one unit of loan in each season.

Irrigation water: total water use in the irrigation areas should not exceed the total allocation in a given month. (Xevi and Khan, 2005).

$$TWREQ = \sum_c (X_c WREQ_m), \quad m=1,\ldots,12 \tag{5}$$

Where: TWREQ …. total water requirements of all crops per month;
WREQ …. each crop of water requirements per month;
X_c… the area allocated to production of crop *c*;
c …. the crop index;
m .... months of the year.

However, the crop water requirements per month *WREQ (c, m)* may be estimated as a function of the crop coefficient, crop growth duration, evapo-transpiration and rainfall using climatic data or based on water balance techniques.

$$\sum_c (X_{(c)} WREQ_{(c,m)}) \le Allocation(m), \quad m=1,\ldots,12 \tag{6}$$

The water requirements in this paper are assumed as the excess from evapo-transpiration over rainfall. Requirements for leaching of salts or pre-irrigation are not considered. The fraction of growth period in a given month for a given crop (*d_ratio (c, m)*) is given by:

$$d\_ratio\ (c,m) = G\_duration\ (c, m)/days(m) \tag{7}$$

Where: *G_duration(c,m)* …. growth duration of crop *c* in one month *m*;
days (m) …. number of days in one month *m*.

The crop water requirements are evaluated as follows:

$$WREQ\ (c,m) = k_a\ (c, m)\ d\_ratio \times ET\ (m) - d\_ratio\ (c, m)\ Rain(m) \tag{8}$$

Where: $k_a(c,m)$ …. crop coefficient of crop *c* in month *m* and *ET (m);*
Rain (m) …. evapo-transpiration and rainfall in one month m.

Commodity balance: crop products can be sold in the market or consumed by the family.

Activities included in the model are as follows:

Farm activities: farming activities for each farming system are more or less the same. The crop activities consist of rice, other annual crops and vegetables (Acharee, 1999).

Labour activities: family labour can be used within the farm to fulfil own requirements and for off-farm activities, too. The family labour for household activities is also required. Hired labour is allowed in order to increase labour supply (Jirawan, 2003).

Credit activities: two forms of credit are available in the model, formal and informal credit. The short term (one year) formal credit is allowed for the household. The informal credit comes from traders or other informal institutes and the long term (ten years) formal credit is allowed for the household from formal credit.

Water activities: water required for crop production is obtained from the available surface water resource which is available in each month (Ranvir Singh, et al., 1987).

Market: production of all crops can be sold in the market at which the farmers can get market price in the period 2010/2011. The model put an average price of cultivation of these crops.

RESULTS

The first goal of the research was to explain existing water resource management within different farming systems in Ping watershed area by comparison of the cropping pattern between the existing crops and the suitable crop by model.

In rainfed area, Maetaeng district

Water resource management in rainfed area, almost of farmers cultivating annual crops; the farmers were using crops not demanding the water. The farmers stored the lacking water in small reservoirs and water tanks on their farm for saving water for the dry season. Such a water on-farm storage is useful for their decision-making on cultivation practices in the next year.

In rainfed areas there is a potential for growing 10 crops (in-season rice, long bean, marigold, maize, sweet corn, tobacco, galangal, lemon grass, banana and perennial crop - longan); all this in the existing cropping pattern. However, the model cropping pattern advises those farmers to grow the in-season rice (0.07 ha), tobacco (0.43 ha) and longan (0.57 ha), only. If the farmers follow the model cropping pattern even the gross margin increases insignificantly by 764,046 baht (see Table 1) and water using increases slightly from the up-to-now existing water on-farm consumption at 101,601 m^3 (Fig. 1).

Table 1. Comparison of existing and suitable crops proposed by the model cropping pattern on rainfed areas, Maetaeng district

Crops	Existing crops (ha)	Model cropping pattern (ha)
In season-rice	0.91	0.07
Long bean	0.28	-
Marigold	0.28	-
Maize	0.67	-
Sweet corn	0.64	-
Tobacco	1.08	0.43
Galangal	0.8	-
Lemon grass	0.16	-
Banana	0.93	-
longan	0.97	0.57
Gross margin (baht)	113,162.6	764,046

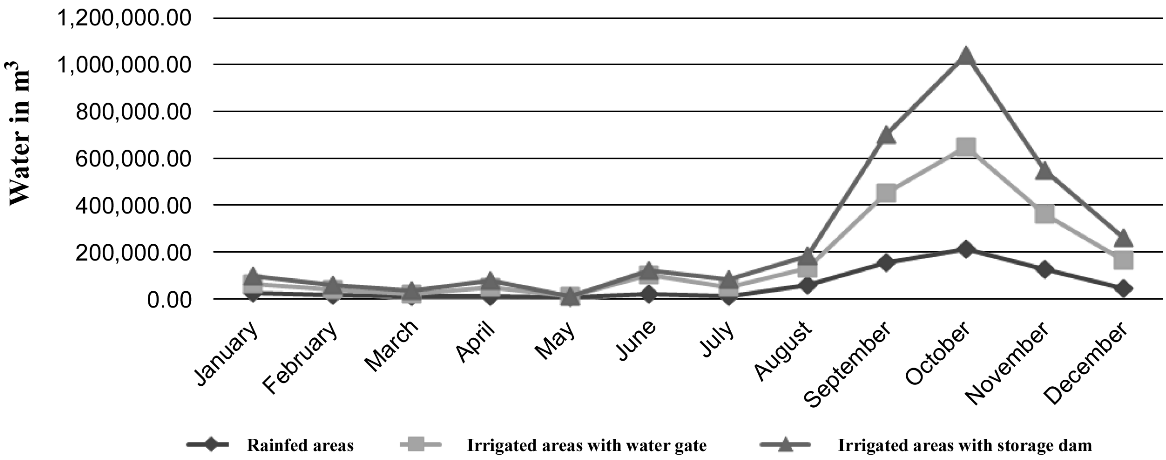

Figure 1. Water use in different farming systems, year 2010/2011 by model cropping pattern

Table 2. Comparison of existing and suitable crops proposed by the model cropping pattern on irrigated areas with water gates, Sarapee district

Crops	Existing crops (ha)	Model cropping pattern (ha)
In season-rice	1.28	0.04
Off season-rice	0.95	0.07
Chili	0.1	0.6
Pak choi	0.15	0.02
Long bean	0.11	0.02
Morning glory	0.43	0.02
Coriander	0.34	0.02
Celery	0.4	0.02
Green shallot	0.08	0.02
Spinach	0.07	0.02
Lettuce	0.08	-
Sugar cane	0.57	0.36
Longan	0.58	0.64
Gross margin (baht)	117,433.35	314,427.9

Table 3: Comparison of existing and suitable crops proposed by the model cropping pattern on irrigated areas with storage dams, Sansai district

Crops	Existing crops (ha)	Model cropping pattern (ha)
In season-rice	1.3	0.14
Off season-rice	1.38	-
Chili	0.36	2.06
Pak choi	0.4	-
Cauliflower	0.75	-
Long bean	0.64	0.02
Soy bean	0.48	-
Sweet corn	0.16	-
Cabbage	0.4	-
Gross margin (baht)	121,684.22	236,351

In irrigated area with water gates Sarapee district

The water resource management on irrigated areas provided with water gates, the farmers created a water users´ group within the same main canal. They have to share the water use on farms on each canal branch by the schedule worked out by the water users´ group, for example 3 days on one canal branch and 3 days on other canal branch, etc. Before the rainy season the water users´ group repaired its canals by cleaning and cutting weeds around canals for an easy water access to their farms. Because of most canals made of earth the weed makes serious barrier for water flowing to farms. The farmers have water resource management on their farms without management interventions for the part of Royal Irrigation Department (RID).

The cultivated crops were composed of the in-season rice, off-season rice, chili, pak choi, long bean, morning glory, coriander, celery, green shallot, spinach, lettuce, sugar cane and longan. The advice on cropping pattern provided by the multi-objective model given to farmers was: to grow the in-season rice (0.04 ha), the off-season rice (0.07 ha), sugar cane (0.36 ha) and longan (0.64 ha). The farmers than have another about 0.02 ha which they should plant with 7 kinds of vegetable such as: pak choi, long bean, morning glory, coriander, celery, green shallot and spinach. If the farmers follow the model cropping pattern their gross margin increases slightly by 314,427.9 baht (Table 2) and the water use increases by 2.25 percent from 1,374,655 m^3 associated with the existing cropping pattern (Fig. 1).

In irrigated area with storage dams, Sansai district

The water resource management in irrigated areas with storage dams required the farmers´ cooperation with Royal Irrigation Department (RID); at this they have a concrete canal leading irrigation water to their farms. The farmers established a water users´ group at the management of authorities of RID. The water users´ group got the policy and action plan from RID to practice on farms. Therefore, the decision-making responsibility depends on the annual action plan from RID.

The crops planted on irrigated areas surrounded by dikes (flood irrigation) include: the in-season rice grown during the rainy season and vegetable (chili, pak choi, cauliflower, long bean, soy bean, sweet corn and cabbage) grown during the dry season. The advice on the cropping pattern given by the model cropping pattern was the following: the in-season rice (0.14 ha), chili (2.06 ha) and longan (0.02 ha); this could give the gross margin at 236,351 baht (see Table 3) whereby the water use for the irrigation purposes decreased by 6.84 percent from the existing cropping pattern consuming 1,198,904 m^3 (Fig. 1).

Sensitivity analysis

The sensitivity analysis was conducted by use of the longan price at rainfed area and irrigated areas (water gates) because the most of annual crops have the price support from the government. On the other hand, the price of longan did not have the price support thus if it changes the cultivation of longan will change, too, following the rising price. The sensitivity analysis results using the longan price did not change the suitable cropping pattern proposed by the models. The analysis data demonstrated the reliability of results given by the model cropping pattern. Therefore both rainfed area and irrigated areas (water gates) still use the suitable cropping pattern given by the model because it got the optimization useful for the crop cultivation. However, the irrigated areas (storage dams) have not longan thus the sensitivity analysis used the chili price because it did not have the price support. The result of sensitivity analysis did not change from the model cropping pattern, therefore the result still uses the suitable cropping pattern given by model.

The second goal was: to determine factors affecting decision-making about water use and management in different water resource management systems.

The first factor affecting the decision-making process on crop cultivation depends on the price. If farmers foresee increased price of some crops they will cultivate it on larger areas than the year before. However, the price support from government is also important to influence the farmers´ decision.

The second factor is the cost of cultivation of each crop. It is because the farmers decide to cultivate crops at lowest possible costs but under the condition they would get the highest farm incomes.

The last factor to be assumed by farmers is water supply capacity. The farmers have to know the inflow potential for each year before the crop planting season. If they know they will have less water they decide to grow less water demanding crops (such as beans). As the consequence of the lack of water the farm economy is always disturbed and the farmers lose incomes.

The last goal was: assessment of the development potential of water resources under sustainable conditions.

The development potential of water resource management under sustainable conditions in each farming system differs each other because the farmers are aware of water scarcity on farms for the next generations. The development potential depends on the conservation and protection of forest resources by the local community. On irrigated areas (storage dams and water gates) the farmers have got a secured development within the water users´ groups which makes them strong in brain storming for getting knowledge. It is especially important for developing their fields and creating a proper water resource management in irrigated areas. It is necessary for getting water security according to a farmers´ plan for solving the water scarcity within the local community on irrigated areas with water gates. On irrigated areas with storage dams the farmers usually work out their annual plans by themselves which gives them opportunity to discuss their problems in detail with RID officers.

CONCLUSIONS

The water resource management in different farming systems is different because of various conditions and different farmers´ thrusts. On basis of the extended surveys and from the above analysis we can deduce the following:

1. In rainfed areas the farmers store the scarce water in small reservoirs and water tanks on their farms for saving it for the dry season because the water on-farm security is an indispensable prerequisite in decision-making upon the next year crop. The multi-objective model advises those farmers to grow the in-season rice, tobacco and longan.
2. In irrigated areas with water gates the farmers created a water users´ group on the same main canal (ground canal); this is made by them without control for the part of the RID. They have to share the water use according to the schedule with other canal branches. The advice to farmers on cropping pattern provided by the multi-objective model was to grow the in-season rice, off-season rice, sugar cane, longan and a few areas under vegetables.
3. In irrigated areas with storage dams the farmers have to cooperate with RID, they have a concrete canal bringing water to their farms. The farmers created the water users group which was managed by RID officers. The farmers through their water groups get a policy orientation and action plan from the RID to implement on their farms. The advice on the cropping pattern given by the multi-objective model is the following: the in-season rice, chili, and longan.
4. The sensitivity analysis was conducted by use of the longan price at rainfed area and irrigated areas (water gates) at the use of suitable cropping pattern given by the model. Because the irrigated areas (storage dams) do not have longan thus the chili price was used for the sensitivity analysis. The result of sensitivity analysis did not change from the model cropping pattern, therefore the result still uses the suitable cropping pattern given by model.
5. The factor affecting decision-making on water use and management in different water resource management systems are prices, costs and water supply capacity. If the farmers see a price increase or a price support of some crops by the government they will cultivate its more area than the year before. The farmers also prefer to grow low cost crops but suppose to get high on-farm incomes. They require to know a future water potential inflow before the crop planting season. If they have prospects to get less water they are going to grow less water demanding crops.
6. The development potential of water resource management under sustainable conditions in each farming system is different because the farmers are aware of water scarcity on farms for the next generations. The development potential consists in conservation of forest resources by the local community especially in rainfed areas. The farmers have the sustained development in the water users´ group to be strong in brain storming for getting knowledge and developing their fields.

Recommendation

It can be recommended to use the cropping patterns proposed by multi-function model on farms in Ping watershed. The model is consistent with each farming system where there are differences in risk and uncertainty. Because the risk and uncertainty come from weather conditions, natural resources and flexible market these factors must be considered as variables which cannot be controlled by farmers themselves. The above model processes these factors and produces management advice which is, according to our survey, acceptable by the farmers for their better operational and economic (including water consumption) parameters.

ACKNOWLEDGMENTS

We gratefully acknowledge the financial aid received from the ERASMUS MUNDUS and also thank the reviewers for recommendations.

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Received for publication January 24, 2012
Accepted for publication: September 3, 2012

Corresponding author:

Teeka Yotapakdee
Czech University of Life Sciences Prague
Institute of Tropics and Subtropics
Kamýcká 129, 165 20 Prague 6-Suchdol
Czech Republic
Email: teeka_y@hotmail.com