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An Allocation LP Model for Planning Dry-Season Irrigation Project

Ounla Sivanpheng[1], Sudarat Compliew[2]

Faculty of Water Resources, National University of Laos, Vientiane, Lao PDR
E-mail: *ounlasvp[at]gmail.com*

Faculty of Engineering, Mahasarakham University, Mahasarakham, 44150, Thailand
E-mail: *scompliew_4[at]yahoo.com*

Abstract: ***Crop pattern is important information for farmers that used to be the guidelines at the beginning of seasonal cultivation. This paper proposes an allocation LP model that can take into account heterogeneity of water requirement and crop yield of irrigation area for finding optimal crop patterns. A sensitivity analysis of irrigation efficiency in the LP model was accounted for in the study. The proposed model was applied to find the dry-season (Mid December – Mid April) crop pattern of the Huai-Ang Irrigation Project located in the Northeast Region of Thailand. The records of seasonal flow requested and actual irrigation areas, crop water requirement, crop yield, evaporation, and effective rainfall of the project were used for this illustrative application. Results showed that the proposed LP model is feasible for finding the optimal crop pattern. Heterogeneous character in allocation LP model provided the crop pattern that suitable for cultivating crop on the actual land area. The consideration of various irrigation efficiency in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.***

Keywords: optimization model, linear programming, irrigation planning, dry-season crop pattern, varied irrigation efficiency

1. Introduction

Irrigation planning under limited available resources (such as water, irrigated area, production cost, manpower, etc.) is one of the classical problems in water resource management. The crop pattern of the irrigation project is the land area that is provided for cultivating each crop. Therefore, the farmer needs to have the optimum cropping pattern which will maximize the economic return.

Linear programming (LP) is an optimization technique which widely used to allocate limited resources because of the proportionate characteristic of the allocation problem [1,2]. One popular application of the technique in the water resource literature is to find an optimal seasonal crop pattern which subjected to limited available resources [3,4,5]. Often, the maximization benefit was set as the objective function based on the resource constraints. The objective function and constraint functions are formulated as linear equations for finding optimum crop patterns. The portion of treated water from wastewater treatment and groundwater is included in the water constraints of the LP model [6,7]. Moreover, water quality parameters (salinity and suspended solid) are incorporated into the LP model [8]. Also, the pricing of irrigation water is considered in the constraints of the LP model [9].

Often, most previous studies assumed homogeneity in crop water requirement and crop yield for all land areas of the considering project. The obtained crop yield is usually affected by sufficient crop water requirement and physical soil type suitable for the cultivation of each crop [10,11]. In addition, most previous studies considered irrigation efficiency as a constant value in calculating available water. Generally, irrigation efficiency is a varied value based on the amount of available water and farmer participation in water resource management [12,13].

The purpose of this paper is to propose an allocation LP model that can take into account the heterogeneity of land area in terms of crop water requirement and crop yield. A sensitivity of irrigation efficiency is presented in this study.

2. Formulation Model

Linear programming is used to be a based model for finding optimal seasonal crop patterns. The model will be formulated to maximize benefit subjected to the limited resources on available dry-season water and crop water requirement, crop yield, and net benefit of each crop. The obtained crop pattern can be used for dry-season planning which considers the heterogeneous character of the irrigation project. The objective function of the model can be presented as:

$$Max\ Z_j = \sum_{h=1}^{H} \sum_{k=1}^{K} \left(Y_{hk} P_{hk} - C_{hk} \right) X_{hjk} \quad (1)$$

where Z_j is the gross benefit of the irrigation project during the dry-season *j*; *h* is the sub-area index (based on the main canal) of the irrigation project (h = 1, 2, 3,...,H); *k* is crop type (k = 1, 2, 3,…,K); Y_{hik} is crop yield of crop *k* in sub-area *h* (kg/ha); P_{hik} is crop price of crop *k* (baht/kg); C_{hik} is the production cost of crop *k* in (baht/ha), and X_{hjk} is irrigated area of crop *k* in sub-area *h* (ha).

The constraints of the model can be divided into two categories including the amount of water constraint and land area constraint. The amount of water constraint considered both constant value and varied value of irrigation efficiency [14]. The net crop water requirement is not greater than the total available water of the irrigation system by multiplying the irrigation efficiency of the irrigation project, which is described as:

$$\sum_{h=1}^{H}\sum_{k=1}^{K} \sigma_{hjk} X_{hjk} \le \phi Vd_j \qquad (2)$$

where σ_{hjk} is the crop water requirement rate of crop k in sub-area h during season j (mm/ha); Vd_j is the total available water of the irrigation system during season j (MCM); and ϕ is the irrigation efficiency of the irrigation project. The seasonally available water of each Canal Zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system by a proportion of each main canal zone and the total area of the project (T_j), which is presented as:

$$q_{hj} = \phi Vd_j \left(\frac{X_{hj}}{T_j} \right) \qquad (3)$$

$$\sum_{k}^{K} \sigma_{hjk} X_{hjk} \le q_{hj} \qquad (4)$$

For the land area constraint, the summation area of all main canal zone is not greater than the available total area of the irrigation project during season j, which is described as:

$$\sum_{h=1}^{H} X_{hj} \le T_j \qquad (5)$$

The net irrigated area of all crops is not greater than the land area of each main Canal Zone. The irrigated area of each crop is not larger than the suitable area for its cultivation. These constraints are of the following form:

$$\sum_{k=1}^{K} X_{hjk} \le X_{hj}; \text{ for } h = 1,...,H \qquad (6)$$

$$X_{hjk} \ge 0 \qquad (8)$$

3. Results and Discussions

The 21-year (1996 - 2016) seasonal flow, irrigated area, crop water requirement, crop yield, related evaporation, and effective rainfall of the Huai Ang Irrigation Project during the dry season (Mid December – Mid April) were considered for illustrating the application of the proposed approach [14]. Figure 1 presents the location of the Huai Ang Irrigation Project in the Northeast region of Thailand.

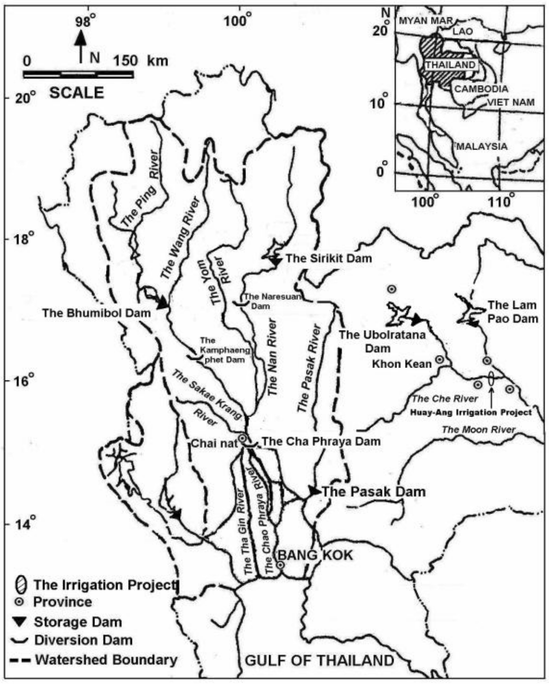


Figure 1: Location of the Huai Ang Irrigation Project

The developed LP model is applied to find an optimum crop pattern of the Huai Ang Irrigation Project subject to restriction on available water and land area. There are four land use types (corn, water melon, vegetable and rice) in the considered project during dry-season. The other crops that irrigated areas below 1 ha (1 ha = 10,000 m^2) are not incorporated. The fish farms are not included in to allocate because they are fixed always. The total area of the scenario during the dry season is 7,200 ha

Table 1 shows calculated values of crop water requirement rate, crop yield, and crop benefit when the irrigation project was considered a homogeneous character and heterogeneous character. It indicates that crop yields of all crops in the considered scenario as the homogeneous characters are smaller than their heterogeneous. Moreover, the crop water requirement rates of the homogeneous consideration are less than the heterogeneous one. For this reason, the benefits per hectare of the homogeneous consideration for all crops are small as compared with those of suitable soil type for heterogeneous consideration. This crop water requirement rate, yield, and benefit in table 1 will be used in the existing LP model for finding optimal crop patterns.

To test the effectiveness of the approaching model in the homogeneity of the irrigation system, a sensitivity analysis was conducted. The analysis tested a variation of the benefit for the considered scenario by changing the homogeneity character under the same resources the results are presented as the following.

Table 2 shows the gross benefit of the scenario using the proposed LP model with heterogeneous (HE) and homogeneous (HO) characters of the project. The results show that the model with the heterogeneous character of the project provided a gross benefit higher than the model with homogeneous characters of the project for all cases. In addition, the obtained patterns of considering heterogeneous are corresponding to the available land areas of the suitable main Canal Zone, while the obtained patterns of homogeneous consideration that having only corn area are not suitable for the availability of land areas.

Table 1: Calculated crop water requirement rate, crop yield, and crop benefit of heterogeneous and homogeneous characters

Crops	Crop water requirement		Crop yield		Benefit	
	HET	HO	HET	HO	HET	HO
	(mm./ha)	(mm./ha)	(kg/ha)	(kg/ha)	(baht/ha)	(baht/ha)
Corn	6,156	5,479	3,625	2,175	45,000	23,250
Watermelon	5,963	5,307	15,625	9,375	34,375	15,625
Vegetable	5,888	5,240	750	450	39,375	19,875
Rice	15,000	13,350	6,375	3,825	20,500	7,750

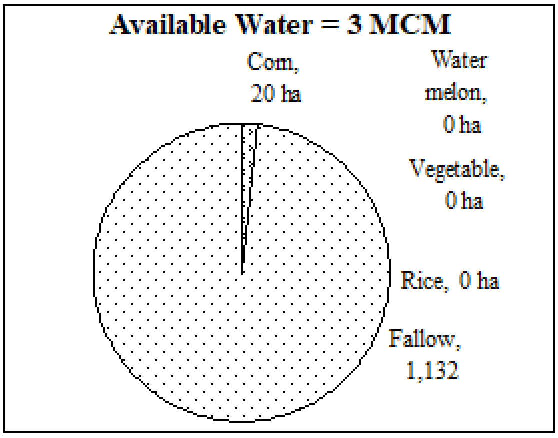
Note: HET = Heterogeneous, HO = Homogeneous, 1 US $ ~ 35 Baht

Table 2: Gross benefit of the irrigation project using the proposed LP model with heterogeneous (HE) and homogeneous characters (HO)

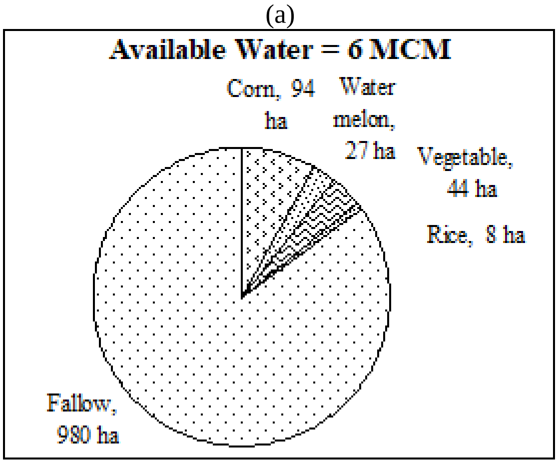
Irrigated Area (ha)	Available Water (MCM)									
	3		6		9		12		15	
	HET	HO	HE	HO	HE	HO	HE	HO	HE	HO
Corn	20.42	22.67	93.95	201.25	156.03	379.83	218.10	558.41	280.17	736.99
Watermelon	-	-	26.72	-	26.72	-	26.72	-	26.72	-
Vegetable	-	-	43.52	-	43.52	-	43.52	-	43.52	-
Rice	-	-	8.12	-	48.64	-	89.16	-	129.69	-
Net Benefit (Million Baht)	0.92	0.57	7.03	5.10	10.65	9.63	14.27	14.16	17.90	18.69

Note: HET = Heterogeneous, HO = Homogeneous, 1 US $ ~ 35 Baht

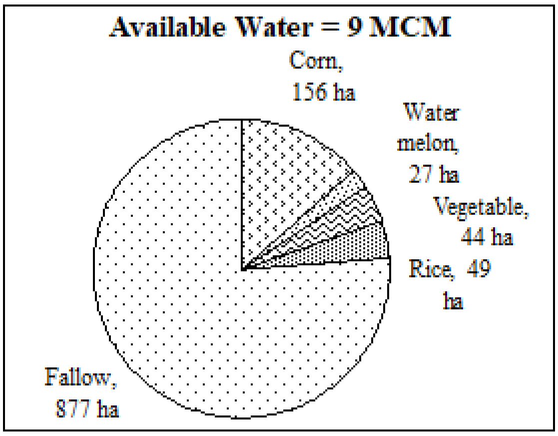
Figure 2 (a, b, c, d, e) shows the optimal crop pattern of the proposed LP models for the available water of 3, 6, 9, 12, and 15 MCM (1 MCM = 10^6 m^3). The crop patterns of the proposed LP model are approximately the targeted irrigation area of the project when having high available water.



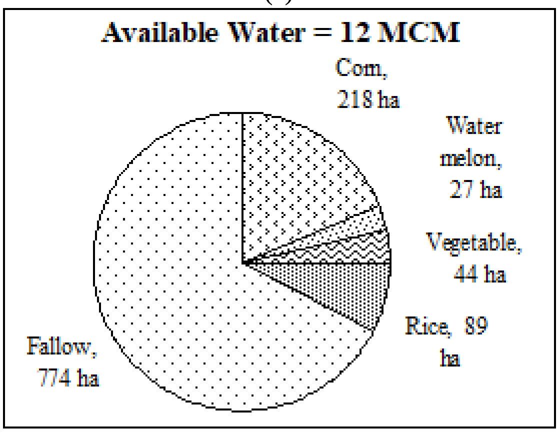
(a)



(b)



(c)



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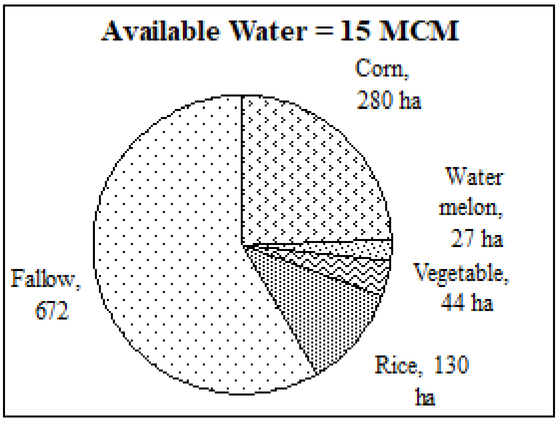

(e)

Figure 2: Optimal crop pattern of the proposed LP model

Table 3 and Figure 3 show the net benefit of the scenario using the proposed LP-based model (heterogeneous character of the project) and the existing LP model (homogeneous characters of the project). The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7, and 0.8, and available release water from the reservoir of 3 MCM (1 MCM = 10^6 m^3), 6 MCM, 9 MCM, 12 MCM, and 15 MCM were used to test the efficiency of the proposed model. The results show that the proposed model with varied irrigation efficiency (V-HE) provides a higher net benefit than the model of constant irrigation efficiency (C-HE) for all cases. In addition, the increase of release water to the project gives a higher net benefit following. It indicates that the variation of heterogeneous characters has a large impact on the optimal solution. For this reason, the LP model with the heterogeneous character of the land area is appropriate for finding optimum crop patterns.

Table 3: Gross benefit of crop pattern using the developed LP model with heterogeneous and homogeneous characters of project

Irrigation Efficiency	Release (MCM)	Benefit (Million Baht)	
		V-HE	C-HE
0.4	3	2.42	0.92
	6	8.56	7.03
	9	12.96	10.65
	12	17.35	14.27
	15	21.68	17.90
0.5	3	4.50	0.92
	6	10.76	7.03
	9	16.25	10.65
	12	21.68	14.27
	15	26.62	17.90
0.6	3	6.37	0.92
	6	12.96	7.03
	9	19.55	10.65
	12	25.69	14.27
	15	31.09	17.90
0.7	3	7.47	0.92
	6	15.15	7.03
	9	22.72	10.65
	12	29.38	14.27
	15	33.28	17.90
0.8	3	8.56	0.92
	6	17.35	7.03
	9	25.69	10.65
	12	32.05	14.27
	15	35.33	17.90

Note: V-HE = varied irrigation efficiency, C-HE = constant irrigation efficiency that is 0.42 %

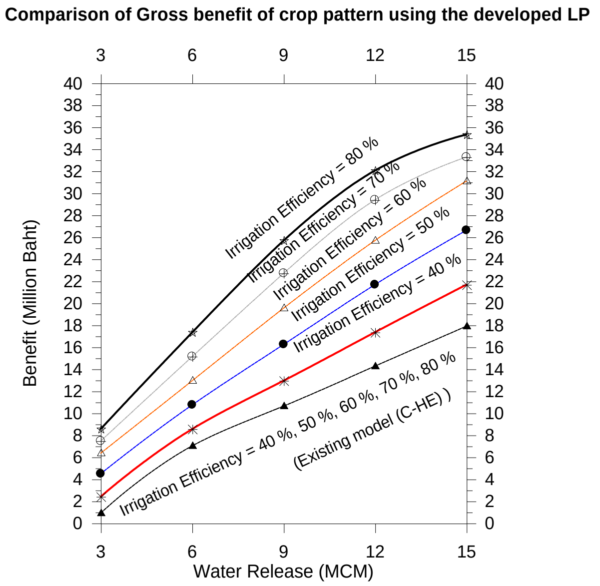

Figure 3: Comparison of gross benefit of crop pattern using the developed LP with heterogeneous (V-HE) and the existing model (C-HE).

4. Conclusion

This paper proposed a LP model considering heterogeneous crop water requirements and crop yield for allocating the available land area. A sensitivity analysis of irrigation efficiency and seasonal release in the LP model was conducted in the study. The proposed LP model gave the optimum crop pattern with gross dry-season benefit that corresponds to seasonally available water and is suitable for the actual irrigated area. It provided a higher benefit as compared to the LP model considering homogeneous character. The obtained patterns of considering heterogeneous are corresponding to the available land areas of the suitable main canal zone. The heterogeneous character of the scenario in terms of crop water requirement and crop yield in the LP model has affected the cropping patterns. The various irrigation efficiency that is used in irrigation planning provided the optimal crop pattern that can be given a higher gross benefit.

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