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An Application of Linear Programming Model for Planning Dry-seasonal Irrigation System

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Abstract: Optimal crop pattern is necessary information for farmer who used to be the guidelines at the beginning of cultivation. This study used an allocation LP model that can take into account heterogeneity of crop water requirement and crop yield of irrigation area for finding optimal crop pattern. A sensitivity analysis of irrigation efficiency in the modified LP model was accounted in the study. The proposed model was applied to find the optimal crop pattern of the Huai-Ang Irrigation Project where located in the Northeast Region of Thailand during dry-season (Mid December-Mid April). 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 modified 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 vary irrigation efficiency in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.

Key words: Optimization model, linear programming, irrigation planning, dry-season crop pattern, varied irrigation efficiency

INTRODUCTION

Nowadays, water resources management and planning under limited resources (such as water, land area, production cost and man power etc.) is the one of the classical problems. Crop pattern of the irrigation project is the land-area that provided for cultivating each crops. Generally, crop pattern is constructed based on the size of land area that used to be cultivated in the previous season. Several crop patterns are not considered in term of economic. Therefore, the farmer needs to have the optimum cropping pattern which will maximize the economic return.

Normally, a Linear Programming (LP) is an optimization technique which widely used to allocate the limited resources because of the proportionate characteristic of the allocation problem (Matanga and Marino, 1979). One popular application of the technique in the water resource literatures is to find an optimal seasonal crop pattern which subjected to limited available resources (Haouari and Azaiez, 2001; Singh *et al.*, 2001; Babatunde *et al.*, 2007). 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 equation for finding optimum crop pattern. The portion of treated water from waste water

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treatment and ground water are included into the water constraints of the LP model (Panda *et al.*, 1996; Sethi *et al.*, 2006). Moreover, water quality parameters (salinity and suspended solid) are incorporated into the LP model (Sethi *et al.*, 2002). Also, a pricing of irrigation water is considered in the constraints of LP model (Salman *et al.*, 2001).

Often, most earlier studies assumed a homogeneity in crop water requirement and crop yield for all land area of the considering project. The obtained crop yield is usually affected by sufficient crop water requirement and physical soil type which suitable for cultivation of each crop (Brown, 1999; Ali *et al.*, 2000). In addition, most earlier studies considered irrigation efficiency as a constant value in calculating available water. Generally, irrigation efficiency is a vary value based on amount of available water and farmer participation in water resource management (Burke *et al.*, 1999).

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

MATERIALS AND METHODS

The linear programming is used to be a based model for finding optimal seasonal crop pattern. 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 considering the heterogeneous character of the irrigation project. The objective function of the model can be presented as:

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

where, Z_j is the gross benefit of the irrigation project during the dry-season j , h is sub-area index (based on main canal) of the irrigation project ($h = 1, 2, 3, \dots, H$), k is crop type ($k = 1, 2, 3, \dots, K$), Y_{hk} is crop yield of crop k in sub-area h (kg ha^{-1}), P_{hk} is crop price of crop k (baht kg^{-1}), C_{hk} is production cost of crop k in (baht ha^{-1}) 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 amount of water constraint and land area constraint. The amount of water constraint considered both constant value and varied value of irrigation efficiency (RID, 2004). The net crop water requirement is not greater than the total available water of the irrigation system multiplying the irrigation efficiency of the irrigation project, which described as:

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

where, σ_{hjk} is crop water requirement rate of crop k in sub-area h during season j (mm ha^{-1}), Vd_j is total available water of the irrigation system during season j (MCM) and ϕ is the irrigation efficiency of the irrigation project.

The seasonal available water of each canal zone (q_{hj}) is calculated by multiplying the net available water of the irrigation system with a proportion of each main canal zone and total area of the project (T_j), which presented as:

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

$$\sum_k^K \sigma_{hjk} X_{hjk} \leq q_{hj} \quad (4)$$

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

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

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:

$$\sum_{k=1}^K X_{hjk} \leq X_{hj}; \quad \text{for } h = 1, \dots, H \quad (6)$$

$$X_{hjk} \geq 0 \quad (7)$$

This method was applied to determine the optimal crop pattern of the Huai-Ang irrigation project where located in Roi-et Province (in the Northeast Region of Thailand). The crop water requirement rate, crop price, crop yield, water release from the reservoirs, evaporation rate, percolation data and rainfall data were used in the study. This research project was conducted from May 2008 to June 2009.

RESULTS AND DISCUSSION

The 21 year (1988-2008) of seasonal flow, irrigated area, crop water-requirement, crop yield, related evaporation and effective rainfall of the Huai Ang Irrigation Project during dry season (Mid December-Mid April) were considered for illustrating the application of the proposed approach (RID, 2004). Figure 1 shows the location of the Huai Ang irrigation project in the Northeast region of Thailand.

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 area below to 1 ha (1 ha = 10,000 m²) are not incorporated. The fish farms are not included to allocate because they are fixed always. The total area of scenario during 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 as homogeneous character and

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

Crops	Crop water requirement (mm ha ⁻¹)		Crop yield (kg ha ⁻¹)		Benefit (baht ha ⁻¹)	
	HET	HO	HET	HO	HET	HO
Corn	6,156	5,479	3,625	2,175	45,000	23,250
Water melon	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

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



Fig. 1: Location of the Huai Ang irrigation project

heterogeneous character. It indicates that crop yields of all crops in considered scenario as homogeneous character 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 compare with those of suitable soil type for heterogeneous consideration. These crop water requirement rate, yield and benefit in Table 1 will be used in the existing LP model for finding optimal crop pattern.

To test the effectiveness of the approach 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: Gross benefit of the irrigation project using the proposed LP model with heterogeneous (HE) and homogeneous (HO) characters

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
Water melon	-	-	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

HET: Heterogeneous, HO: Homogeneous, 1 US \$ ~ 35 baht

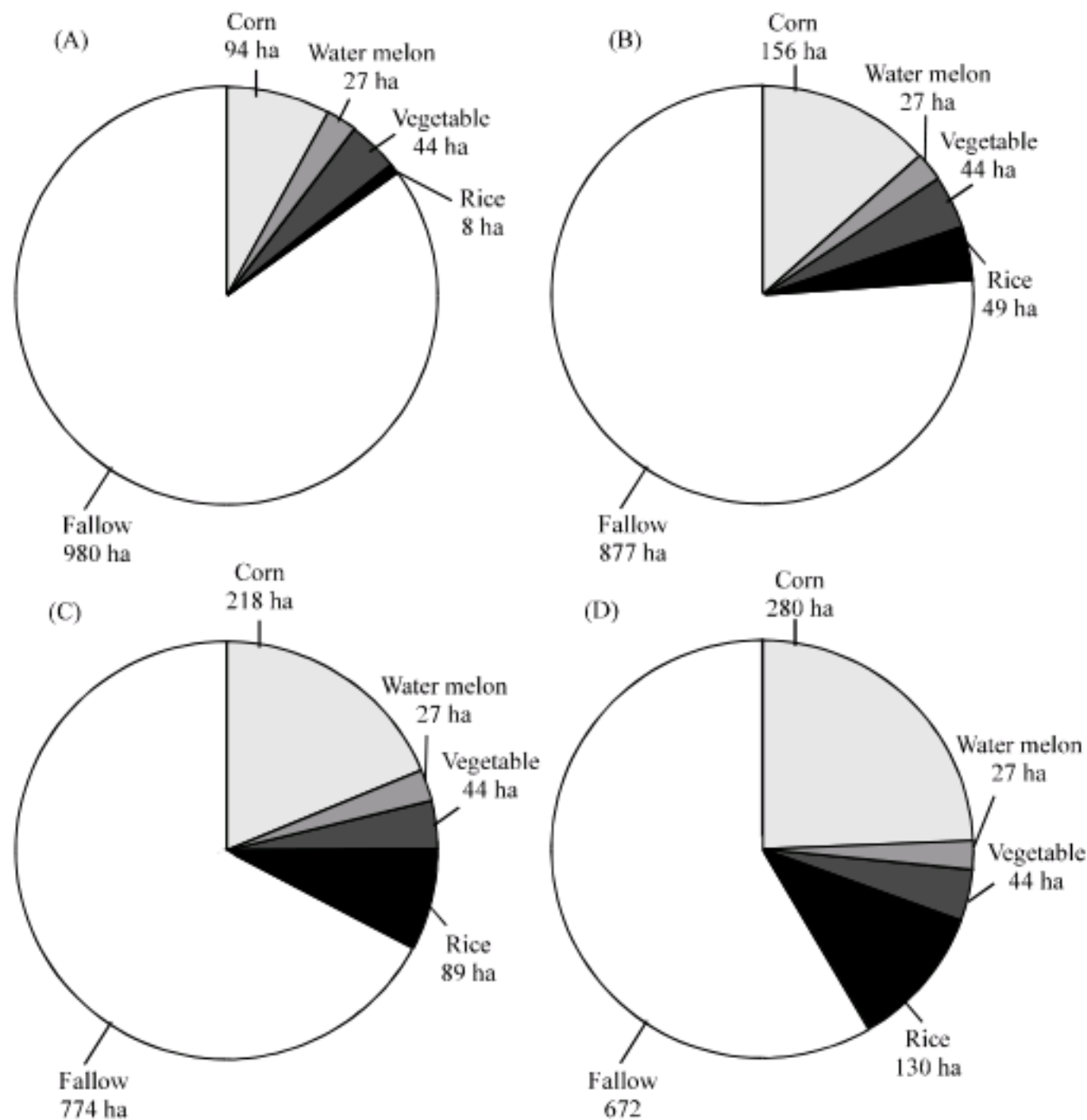


Fig. 2: Optimal crop pattern of the proposed LP model. (A) Inflow = 6 MCM, (B) Inflow = 9 MCM, (C) Inflow = 12 MCM and (D) Inflow = 15 MCM

Table 2 shows the gross benefit of the scenario using the proposed LP model with heterogeneous (HE) and homogeneous (HO) characters of project. The results show that the model with heterogeneous character of project provided gross benefit higher than the model with homogeneous characters of 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 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

V-HE: Vary irrigation efficiency, C-HE: Constant irrigation efficiency that is 0.42%

Figure 2A-D show the optimal crop pattern of the proposed LP models for the inflow to irrigation project of 6, 9, 12 and 15 MCM ($1 \text{ MCM} = 10^6 \text{ m}^3$). The crop patterns of the proposed LP model are approximately the targeted irrigation area of the project when having high available water. It indicated that, the obtained crop pattern is affected by crop water requirement and physical soil type which suitable for cultivation of each crop according to the earlier study (Brown, 1999; Ali *et al.*, 2000).

Table 3 shows the net benefit of the scenario using the proposed LP-based model (heterogeneous character of project) and the existing LP model (homogeneous characters of project). The varied irrigation efficiency of 0.4, 0.5, 0.6, 0.7 and 0.8 and available release water from reservoir of 3, 6, 9, 12 and 15 MCM ($1 \text{ MCM} = 10^6 \text{ m}^3$) were used to test the efficiency of the proposed model. The results show that the proposed model with varied irrigation efficiency (V-HE) provides higher net benefit than the model of constant irrigation efficiency (C-HE) for all cases, because irrigation efficiency is a vary value based on amount of available water (Burke *et al.*, 1999). In addition, the increasing of release water to project gives the higher net benefit following. It indicates that the variation of heterogeneous character has a large impact on the optimal solution. For this reason, LP model with heterogeneous character of land area is appropriate for finding optimum crop pattern.

CONCLUSION

This study modified LP model considering heterogeneous of crop water requirement and crop yield for allocating the available land area of the irrigation project. A sensitivity analysis of irrigation efficiency and seasonal release in the LP model was conducted in the study. The modified LP model gave the optimum crop pattern with gross dry-season benefit that

corresponding seasonal available water and suitable for actual irrigated area. It provided the higher benefit as compare to the existing LP model considering homogeneous character. The obtained patterns of considering heterogeneous are corresponding to the available land areas of the suitable main canal zone. Heterogeneous character of scenario in term of crop water requirement and crop yield in the LP model has affected to the cropping patterns. The vary irrigation efficiency that used in irrigation planning provided the optimal crop pattern that can be given the higher gross benefit.

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