Application of Dynamic Programming to Agricultural Land Allocation: Case study Phutthamonthon District, Nakhon Pathom Province, Thailand

Thana Sarttra, Suchada Manokuakoon, Sunthorn Horadee, Kittikorn Choosakulwong

***Abstract*— Agricultural land allocation problem under dynamic environments in selling prices and planting costs is complicated. Preliminary study found that most farmers decide on what to plant based on either current selling prices or traditional crops planted in the past. Main objective of this study is to determine the optimal agricultural land allocation. Firstly, product prices during different time periods are forecasted. Linear programming is formulated to represent the problem. Dynamic programming is then applied to solve for the optimal plan. Case study is the agricultural land allocation in Phutthamonthon district, Nakornpathom province, Thailand with the wish to improve famer's standard of living. The analytical results found that the benefit from agricultural planning using dynamic programming is superior to the traditional ways.**

***Keywords*— Agriculture, Land Allocation, Dynamic Programming**

I. Introduction

Agriculture in Thailand plays a crucial role in nation economic. Significant portion of population is in the agricultural sector. Agriculture is mostly dominated by smallholders, farmers. One of their main problems is how to utilize their land most effectively so that they can gain more income. Although Thai farmers generally have a good skill in plantation, they have been, however, facing essential decision making problems on what and when should be planted. One of main factors affecting these problems is product price and planting cost fluctuation throughout the year. After preliminary study, it is revealed that this fluctuation is in a seasonal manner. At present, some farmers choose plants to grow based on the current market price, or what they traditionally plant. The obvious flaw of these plans is that the prices after products harvested are not generally as good as expected leading to losing capital or profit.

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The initiative of the study is to incorporate the optimization technique “Dynamic Programming” to agricultural-land allocation problem. Product price fluctuation, planting costs, time to harvest, product yield per area, and other conditions are taken into consideration. Under dynamic environment, dynamic programming is the powerful technique to solve complex problem by breaking it into sub problems which can be considered individually. In this study, annual crops, vegetables in particular, are considered. The studied area “Phutthamonthon District, Nakhon Pathom Province” is located in the central of Thailand where agriculture is desirable due to a tropical climate, good conditions of soil and well-planned irrigation system allowing plantation throughout the year. However, seasonal factor affecting on product yields in each month and derivation of skill deviation on planting different vegetables of farmers are also regarded.

II. Literature Review

For a certain period of time this problem can be referred to as a resource allocation problem. Resource allocation problems were widely studied by many researchers. Metaheuristic algorithms were usually applied in problem solving. Using dynamic programming, multiple-objective resource allocation can be decomposed into smaller sub-problems [1]. Genetic algorithm (GA) was then applied to solve the problem. The results showed that GA is effective. Ant Colony Optimization (ACO) was employed for the nonlinear resource allocation problem [2], and proved to be more efficient than GA. Another novel technique is particle swarm optimization (PSO). A nonlinear resource allocation problem was also tackled by PSO [3]. With adaptive bound for guiding the search, this algorithm is superior to GA in term of performance.

More specifically, the focus of this study is on an agricultural land allocation. Some researches on agricultural planning previously studied are reviewed. The investments in IT on dairy farms were studied in 1999 [4]. Dynamic programming was applied to find out the optimal investment patterns over the specific planning horizon under some degree of uncertain environments. The contribution on this research is mainly for Dutch farm industry. It may need some extra efforts to extend this concept to somewhere else where basic conditions are significantly different. Agriculture in Northern Italy was considered to measure the impact of investment policy and behavior [5]. Multiple-objective programming was formulated, and integer dynamic programming was applied to mimic in farming behavior. This paper also considered different price scenarios which makes it more useful. Land-use allocation research in Spain was carried out in 2008 [6]. In contrast to previous approach, this study utilized Simulated Annealing (SA) technique to maximize the average land-use suitability, and the technique was proved to be efficient. Nevertheless, there is no time-period consideration in this research. Peri-urban agricultural resource allocation in Manila was analyzed by the application of Multiple-Objective Programming (MOP) [7]. After solving multiple steps, the results shown that higher farmer's income is a consequence of investing higher farming technology, yet at the higher risk.

The objectives of this study are to formulate a linear programming model to represent the problem as previously mentioned, and develop dynamic programming approach with non-serial stage to optimize land allocation problem. Results of the study will be discussed in the following sections.

III. The Model

A. Mathematical model formulation

In this paper a linear programming is developed to mathematically represent the agricultural land allocation.The problem cosists of i types of vegetables ($i = 1,2,\dots,N$), and t time periods ($t = 0,1,2,\dots,T$). In the model, the decision is the number of area units to plant vegetable i at the particular time period (x_{it}), and it will involve the change in number of available area units at in end of the period (A_t). In addition, some information is defined as model parameter. First of all, the average yield of vegetable i per area unit (Y_i), seasonal factor affecting on average yield i in month t (F_{it}), time to harvest of vegetable i (H_i) and skill deviation of a famer on average product yield i (D_i) are fundamental information. Total costs of cultivation for vegetable i at period t (C_{it}) per area unit depends on, for example, different climate, and water supply. Selling price of vegetable i at period t is denoted as S_{it}. Let A be the number of total area units owned by a farmer. Notation definition, objective function and a set of constraints are illustrated as follows:

Indices

$i = \ type\ of\ vegetables\ (i = 1,2,3,\dots,N)$

$t = period\ (t = 1,2,3,\dots,T)$

Decision Variables

$x_{it} = Amount\ of\ area\ to\ plant\ vegetable\ i\ at\ period\ t$

$A_t\ =\ Number\ of\ avaiable\ area\ at\ period\ t$

Parameters

$Y_i =\ Average\ yield\ of\ vegetable\ i\ per\ area\ unit$

$F_{it}\ = Seasonal\ Factor\ i\ in\ period\ t$

$H_i = Time\ to\ harvest\ vegetable\ i$

$D_i = Skill\ deviation\ of\ a\ farmer\ on\ average\ vegetable\ yield\ i$

C_{it} = $Total\ planted\ cost\ for\ vegeable\ i\ at\ period\ t$

S_{it} = $Selling\ price\ of\ vegetable\ i\ at\ period\ t$

$A = Number\ of\ total\ area$

Objective Function

$$\text{Max Profit Z} \quad = \sum_{t=1}^{T}\sum_{i=1}^{N} x_{it}\,(Y_i D_i F_{it} S_{i(t+H_i)} - C_{it}) \quad (1)$$

Subjected to

$$A_{t-1} + \sum_{i=1}^{n} x_{i(t-H_i)} \;=\; \sum_{i=1}^{n} x_{it} + A_t \;;\ \forall t \quad (2)$$

$$A_0 \;=\; A \quad (3)$$

$$x_{it} \;\geq\; 0\ ;\ \forall\, i,t \quad (4)$$

$$A_t \geq\; 0\ ;\ \forall\, t \quad (5)$$

In the first equation, the objective function, which is summation of profits, consists of two components. The first one is $Y_i D_i F_{it} S_{i(t+H_i)}$ representing the actual yield ($Y_i D_i F_{it}$) multiplied by selling price ($S_{i(t+H_i)}$) in the harvested period. The other is the total costs (C_{it}) at the planted period. Similar to an inventory balance constraint in the inventory problem, the relationships among the available beginning area, available ending area, area restored after previously harvested, and area decided to allocate in a particular period are described in (2) illustrated in Fig 1. Equation (3) is to specify the maximum area units owned by a farmer. The last two equations are basically variable type constraints. Although some exist algorithms are capable to solve this problem optimally, the computational time for solving the model will be grown exponentially especially when the planning horizon is considerably long. In later sections, the developed dynamic programming with non-serial stages when selling price scenario is changed only in specific period (e.g. month), and harvesting time is considered constant for each vegetable will cut down the total computation.

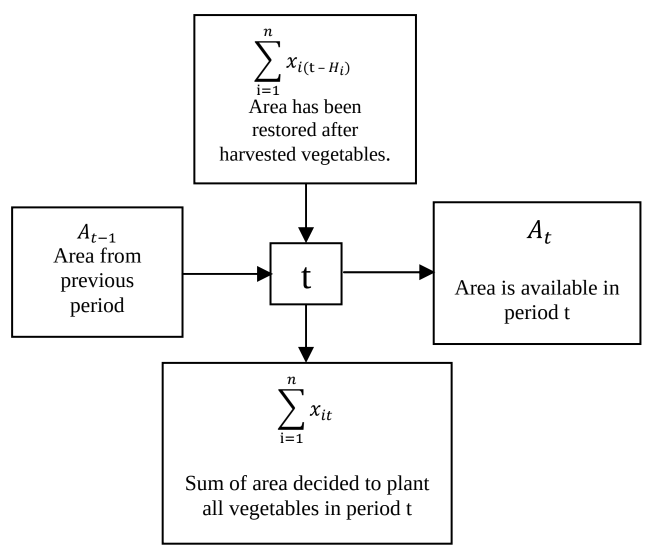

Fig1. Relationship between the numbers of area units at period *t*

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B. Dynamic programming in agricultural land allocation

Dynamic programming is an effective technique in solving multi-stage decision problems that can be divided into many smaller problems. Sub problems are then solved individually for optimality regardless of what have been done previously [8] At each stage (t), the information needed to know for decision making in order to obtain the optimal solution is the land available for plantation (L) as well as the land being planted and waiting until harvest in the next particular periods (L'_k) in which k is a set of vegetables being planted and not yet harvested. That information can be regarded as a state of the sub problem. Vegetables (L'_k) are associated with the remaining time to harvest (t'_k).

Number of possible states in each stage can be calculated by $\sum_{l=0}^{A}(A-l).\max_i\{H_i\}$. For example if there are 10 area units and longest time to harvest is 90, then the possible states in one stage can be up to 4950 states. Suppose that the planning horizon is one year, the possible stages will be 365 stages on a daily basis. As a result, the maximum possible components to consider will be 1,806,750 combinations. Decision variables (x_{it}) based on each stage and state are the number of area units to plant for a certain type of vegetable. Recursion is a reward of plantation $r(x_{it})$, total profit in this case. Subsequently backward procedure is utilized starting from the final stage to the beginning period of the planning horizon. More explanation will be discussed as follows;

Let U be a set of vegetables decided to plant at the current period (t) which is $U = \{H_j | j \in i \leftrightarrow x_{it} > 0\}$. The next stage, which is current stage(t) plus the minimum between $t'_k$and time to harvest of vegetables planted in the current stage(t), will follow the transition described by $t+g$ when $g = min\{t'_k, U\}$. Furthermore, in the next stage $(t+g)$, the transition of state is explained by available area units, and the area units being planted and not yet harvested. This first part is explained by $L - \sum_i x_{it} + \tau$, and the second is $L'_k(t''_k) - \tau + \sum_i x_{it}$, where τ is a number of area units to restore at the $(t+g)$ stage expressed by $\sum_k L'_k(t'_k = g)$, and t''_k represents the remaining time to harvest updated. Based on information previously mentioned, recursive function can be formulated as the following equation.

$$f_t(x_{it}: L, L'_k(t'_k)) = \max\,(r(x_{it}) + f_{t+g}(L - \textstyle\sum_i x_{it} + \tau\,, L'_k(t''_k) - \tau + \sum_i x_{it}) \quad (6)$$

where the reward $(r(x_{it}))$ is defined in (7).

$$r(x_{it}) = \sum_i^N x_{it}(Y_i D_i F_{it} S_{i(t+H_i)} - C_{it}) \quad (7)$$

Non serial stage computation

The possible number of stages can easily be computed as the total number of days throughout the planning horizon. However, time consuming for computation is a major concern. To shorten down computation, this study will regard simply the stages that can affect decision changing. As a result of the change in price occurring simply when the time goes across to another month, the next stages for planting a particular vegetable i can be considered into two cases: The first case is the next stage based on waiting to plant vegetable i and to harvest for the change in price of the next month shown in (8), and the second is to plant vegetable i at the current stage and harvest in the period of current stage plus time to harvest of vegetable i express in (9). Figure 2 is represented graphically for this transition.

$$\begin{aligned} &Next\ stage \\ &= Current\ stage \\ &+ \begin{pmatrix} (Current\ stage - Time\ to\ harvest\ of\ product\ i) \\ \%\ Number\ of\ days\ in\ the\ harvested\ month \end{pmatrix} \\ &\qquad - Time\ to\ harvest \end{aligned} \quad (8)$$

$$Next\ stage = Current\ stage - Time\ to\ harvest \quad (9)$$

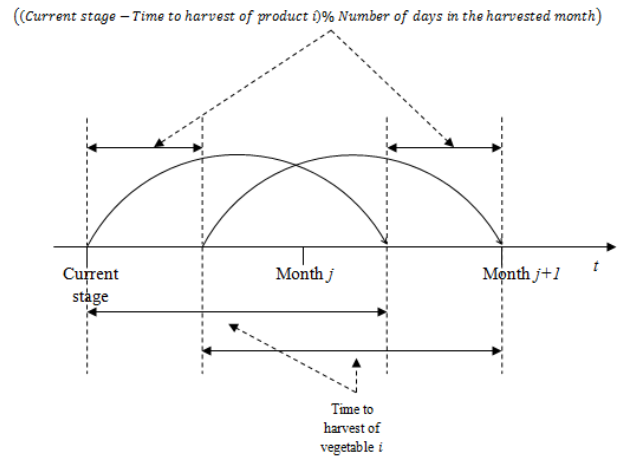

Fig.2. Non serial stage illustration

IV. A CASE STUDY APPLICATION

Based on the reason mentioned previously, Phutthamonthon District, Nakhon Pathom Province, Thailand is the case study area. There are many vegetables that can be grown in this area. An area unit in the experiment is equal 1,600 square meters (1 *Rai,* a Thai area unit). In order highlight the major contribution to general farmers, Pareto principle is utilized to focus only important types of vegetables. In the Table I and Table II, the information of selected vegetables including plantation costs, whole sale price during a month, time to harvest, for instance, is summarized.

TABLE I
SELECTED VEGETABLES AND TIME TO HARVEST

Vegetables	Time to harvest (Days)	Average yield (kg/area unit)	Average Costs (Baht/area unit)
1. Culantro	120	417	1497
2. Lemongrass	90	541	457
3. Chinese Chives	45	450	766
4. Chinese Kale	55	208	980
5. Angled gourd	60	417	492
6. Dill	50	167	1246
7. Morning Glory	25	208	422
8. Celery	90	117	450

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TABLE II

MONTHLY WHOLESALE PRICE OF VEGETABLES

	Monthly wholesale price (Baht/kg)							
Month	**Culantro**	**Lemongrass**	**Chinese Chives**	**Chinese Kale**	**Angled gourd**	**Dill**	**Morning Glory**	**Celery**
January	42.9	9.32	28.55	18.26	18.19	22.5	21.13	34.27
February	41.96	9.64	27.59	8.71	14.29	20.36	10.75	29.46
March	39.6	12.77	27.26	23.45	15.23	31.53	22.26	46.29
April	40.5	14.07	25.69	22.9	16.67	27.33	17.02	35
May	37.87	11.53	24.76	19.71	14.35	31.85	14.9	75.45
June	33.75	9.93	26.83	27.03	12.87	41.58	14.67	81.92
July	34.92	8.63	30	12.65	13.58	26.77	11.97	56.53
August	32.42	6.98	30.08	17.03	17.29	27.66	15.23	61.69
September	34.5	9.07	29.42	21.9	16.47	34.25	17.85	62.42
October	51.77	10.82	30.07	26.13	19.03	50.89	34.13	90.65
November	50.08	12.6	31.42	21.57	17.83	36.83	24.53	61.83
December	48.23	15.15	37.63	8.92	19.45	30.16	20.85	40.48

Due to lack of information of farmer's skill deviation, and seasonal factor affecting on average yield for each product, the experiment is done under the assumptions that a considered farmer can grow any vegetable at the average yield and seasonal factor at different period plays no role on vegetable yield as well as the average costs of plantation for each vegetable are assumed equal throughout the planning horizon.

In order to compare the performance of different land allocation strategies, the experiment is needed to be under the same conditions as following;

Suppose that there are four area units to be planned within one year horizon, the decision in each stage is what and how many area units to plant under the information about price in harvested period, available land, and vegetable already being planted at the beginning. At the first stage, Culantro has been planted for 30 days for one area unit, Lemon grass has been grown for 60 days for one area unit, Dill and Morning glory is decided to plant in this period, illustrated in Fig.3.

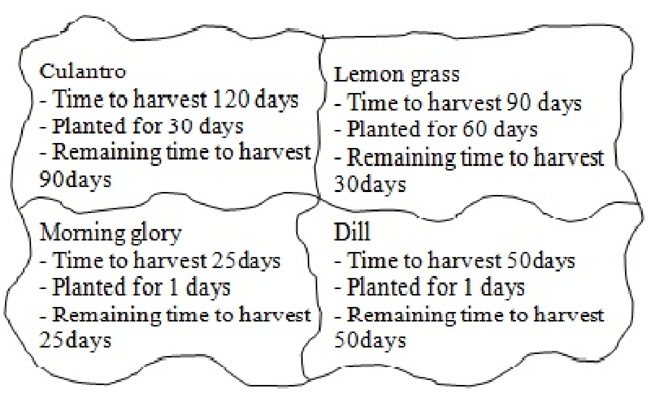

Fig.3. Land used at the beginning stage

In this experiment, three land allocation strategies are compared based on the same conditions previously described. In the first strategy, selection of vegetables is based on what have been done in the past without consideration on climate, or price fluctuation. The second is planting based on the current best profit of vegetables (current selling price minus cost of plantation) that will not reflect the profit when harvested. The last one is the application of dynamic programming to solve for the optimal plan under the fluctuating price scenarios. Without reducing unnecessary stages, the number of possible stages will be equal to the number of days, which are 365 days leading to very much computational time. By considering price fluctuation under monthly basis, the total number of stages will be significantly cut down to a small number as described in previous section. Dynamic programming is written in freeware (Dev C++), and run on personal computer AMD A8 3530 MX with 6 Gigabits of ram.

In Table III, compared to other traditional techniques with the same starting conditions, the result from applying dynamic programming is the best in term of annual profit 365361.60 Baht. Besides, the details in each plan are displayed in the column denoted as (Vegetable type number, Day to plant).

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TABLE II
COMPARISON ON PROFIT FROM DIFFERENT STRATEGIES

	First strategy (Plant based on previous vegetable)				**Second strategy (Plant referred to current profit)**				**Third strategy (Dynamic Programming)**			
	Area Unit											
	First	Second	Third	Forth	First	Second	Third	Forth	First	Second	Third	Forth
(Types of	1,90	2,30	6,50	7,25	1,90	2,30	6,50	7,25	3,90	3,30	3,50	3,25
vegetable,	1,210	2,120	6,100	7,50	1,210	1,150	1,170	1,145	3,135	3,75	3,95	3,70
days to	1,330	2,210	6,150	7,75	3,255	1,270	1,290	1,265	3,180	3,120	3,106	3,115
plant)		2,300	6,200	7,100	3,300	3,315	5,335	3,310	3,225	3,165	3,151	3,160
			6,250	7,125	3,345	7,340	7,360	7,360	3,270	3,210	3,196	3,166
			6,300	7,150					3,315	3,255	3,241	3,211
			6,350	7,175					3,360	3,300	3,286	3,256
				7,200						3,345	7,311	3,301
				7,225							3,356	3,346
				7,250								
				7,275								
				7,300								
				7,325								
				7,350								
Profit	47428	21375	28212	52090	70332	48440	45062	47829	95075	93183	84322	92782
Total Profit	149104.97				211663.03				365361.60			

V. CONCLUSION AND FUTURE WORKS

This research is the application of dynamic programming approach with non serial stages to agricultural problem. For the analytical results, dynamic programming is able to obtain the optimal agricultural land allocation problem which is, of course, superior to other strategies. However, in this study, the problem is considered deterministic in which all input parameters are constant. Therefore, main challenge is to incorporate some practical stochastic components in order to make the problem more realistic potentially considered as a future work.

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