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A Design of an Expert System for Intercropping Planning

Saharat Arreeras, Thara Angskun, and Jitimon Angskun

School of Information Technology, Institute of Social Technology, Suranaree University of Technology, 111 University Ave., Tambon Suranaree, Muang District, Nakhon Ratchasima, 30000, Thailand
e-mail: m5020409@g.sut.ac.th, angskun@sut.ac.th, jitimon@sut.ac.th

Abstract In the past decades, the world's food production was mostly practiced by a monoculture system, i.e., growing only a crop over an area. The monoculture causes damages (or changes) to the biological diversity, especially the soil fertility. The sustainable agriculture is an approach of managing crop ecology in order to maintain the biological diversity, productions and long-term human existence. One methodology of sustainable agriculture is called Intercropping, i.e., multiple crops are planted in the same area. In the intercropping planning, many cultivating factors, such as diseases, sale prices and cultivating areas, must be concerned because those factors are affected to ecological succession and total income of production. Producers have to face with the complication of many factors in order to obtain the optimal plan under the concept of sustainable agriculture. This paper proposes an expert system model for intercropping planning. The model analysis and design were exhaustively discussed in terms of ecology as an agricultural expert, benefit as an economist and system analysis and design as an information technologist. This model has been proved to provide the efficient and practical intercropping plans.

Key words: Sustainable Agriculture, Intercropping Planning, Crop Price

1. Introduction

In the past decades, the agriculture is practiced with the single cropping, i.e., only one of the most profitable crops will be planted at a time. This single cropping causes damages (or changes) to biological diversity and has greater drain on soil nutrients [1]. It also has a high economic risk to growers from surplus of crop. Therefore the challenge is not only emphasized on the biological diversity, but it also considers on the risk minimization [2].

Sustainable agriculture can facilitate the mentioned problem. The sustainable agriculture is a method of managing crop ecology in order to maintain the biological diversity, productions and reproductions while it will not harm other ecology systems [3]. One of the sustainable agriculture methodologies is an intercropping, i.e., multiple crops are planted in the same area that conduces to the biological diversity [4, 5]. Although the intercropping is well recognized today, each local area must be able to apply to this theory properly owing to different environments of each area, such as climate, soil fertility and water quantity [6].

In the intercropping planning, many cultivating factors, such as pests, diseases, periods of planting, growing and harvesting, sale prices and cultivating areas, must be considered because those factors are affected to ecological succession and economic risk minimization. For instance, if diseases spread over an area, any crop affected by the diseases will be destroyed. Hence the intercropping planning must be considered on common diseases, i.e., crops planted in the same area should not have the same disease.

As discussed above, producers have to face with the complication of many factors in order to obtain the optimal plan under the concept of sustainable agriculture. Therefore the information technology can be very helpful to support the intercropping planning. An agriculture expert system is one of information technologies which help to store and manage the cultivation information and automatically generate the cropping plans. However, all the existing expert systems are not considered on the economic risk minimization. For instance, growveg.com [7] is an online expert system which helps growers plan periods of planting, growing and harvesting of vegetables specified by the growers; however, those vegetables may be not suitable to plant together.

This paper proposes an expert system model for intercropping planning under the concept of economic risk minimization. The system framework is proposed in section 2. Section 3 presents a discovery of crop groups that can be planted together, called an intercrop group discover process. Section 4 describes the model construction for intercropping planning. Section 5 presents the model evaluation by comparing with a linear programming-based model. The conclusions and future work are presented in section 6.

2. System Framework

The framework of intercropping planning system is depicted in "Fig. 1" consisting of input and process. The input consists of data and a method. There are two types of data used in the model development, which are user preferences and a crop database.

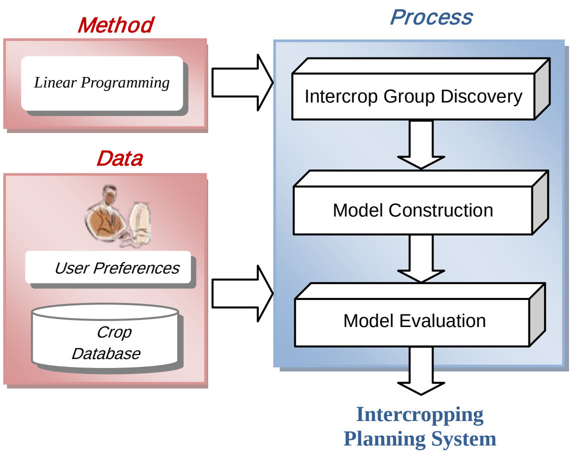

Fig. 1 System framework.

The user preferences are data defined by user, e.g., areas that users plan to plant all crops. By default, all cultivating areas (A) are 1,600 square meters.

The crop database stores specific details of each crop, e.g., sale prices per plant of each crop (Baht), s_i, where $1 \leq i \leq n$ and n is the number of all types of crops; periods of growing until harvesting (Day), d_i, and a cultivating area per plant of each crop (Square meter), a_i. The proposed intercropping planning model uses vegetables in lieu of the crops as illustrated in “Table 1”.

Table 1. Vegetable database.

Database	Kale	Long Bean	Tomato
Sale price per plant (Baht), s_i	2.63	0.37	1.86
Periods of growing until harvesting (Day), d_i	85.5	50	133
Cultivating area per plant (Square meters), a_i	0.09	0.02	0.3

In addition to crop database, the discovery of crop groups that can be cultivated together is an important and complicated issue for the intercropping plan. This is due to the fact that if diseases spread over an area, any crop affected by the diseases will also be destroyed. Hence the intercropping planning must be considered on common diseases. The crop databases also store diseases of each crop. In section 3, the other data of crop database and the discovery process will be discussed.

Next, the method used in this model development is a linear programming (LP). The LP method is a main technique applied to plan the intercropping. The LP, sometimes known as linear optimization, is a method for solving problem of maximizing or minimizing a linear function [8, 9]. In intercropping planning, the LP method would be applied to find cultivating area distribution that maximizes total income (I) where total allocated area (A_{alloc}) of every vegetable is less than or equal to all cultivating areas (A).

The results of applying the LP, as shown in “Table 2”, found that the generated plan was emphasized on maximizing the total income only; but it was not considered on the economic risk minimization (i.e., it still plans with single cropping – most of the total areas was allocated to Kale, while allocated areas of Long Bean and Tomato were near or equal to zero).

Table 2. Results from applying the LP method.

System	Kale	Long Bean	Tomato
Allocated area of each vegetable, $A_{alloc}\,(i)$	1,599.93	0.06	0
Total allocated area, A_{alloc} or $\sum_{i=1}^{n} A_{alloc}\,(i)$	1,599.99		
Number of cultivated plants of each vegetable, P_i or $(A_{alloc}\,(i)/a_i)$	17,777.00	3.00	0
Total sale price of each vegetable, S_i or $(P_i \times s_i)$	46,753.51	1.11	0
Total income, I or $\sum_{i=1}^{n} S_i$	46,754.62		

The data and method are passed through the model development process in order to filter crops, construct and evaluate the proposed model.

3. Intercrop Group Discovery

The acquisition of crop groups that can be cultivated together (called intercrop groups) is discussed in this section. The data used in the group discovery process are types and diseases of vegetables. First, there are 21 types of economic vegetables in Thailand, which has short periods of growing until harvesting as shown in “Table 3”. The data were also defined an identification number (ID) for each vegetable.

The second data is diseases of each vegetable which are caused by fungi, bacteria and viruses as shown in “Table 4”. Both types and diseases of each vegetable are applied to discover all the intercrop groups.

Table 3. Identification numbers (ID) and names of all vegetable used in the discovery process.

ID	Name	ID	Name
1	Cauliflower	10	Kale
2	Cabbage	11	Coriander
3	Celery	12	Water Spinach
4	Welsh Onion	13	Bird chili
5	Cucumber	14	Hot chili
6	Long Bean	15	Eggplant
7	Flowering White Cabbage	16	Tomato
8	Chinese Cabbage	17	Bitter ground
9	Head lettuce	18	Chinese Radish

Table 4. An example of diseases in Kale and Long Bean.

Diseases	Kale	Long Bean
Fungi	1. Peronospora parasitica (downy mildew on leaves and heads) 2. Pythium ultimum (damping-off)	1. Cercospora capsici (leaf spot) 2. Colletotrichum lindemuthianum (anthracnose) 3. Erysiphe polygoni (powdery mildew) 4. Uromyes vignae (rust)
Bacteria	-	1. Pseudomonas phaseoli (bacterial blight)
Viruses	1. Cauliflower mosaic virus (CauMV) 2. Turnip mosaic virus (TuMV)	1. Cowpea aphidborne mosaic virus 2. Cowpea witches’ broom virus

The intercrop group discovery process has 4 steps. *The first step* is to choose one type of vegetables which wants to plant, e.g., Kale, and then add it into a selected vegetable list (*L*). *The second step* is to search for vegetables that can be cultivated with Kale (or every member in *L*), i.e., all diseases of these vegetables must be not the same as all diseases of Kale as shown in “Table 5”. Where the symbol “/” represents the mismatch of each disease and the symbol “x” represents the mismatches of every disease. In conclusion, all vegetables that can be cultivated with Kale (ID 10) are Long Bean (ID 6), Bird Chili (ID 13), Hot Chili (ID 14), Eggplant (ID 15) and Tomato (ID 16).

Table 5. All diseases of several vegetables related with Kale.

Diseases	Vegetable IDs								
	1	2	3	4	5	6	7	8	9
Fungal						/			
Bacterial	/	/	/	/	/	/	/	/	/
Virus		/	/	/	/	/			/
All Diseases						x			
	10	11	12	13	14	15	16	17	18
Fungal		/		/	/	/	/		
Bacterial		/	/	/	/	/	/	/	/
Virus		/	/	/	/	/	/	/	/
All Diseases		x		x	x	x	x		

The *third step* is to generate intercrop groups of all vegetables obtained in the second step that can be cultivated together. “Fig. 2” shows an example of generating the fist intercrop group.

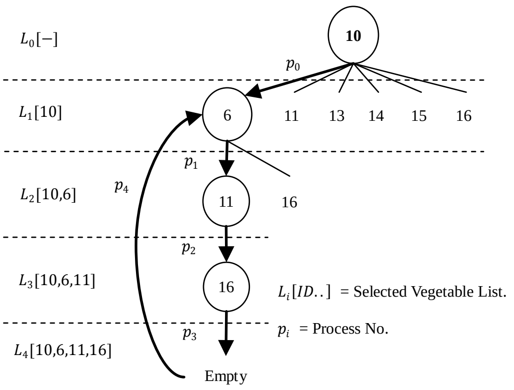

Fig. 2 The first intercrop group generation.

The first round of this step is to find vegetables that can be cultivated with vegetable-ID 10. Suppose that vegetable-ID 6 is selected and added into the selected vegetable list (L), the second round searches for vegetables that can be cultivated with vegetables in L, i.e., vegetables ID-6 and ID-10. Suppose that vegetable ID-11 can be cultivated with vegetables ID-6 and ID-10, the next round is to look for vegetables that can be cultivated with vegetable ID-6, ID-10, ID-11 and so on until the set of vegetables that can be cultivated with vegetables in L is empty. The third step is repeated for every vegetable returned from the second step. All generated intercrop groups of vegetable ID-10 is shown in "Fig. 3".

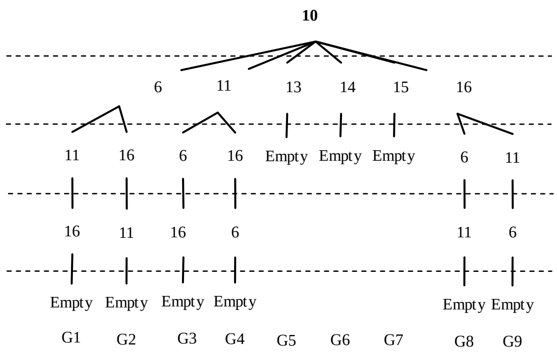

Fig. 3 Intercrop groups of all vegetables that can be cultivated with Kale (ID-10).

Table 6. The unique intercrop groups that can be cultivated with Kale.

Groups	Vegetable IDs	Vegetable Names
1,2,3,4,8,9	6,10,11,16	Kale, Long bean, Coriander and Tomato
5	10,13	Kale and Bird chili
6	10,14	Kale and Hot chili
7	10,15	Kale and Eggplant

Notice that there are several intercrop groups that are duplicated or have the same intercrop group, e.g., G1, G2, G3, G4, G8 and G9. The duplicated intercrop groups will be eliminated in the fourth step. The *fourth step* is to find unique intercrop groups received from the third step. In the example case, there are four unique intercrop groups that can be cultivated with Kale (vegetable ID-10) as shown in "Table 6". All discovered intercrop groups are preceded to the planning process as discussed in the next section.

4. Model Construction

This section selects three types of vegetables that could be cultivated together as presented in the first rows of "Table 6" such as Kale, Long Bean and Tomato.

The proposed model is constructed to solve the problem of LP consisting of four steps. *The first step* is to appropriately distribute entire or partial areas to every vegetable before using the LP method to maximize the total income. Each vegetable is allocated a specific area as the minimum area that is bounded for individual vegetable in order to reduce the economic risk. The minimum area of each vegetable ($A_{min}(i)$) is derived from multiplication of areas that need to be allocate ($k \times A$) and a weight of each vegetable (W_i) as

$$A_{min}(i) = k \times A \times W_i \tag{1}$$

where *k* is a constant (between 0 and 1). It is a value to specify how much portion of area is needed to distribute, i.e., if k = 1, entire cultivating areas will be distributed using the proposed weight instead of the LP method. If k=0, none of the area is distributed using the proposed weight but all cultivating areas is distributed using the LP method. The proposed weight is derived from many cultivating factors which are extensively discussed in the next section.

The second step is finding allocated areas of each vegetable. As previously discussed, each vegetable is allocated a specific area; therefore unallocated areas after the allocation must be properly assigned to some vegetables. A principle of unallocated area assignment is applying LP method to optimally distribute the areas such that total income is maximized. When the unallocated areas ($A_{unalloc}$) are passed through the LP method, the allocated areas of each vegetable ($A_{alloc}(i)$) are provided where total allocated area of every vegetable is less than or equal to all cultivating areas (A) as

$$A_{unalloc} = A - \sum_{i=1}^{n} A_{min}(i). \tag{2}$$

$$A_{min}(i) + LP(A_{unalloc}) = A_{alloc}(i). \tag{3}$$

$$\sum_{i=1}^{n} A_{alloc}(i) \le A. \tag{4}$$

The third step is finding the number of cultivated plants of each vegetable (P_i). The number is derived from quotient between the allocated area of each vegetable and the cultivating area per plant of each vegetable (a_i) as defined by

$$P_i = A_{alloc}(i)/a_i. \tag{5}$$

The final step is to compute total income (I). The total income is derived from sum of product between the number of cultivated plants of each vegetable (P_i) and sale price per plant of each vegetable (s_i) as

$$I = \sum_{i=1}^{n} P_i s_i. \tag{6}$$

The next section is discussed about weight derivation used in the "Eq. 1".

4.1 Weight Derivation

The weight is used to allocate specific areas for each vegetable (a_i). The proportion of a specific area of each vegetable or a weight (W_i) is derived from three factors, e.g., sale price per plant of each vegetable (s_i); periods of growing until harvesting of each vegetable (d_i); and cultivating area per plant of each vegetable (a_i) under three concepts as

Concept 1: Any crop gaining the highest sale price (per plant) should be cultivated in proportion of the most number of plants (i.e., $W_i \; \alpha \; s_i$).

Concept 2: Any crop having the minimum periods should be cultivated in proportion of the most number of plants because the crop can be produced more number of times per year.

Thus the period is inversely proportional to the number of plants (i.e., $W_i \,\alpha\, 1/d_i$).

Concept 3: Any crop using the minimum cultivating area per plant should be cultivated in proportion of the most number of plants because the same size of area could cultivate more number of plants. Thus the area per plant is inversely proportional to the number of plants (i.e., $W_i \,\alpha\, 1/a_i$).

The weight acquisition or the proportion of a specific area of each vegetable (a_i) is defined in "Eq. 7" and results of weight derivation from all the factors are shown in "Table 8".

$$W_i = \frac{a_i(s_i/d_i a_i)}{\sum_{k=1}^{n}\left(a_k(s_k/d_k a_k)\right)} = \frac{s_i/d_i}{\sum_{k=1}^{n}(s_k/d_k)} \quad (7)$$

Table 8. Results of weight derivation from all the factors.

Parameters	Kale	Long Bean	Tomato
All the factors of each vegetable, $s_i/d_i a_i$	0.34	0.37	0.05
Proportion of a specific area of each vegetable (weight), W_i	0.59	0.14	0.27

5. Model Evaluation

After the weights have been derived, each vegetable is allocated a specific area as the minimum area that is bounded for individual vegetable. The minimum area of each vegetable ($A_{min}(i)$) is derived as "Eq. 1".

"Table 9" presents a comparison of the minimum areas and total incomes when derived from the proposed weights and several constant values (k) (e.g., 0, 0.25, 0.50, 0.75 and 1.00). The experimental results showed that when the constant k is 1.00, entire cultivated areas are allocated using the proposed model and the total income related to LP is 74% (34,440.85/46,754.62*100). While the constant k is 0, the minimum area is none and the total income is comparable to the LP method (46,754.62 baht) because entire cultivating areas are divided using the LP method.

Table 9. Results of allocated areas of each vegetable and total income.

		Constant Values (k)				
		0	0.25	0.50	0.75	1.00
A_{min}	Kale	0	235.96	471.92	707.88	943.83
	Long Bean	0	56.77	113.53	170.29	227.06
	Tomato	0	107.23	214.55	321.83	429.11
$A_{unalloc}$		1,600.00	1,200.00	800.00	400.00	0
A_{alloc}	Kale	1,599.93	1,435.68	1,271.52	1,107.72	943.83
	Long Bean	0.06	56.92	113.68	170.38	227.06
	Tomato	0	107.40	214.8	321.83	429.11
Total Income (Baht)		*46,754.62*	*43,672.66*	*40,591.48*	*37,517.85*	*34,440.85*

Although the constant $k = 0$ provided the highest income, it could not achieve the risk minimization (i.e., almost all areas were allocated to Kale, while allocated areas of Long Bean and Tomato were closed to or equal to zero). Therefore the use of a proper constant value could minimize the economic risk where the total income of the proposed model is dramatically lower than that of the LP-based model.

6. Conclusions

This paper proposes an expert system model for intercropping planning in order to maximize income while minimize the economic risk. The model analysis and design were exhaustively discussed in terms of ecology as an agricultural expert, benefit as an economist and system analysis and design as an information technologist. Several cultivating factors have been investigated and applied to construct the proposed model. The model was evaluated by comparing with a linear programming method. The experimental results revealed that the linear programming method provided the highest income; but it could not accomplish in the risk minimization. On the other hand, the proposed model could minimize the risk and also obtained at least 74% when compared with the linear programming method.

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