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Crop rotation model for contract farming with constraints on similar profits

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ABSTRACT

In China, investors have contracts with smallholder farmers to plant organic vegetable crops. The objective of the smallholder farmers is to maximize profits per unit of farm area, and minimize the differences in profits between farmers. Farmers' profits are a function of the crop rotation scheduling and the achieved prices. Here we propose an operational model that considers a crop rotation scheduling for an investor that offers contracts to many smallholder farmers. A heuristic algorithm was designed to identify the optimal rotation scheduling that would achieve both objectives of maximizing prices and minimizing the profit differences between smallholder farmers. Real data from a Chinese company was used to parameterize the model. Model results indicate that significant improvements in profits and farmers equality could be obtained if an optimal crop rotation scheduling would be used.

1. Introduction

In China, the government rents land to many smallholder farmers and it is difficult for investors to acquire large areas of land from the government to grow high-quality crops. Contract farming has been used for agricultural production in recent years in China. Investors cooperate with smallholder farmers to plant high-quality agricultural products using high yielding agricultural technologies. This cooperative arrangement can offer both an assured market and production support to smallholder farmers. The rotation of crops and the process of growing crops are controlled by the investor to ensure the yield and quality of the crops.

In the region of south Jiangsu Province, China, vegetables can be planted all over the year and the growing periods for the different vegetables are known to the investors. Therefore, vegetable production in the region is suitable for rotation planning. With the increase in income in China high-quality vegetables are selling well and are usually in short supply. Many companies and schools' canteens make orders with these agricultural companies at the start of each year. The prices for each vegetable is decided at the time the orders are made, and prices vary depending on whether the produce was produced using conventional or organic methods. As the diversity in produce in the market needs to be maintained throughout the year, the agricultural company proposes that different crops should be planted at any time. Agronomic studies demonstrate that an increases in species diversity is also associated with sustainable soil fertility, better nitrate recycling and fewer pest attacks (Gliessman, 2000).

Contract farming is also of interest to investors, who seek supplies of high-quality products for markets at all seasons. Based on a survey of Chinese contract farming companies (investors), the problem of rotational scheduling of crops in smallholder farming, is widespread. The first reason for this problem is that all farmers naturally seek more profits. The second reason for this problem is that the smallholder farmers seek to allocate profits in a fair manner, i.e., all smallholder farmers must have similar profits per unit of area. This main objective of this study was to optimize the rotation scheduling of vegetable crops in contract farming.

Previous studies on the optimization of rotation scheduling include those of dos Santos et al. (2011) and Schönhart et al. (2011). In those studies the target was to maximize profits for the company, ignoring the variability of profits among the farming community.

Here we propose a 0–1 optimization model for crop rotation scheduling, that takes into account real conditions of rural China, and both the objective of maximizing the profits of smallholder farmers, while minimizing the differences in profits among farmers. Four constraints are considered.... To demonstrate the applicability of the proposed model, here w consider a case study based on the Tianlandilv Farm Ltd., which is located in Wuxi, China. Eighty smallholder farmers have contracts with the company to plant organic vegetable crops. The optimal rotation scheduling requires that the profits of all farmers is maximized and that the differences in profits among all farmers is minimized.

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The remainder of the paper is organized as follows. The literature review of related topics is presented in Section 2. The third Section proposes the problem statement and the operational model for finding the optimal rotation scheduling of all of the farmers. A new heuristic algorithm for the operational model is designed in Section 4. In the Section 5, an illustrative example is developed and analyzed to demonstrate the validity of the model and the algorithm. Conclusions and future research regarding this problem are presented in the final section.

2. Literature review

The use of crop rotation systems has had effects on the economic performance and the concentrations of grain protein and many mineral components (Bockstaller et al., 1997; Ball et al., 2005; Leteinturier et al., 2006; Houx III et al., 2014). Castellazzi et al. (2008) described three types of flexible crop rotations: cyclical with fixed rotation length, variable rotation length and highly variable rotation length. Our paper studies the crop rotation with fixed rotation length. For this problem, the papers reviewed in our paper considered the same case as our paper. Many researchers conducted field experiments over multiple years to study the productivity and economic potential of different cropping rotation systems (Rathore et al., 2014; Rasmussen, 2014). Borrelli et al. (2014) assessed maize yield and yield stability over 26 years in several long-term crop rotation experiments. Many researchers applied mathematical or simulation approaches to study crop rotation systems. These works are significant to the research of our work. For example, Tidåker et al. (2014) recommended that the rotation of perennial grass/clover had multiple effects in cropping systems dominated by cereals. Hennessy (2006) used quasi-convexity of choice functions to research rotation structures. Colbach et al. (2014) used a cropping system model to evaluate the potential impacts of modified agricultural practices. Münch et al. (2014) presented a Farm Economy Coefficient Generator to study the performance of crop production. Hendricks (2014) proposed how the benefits of crop rotation generate farmers' changing of crops due to a price shock. The example of crop rotation in Germany is used to analyze the costs and benefits of irrigation.

Because the production plan is related to the crop rotation system, the previous significant works in this field are important for our paper. Considering product types and scheduling decisions, Cai et al. (2008) proposed a model for different types of products produced by a certain amount of perishable raw material. Ahumada and Villalobos (2011) built an optimal model to make decisions on the production of multiple crops. Different from these studies, our paper mainly studies the optimization of crop rotation scheduling.

Many researchers proposed a Linear Programming model for the multi-period crop rotation optimization problems (Detlefsen and Jensen, 2007; Kein Haneveld and Stegeman, 2005; Alfandari, 2011; Dogliotti et al., 2003; Dogliotti et al., 2004). dos Santos et al. (2011) proposed a 0–1 optimization model to study a crop rotation schedule for multiple plots. The effects of the crop rotation on the expected revenue were analyzed by Myers et al. (2008) using a risk-neutral discrete stochastic sequential programming model. Schönhart et al. (2011) proposed a crop rotation model that integrated agronomic criteria and land use data to determine the optimal crop rotations for farms.

Goal programming was used to solve cropping plan decision problems in many significant works (e.g., Piech and Rehman, 1993; Sarker and Quaddus, 2002; Annetts and Audsley, 2002; Bartolini et al., 2007). To find the optimal result of the crop rotation model, a heuristic algorithm is proposed in our paper because of the characteristic of the complex models. Past researchers have also designed many heuristic algorithms to study production plans. Benavides et al. (2014) proposed a heuristic based on scatter search to solve the flow shop scheduling problem. A heuristic algorithm is proposed by dos Santos et al. (2011) to study the optimization of a crop rotation model. Based on the beam search, Borba and Ritt (2014) proposed a heuristic algorithm to maximize the production rate of an assembly line. The heuristic algorithm was presented to find the optimal result in complex systems in many works (Li et al., 2014, 2013). These works inspired the design of our paper's heuristic algorithm.

Based on the results in the existing literature, the optimization of the crop rotation scheduling is concluded to have a significance impact on the performance of farmers and is attracting growing interest. However, the optimization of rotation scheduling under the situation in China (land is controlled by smallholder farmers, combined with the requirement of similar profits for all farmers) is seldom researched. This paper presents an operational model for this problem and designs a heuristic algorithm to calculate the model.

3. Problem statement and model formulations

Crop rotation is a recursive system of planting a crop sequence for all smallholder farmers in this paper. For example, farmer j plants crops with the sequence of crops of 3, 1, and 2, which indicates that farmer j plants the three crops within a period of T (maximal months for a rotation) and restarts the crop sequence after the period of T. The crop rotation scheduling is a cropping calendar that shows the period of each crop in the rotation. The paper proposes an optimal rotation scheduling for all smallholder farmers simultaneously according to the farmers' requirements. This section provides a detailed description of the operational model for the crop rotation scheduling problem. According to the selling orders (updated each year), the model would be used to design the rotation schedule each year.

The definition of the problem is described as follows. Given a set of smallholder farmers with land for planting, a set of crops that can be selected for each rotation, and a predetermined production period (equal for all smallholder farmers), this paper finds a crop rotation scheduling that maximizes the profit of all farmers and minimizes the difference of the profits per acre among all farmers. Because the following discussion is notation intensive, all of the indices, parameters and decision variables used in this paper are summarized in the following.

Parameters:	
I	number of crops;
t_i	production time of crop i;
J	number of farmers;
a_j	area of land for farmer j;
R_j	crop changing times in each rotation for farmer j;
π_i	profit of crop i per acre;
T	maximal months for a rotation (the length of rotation);
D_i	minimal planting area of crop i (minimal market demand);
α	threshold of the profit gap between farmer j and the average profit of all farmers.
Indices:	
$i \in \{1, 2, \ldots I\}$	NO. of crops;
$j \in \{1, 2, \ldots J\}$	NO. of farmers;
$r \in \{1, 2, \ldots R_j\}$	NO. of the rotation batch for farmer j.
Decision variables:	
$x_{ijr} = 1$	if crop i is planted by farmer j at the batch of r; otherwise, it is equal to 0; $i = 1, \ldots, I$, $j = 1, \ldots, J$, and $r = 1, \ldots, R_j$.

The crop rotation scheduling problem can be formulated as a 0–1 programming model $\max f(x_{ijr})$, where $f(x_{ijr})$ is defined in formula (1).

$$f(x_{ijr}) = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R_j}\pi_i a_j x_{ijr} \tag{1}$$

The constraints of the model can be defined as follows:

$$\sum_{r=1}^{R_j} x_{ijr} \leqslant 1, \quad \forall i,j \tag{2}$$

$$\sum_{j=1}^{J}\sum_{r=1}^{R_j} a_j x_{ijr} \geqslant D_i, \quad \forall i \tag{3}$$

$$\sum_{i=1}^{I}\sum_{r=1}^{R_j} t_i x_{ijr} \leqslant T, \quad \forall j \tag{4}$$

$$\frac{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R_j}\pi_i a_j x_{ijr}\Big/\sum_{j=1}^{J}a_j - \sum_{i=1}^{I}\sum_{r=1}^{R_j}\pi_i x_{ijr}}{\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R_j}\pi_i a_j x_{ijr}\Big/\sum_{j=1}^{J}a_j} \leqslant \alpha, \quad \forall j \tag{5}$$

Objective function (1) provides the total profits of all farmers in each rotation period. The goal of the contract farming company is to find the maximal profits. This goal should follow constraints (2)–(5).

Constraint (2) ensures that a crop can be planted by a farmer no more than one time. If $\sum_{r=1}^{R_j} x_{ijr} = 0$, crop i is not planted by farmer j. If $\sum_{r=1}^{R_j} x_{ijr} = 1$, crop i is planted by farmer j one time along one year. Other values are not allowed in this model. The reason of constraint (2) is that the agricultural sustainability could be destroyed by one kind of crop planted at a plot more than one time along a year. The influence of species from same botanic family would be considered in the following algorithm.

Constraint (3) guarantees that the planting area of each crop is more than the minimal requirement of the crop. If $\sum_{j=1}^{J}\sum_{r=1}^{R_j} a_j x_{ijr} < D_i$, then the yield of crop i is not sufficient for the minimal market demand.

Constraint (4) ensures that the production period of farmer j is no more than the length of rotation (the maximal production period, T). Because the rotation scheduling is restarted after the length of rotation, $\sum_{i=1}^{I}\sum_{r=1}^{R_j} t_i x_{ijr} > T$ was not allowed in this model. Meanwhile, if the land must have a month as the fallow period, then constraint (5) should be changed to formula (6).

$$\sum_{i=1}^{I}\sum_{r=1}^{R_j} t_i x_{ijr} \leqslant T-1, \quad \forall j \tag{6}$$

Constraint (5) is used to limit the difference of profits per acre among all of the farmers. $\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R_j}\pi_i a_j x_{ijr}\Big/\sum_{j=1}^{J}a_j$ is the average profit per acre for all farmers. If the profit $(\sum_{i=1}^{I}\sum_{r=1}^{R_j}\pi_i x_{ijr})$ per acre of farmer j is more than the average profit per acre, then the rotation scheduling of farmer j is not limited by constraint (5). If $\sum_{i=1}^{I}\sum_{r=1}^{R_j}\pi_i x_{ijr} < \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{r=1}^{R_j}\pi_i a_j x_{ijr}\Big/\sum_{j=1}^{J}a_j$, then farmer j is unfairly treated in the contract farming team. Under this condition, constraint (5) prohibits the profit gap between farmer j and the team from being greater than α.

Given the characteristics of the variables in the presented model, finding the optimal rotation scheduling is infeasible because the constraints limit the use of exact solution methods. Traditional heuristic algorithms, such as Genetic Algorithm, are not suitable for this model because the choice and sequence of several crops is significant in each result. Traditional heuristic algorithms are difficult to use to describe the dynamics of a feasible solution of the model. Based on the heuristic algorithms in previous literature reports, this paper designed a new algorithm to find the optimal rotation scheduling of the model.

4. Algorithm design for the model

Considering the characteristics of the model in Section 3, this paper proposes a heuristic algorithm to find the optimal rotation scheduling of the model. The algorithm uses the Boltzmann softmax distribution (according to the minimal demand of each crop) to first select crops for each farmer. Next, the algorithm changes the inappropriate rotation schedules and chooses different crops to decrease the profit gaps. Based on the basic rules of heuristic algorithms, the steps of the heuristic algorithm are proposed in the following.

Step 0:

Initialize all of the variables. Set $k = 1$ and go to the next step.

Step 1:

If $k > 3$, go to Step 2. Otherwise, use the Boltzmann soft-max distribution to compute the probability of choosing crop i $(D_i/\sum_{k=1}^{I} D_k)$. Select the crops for all farmers according to the probabilities. If crop i is planted by farmer j, then $D_i = \max\{D_i - a_j, 0\}$. Go back to Step 1;

Step 2:

Build the set (FT) of farmers with the attitude of $\sum_{i=1}^{I}\sum_{r=1}^{R_j} t_i x_{ijr} > T$.

Step 3:

Delete crop i with minimal production times in all crops planted by farmer j and set $FT = FT - j$. If FT is null, then go to Step 4; otherwise, go back to Step 2.

Step 4:

Build the set (FA) of farmers with formula (5). If FA is null, then end this algorithm; otherwise, go to Step 5.

Step 5:

If $\sum_{k=1}^{I} D_k > 0$, then use the rule of Step 1 and formula (4) to choose the crop for the farmer in the set of FA. If no crop can be planted by the farmer, then choose crop i with the probability of $\pi_i/\sum_{k=1}^{I}\pi_k$ to replace the crop with the minimal profit planted by the farmer and set $FA = FA - j$. If FA is null, then go to the next step; otherwise, go back to Step 5.

Step 6:

Build the set (FD) of farmers that do not follow formula (2). In this case, crop i is planted by a farmer more than one time. Use the crop with the production time t_i to replace crop i for the farmer and set $FD = FD - j$. If FD is null, then go to Step 4; otherwise, go back to Step 6.

The result of the heuristic algorithm is the crops chose by each farmer. However, planting sequences are not decided by the algorithm. The paper uses the following rules to adjust the sequence of vegetables for farmers. The application sequence of the following rules is *Rule 5*, *Rule 4*, *Rule 3*, *Rule 2*, and *Rule 1*. *Rule 1* has the most priority than other rules. *Rule 2* has the second priority. *Rule 5* has the minimal priority.

Rule 1: Crops from same botanic family are not planted in sequence of same farmer. If there are only two crops for a farmer and two crops have same botanic family, the model sets a new crop with different botanic family as the substitute of the two crops. The new crop should has similar profit with the crop been deleted.
Rule 2: Cucurbitaceae cannot plant in sequence with Solanaceae.
Rule 3: Leaf vegetables should be planted in sequence with stem vegetables and fruit vegetables.
Rule 4: Deep rooted vegetables should be planted in sequence with shallow rooted vegetables.
Rule 5: Crops sensitive with soil acidity (such as onion) should be planted following the crops with the ability of decreasing soil acidity (such as Cabbage).

Based on the heuristic process and the sequence rules, the algorithm finds the optimal rotation scheduling of formula (1). JAVA was used to code the algorithm on the platform of WinXP. In the next section, an example is proposed to show the validity of the algorithm.

5. Case study

Jiangsu Tianlandilv Farm Ltd. is located in Wuxi, China. Tianlandilv is a large-scale technological and ecological farm. The company provides fresh organic vegetables to many companies, hotels and schools at all seasons. The company utilizes a contract farming team of 80 smallholder farmers that use large facility agricultural technologies. The product manager proposes the rotation schedules for all of the farmers. The process of planting is controlled by the company to ensure the quality and time-to-market of all crops. The rotation schedules must improve the profit of all farmers and ensure that all farmers have similar profit per acre. The profits of all farmers are about 40,000,000 RMB in 2013. Meanwhile, more than 5 farmers have conflict with Tianlandilv because their profits are lower than the average profit of all farmers. The land areas of the eighty smallholder farmers are:

$$\begin{aligned} A = &\{a_1, a_2, \ldots a_J\} \\ = &\{34,44,10,35,25,42,30,27,46,36,37,31,28,32,32,13,8,24,27,23, \\ &43,34,31,23,34,44,6,44,42,21,28,26,17,29,19,35,37,36,35,24, \\ &45,32,35,39,25,23,23,33,24,31,42,38,27,13,36,37,24,28,33,35, \\ &26,22,26,21,23,23,42,16,28,17,38,29,29,25,21,23,32,16,41,26\}; \end{aligned} \tag{7}$$

Table 2
Profits distributions of the 40 results.

Profits of 80 farmers (ten thousand RMB)	Frequency of profits
4050	0
4090	0.15
4120	0.325
4135	0.2
4150	0.15
4175	0.175

Table 3
Distributions of the 40 results' standard deviations.

Deviation of profits (ten thousand RMB)	Frequency of deviation
0.1	0
0.11	0.15
0.12	0.45
0.13	0.3
0.14	0.075
0.15	0.025

Table 4
Top five results ranked by profits (ten thousand RMB).

Best results' profit	Best results' deviation	NO. of results
4170.99	0.1108	13
4168.61	0.1044	32
4167.41	0.1378	35
4158.21	0.1208	8
4157.87	0.1239	39

Table 5
Top five results ranked by standard deviations (ten thousand RMB).

Best results' profit	Best results' deviation	NO. of results
4168.61	0.1044	32
4101.75	0.1044	30
4074.95	0.1050	15
4137.93	0.1051	19
4137.83	0.1088	28

Table 1
Data of the fifteen typical crops.

Crops	Botanic family	Planting time (month)	Minimal plating area (acre/year)	Profits (selling orders of 2013) (ten thousand RMB/acre)
Pakchoi	Brassicaceae	1	180	0.2
Radish	Brassicaceae	1	100	0.25
Garland chrysanthemum	Asteraceae	2	120	0.35
Lettuce	Compositae	2	160	0.38
Sweet corn	Gramineae	3	140	0.45
Amaranth	Amarantaceae	3	120	0.4
Chinese watermelon	Cucurbitaceae	3	100	0.35
Coriander	Umbelliferae	3	80	0.6
Cucumber	Cucurbitaceae	4	160	0.55
Hot pepper	Solanaceae	4	180	0.46
Celery	Umbelliferae	4	120	0.62
Broccoli	Brassicaceae	4	100	0.42
Broad bean	Leguminosae	4	100	0.59
Garlic bolt	Amaryllidaceae	4	160	0.52
Tomato	Solanaceae	5	180	0.65

Table 6
Best rotation scheduling of 80 farmers.

Month / Farmer	1	2	3	4	5	6	7	8	9	10	11	12
1	Garlic bolt				Lettuce		Amaranth			Sweet corn		
2	Broad bean				Broccoli				Coriander			Pakchoi
3	Garlic bolt				Broccoli				Coriander			Pakchoi
4	Hot pepper				Amaranth			Lettuce		Sweet corn		
5	Tomato					Pakchoi	Broad bean			Garland chrysanthemum		
6	Pakchoi	Hot pepper				Garlic bolt				Coriander		
7	Garland chrysanthemum		Chinese watermelon			Coriander			Cucumber			
8	Garlic bolt				Amaranth			Broad bean				Pakchoi
9	Celery				Tomato					Coriander		
10	Sweet corn			Broad bean				Tomato				
11	Hot pepper				Sweet corn			Pakchoi	Cucumber			
12	Pakchoi	Coriander			Cucumber				Garlic bolt			
13	Pakchoi	Amaranth			Coriander			Tomato				
14	Cucumber				Garland chrysanthemum		Tomato					Pakchoi
15	Lettuce		Celery				Amaranth			Sweet corn		
16	Broccoli				Coriander			Chinese watermelon			Garland chrysanthemum	
17	Coriander			Chinese watermelon			Pakchoi	Tomato				
18	Celery				Cucumber				Garlic bolt			
19	Garlic bolt				Pakchoi	Broad bean				Sweet corn		
20	Tomato					Coriander			Hot pepper			
21	Amaranth			Garland chrysanthemum		Celery				Sweet corn		
22	Tomato					Broccoli				Chinese watermelon		
23	Celery				Garlic bolt				Broad bean			
24	Cucumber				Garlic bolt				Chinese watermelon			Pakchoi
25	Cucumber				Coriander			Chinese watermelon			Garland chrysanthemum	
26	Cucumber				Pakchoi	Hot pepper				Sweet corn		
27	Sweet corn			Chinese watermelon			Garland chrysanthemum		Hot pepper			
28	Garland chrysanthemum		Coriander			Sweet corn			Celery			
29	Chinese watermelon			Celery				Hot pepper				Pakchoi
30	Chinese watermelon			Broad bean				Celery				Pakchoi
31	Cucumber				Celery				Garlic bolt			
32	Coriander			Sweet corn			Pakchoi	Tomato				
33	Sweet corn			Pakchoi	Tomato					Coriander		
34	Pakchoi	Garland chrysanthemum		Broccoli				Tomato				
35	Tomato					Sweet corn			Broad bean			
36	Broccoli				Garland chrysanthemum		Hot pepper				Lettuce	
37	Pakchoi	Coriander			Garlic bolt				Cucumber			
38	Coriander			Chinese watermelon			Garland chrysanthemum		Cucumber			
39	Tomato					Sweet corn			Cucumber			
40	Hot pepper				Celery				Sweet corn			Pakchoi
41	Tomato					Coriander			Broad bean			
42	Garland chrysanthemum		Lettuce		Garlic bolt				Cucumber			
43	Garlic bolt				Broad bean				Cucumber			
44	Sweet corn			Pakchoi	Cucumber				Garlic bolt			
45	Sweet corn			Hot pepper				Pakchoi	Cucumber			
46	Amaranth			Pakchoi	Garland chrysanthemum		Tomato					Pakchoi
47	Celery				Tomato					Coriander		
48	Coriander			Sweet corn			Amaranth			Chinese watermelon		
49	Lettuce		Coriander			Garlic bolt				Sweet corn		
50	Amaranth			Pakchoi	Celery				Cucumber			
51	Sweet corn			Coriander			Chinese watermelon			Amaranth		
52	Lettuce		Pakchoi	Tomato					Garlic bolt			
53	Sweet corn			Coriander			Tomato					Pakchoi
54	Amaranth			Sweet corn			Garland chrysanthemum		Cucumber			
55	Sweet corn			Chinese watermelon			Garland chrysanthemum		Garlic bolt			

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<tr><td>56</td><td colspan="4">Celery</td><td colspan="5">Tomato</td><td colspan="2">Garland chrysanthemum</td><td colspan="1">Pakchoi</td></tr>
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<tr><td>76</td><td colspan="3">Amaranth</td><td colspan="4">Hot pepper</td><td colspan="2">Garland chrysanthemum</td><td colspan="3">Sweet corn</td></tr>
<tr><td>77</td><td colspan="4">Cucumber</td><td colspan="3">Sweet corn</td><td colspan="5">Tomato</td></tr>
<tr><td>78</td><td colspan="1">Pakchoi</td><td colspan="3">Chinese watermelon</td><td colspan="4">Garlic bolt</td><td colspan="4">Cucumber</td></tr>
<tr><td>79</td><td colspan="5">Tomato</td><td colspan="3">Coriander</td><td colspan="4">Cucumber</td></tr>
<tr><td>80</td><td colspan="4">Celery</td><td colspan="3">Sweet corn</td><td colspan="1">Pakchoi</td><td colspan="4">Garlic bolt</td></tr>
</table>

Because many crops have the same requirements and profits, this paper selected 15 typical crops from the all of the crops of the company. Even the costs is different for vegetables, the prices are same for all vegetables in the order between Tianlandilv and his customers (The price in 2013 is 16 RMB/kg). The selling price is much higher than the price of non-organic vegetables. Tianlandilv could not only sell vegetables with higher profits, because there are also requirements of diversity in the selling order. Tianlandilv should propose the combination of different vegetables for his customers. Because the selling order would be updated each year, Tianlandilv is interesting in the 12 months rotation schedule. The data of the 15 typical crops are presented in Table 1. The profits in Table 1 are based on the selling orders of 2013.

To show the validity of the proposed model and the algorithm, the proposed parameter setting of the model is $T = 12$ and $\alpha = 0.1$, i.e., the lands do not have fallow periods and the crop sequence is restarted after 12 months. The gap of profits per acre for the farmers is no more than 10% compared with the average profit. This situation is the same as the real-world data of Tianlandilv Farm Ltd.

The heuristic algorithm finds the best result step by step through the rules with many stochastic processes (considered with Boltzmann soft-max distribution). This means the heuristic algorithm may have different results like genetic algorithm. In order to find the best results, the model is computed 40 times in the paper. The distributions of the profits and the deviation for the 40 results are presented in Tables 2 and 3.

Table 2 shows the profit distribution of the 40 results. For example, the value of 0.325 in the second column means that the probability of 80 farmers' profits being between 4090 and 4120 is 0.325. The probability of profits between 4050 and 4150 is 0.825 (0.15 + 0.325 + 0.02 + 0.015). This result indicates that the algorithm is stable for the 40 results, even though each result is not the same. The second column in Table 3 is the probability of different deviations. Here, the deviation of profits means the deviation of 80 farmers' profits per acre. Because the model is computed 40 times, this paper has 40 deviations. The value 0.3 in the second column means that the probability of deviation between 0.12 and 0.13 is 0.3. The probability of deviation between 0.1 and 0.13 is 0.9 (0.15 + 0.45 + 0.3). This result indicates that the deviation of the 80 farmers' profits is stable for the 40 results. As a result, the data in Table 2 and Table 3 demonstrate the validity of the algorithm.

Table 4 presents the top five results of the rotation schedule optimization procedure as ranked by profits. Meanwhile, Table 5 shows the top five results ranked by standard deviation. Result 32 is found to have the smallest deviation and the second highest profit. Because all farmers want to have similar maximal profits, the paper chooses result 32 as the best result of the model. In this condition, the group of all farmers has the second maximal profits and there is the minimal gap among these farmers. Considered the requirement of agronomic knowledge, the paper uses the five rules (in Section 4) to adjust the planting sequence of each farmer. The final rotation schedules of the 80 farmers proposed by result 32 are presented in Table 6 in Appendix A.

The results obtained from the model for the rotation scheduling of farmers suggest that the proposed model is effective in finding the optimal rotation scheduling for multiple farmers and crops. About 4% ((4168 − 4000)/4000) of profits could be increased for these farmers in 2013. Meanwhile, no farmer has conflict with the leading company because the profit gap among these farmers. The use of the proposed model and algorithm would be useful for maximizing the profits of contract farming companies faced with similar profits (per acre) for all smallholder farmers.

6. Conclusions and future research

This paper presented an operational model for the crop rotation scheduling of vegetables contract farming in China, with the goals of maximizing profits and providing similar profits for all smallholder farmers. A new heuristic algorithm was developed to find the optimal result of the model. The production of Tianlandilv Farm Ltd. was used as a case study. Results indicate that the model and algorithm are valid to solve the problem. The profits of farmers can be maximized with the proper rotation scheduling, while the deviation of profit among farmers can be minimized.

This study provides a model for the investors (China contract farming) to implement an optimal crop rotation scheduling that accounts for the real conditions of Chinese land strategies.

The proposed approach has room for improvement, namely the need to account for real-world situations. The use of different constraints for different crops is a new topic for future research. Thus, the current work can serve as the first step for further development in the optimization of crop rotation scheduling for developing a country's agricultural production.

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Appendix A

See Table 6.

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