Model of plant schedules for organic vegetables considering crop rotation rules to reduce pesticide usage

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Abstract. This paper deals with organic vegetable production planning by which the farmer has to determine the cropping schedules for each land parcels to maximize land parcels occupation. There is more than one variety of crops to be planted and some of these crops are included in one type of botanical family. The farmers do not use pesticide, instead, they use crop rotation in the planting process to minimize pest attack to obtain optimal yields. They must consider the ecological constraints in which farmers must determine the crop sequence and in which land parcel each vegetable must be planted in firm lands by following the rules of crop rotation. The crop included in one botanical family should not be planted sequentially in the same land parcel. We propose a linear programming model to develop organic vegetable production. The decision variable in this study is binary, 1 if one of the crops is cultivated during period \(j\) at land parcels \(k\), 0 otherwise. The result show that the cropping schedules of each crop in each land parcel are in one rotation period. To evaluate the performance of the model, numerical experiments using real-world data were performed.

1. Introduction

The demand for organic products (vegetables and fruits) has increased recently due to changes in the lifestyle of people who are more aware of a healthy lifestyle. Based on IFOAM, (2017) the market for organic products (vegetables and fruits) in the world increased by 8.1 billion USD from 81.6 billion USD in 2015 to 89.7 billion USD in 2016. Based on the potential market for organic vegetables that continues to increase, many farmers have begun to explore organic farming. To get maximum crop yield in organic production system, farmer do not use pesticide and chemical fertilizer. Organic production system focuses on practices and production strategies. One of production strategies in organic production system is diversification of the cropping area [2]. Based on agronomic and ecological study, an increase in crop species diversity can reduce pest attacks thereby enhancing the exploitation of productive resources [3].

The criteria for diversification planning and crop allocation are planting more than one crop at the same time and planting area in a crop rotation period. The main goal for cultivating land parcels with crops of different botanic families is to reduce the resources available to arthropods and microorganisms, thus reducing their population and reducing plants damage. Although there are polyphagous pests, many of them get resources from crops of the same botanic family [3].

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The technological rules for planting organics crop consist of two rules. The first rule is to avoid the cropping system of cultivating two crops of the same botanical family on the same piece of land parcels because this may have impact on crop root zones and result in decreasing soil fertility. Moreover, cultivating two crops of the same botanical family on the same land parcel may have impact to the crops that are vulnerable to diseases, weeds or plagues [4]. The second is to use fallow period to rehabilitate soil structure and fertility [2].

In these studies, we deal with crop rotation problem. The main purpose of this paper is to determine plant schedules of organic vegetables by considering crop rotation. We propose a linear programming with 0-1 optimization for crop rotation. The objective function in this paper is to maximize the occupancy of the land parcel subject to adjacency constraints and sequential planting constraints for crops belonging to the same botanical family. The composition of this paper is as follows in Section 2 providing a literature review. In section 3 we explain the problem and the development of the plant schedule model and case studies. In section 4 we conduct a computational study and analyse the results.

2. Literature review

2.1 Production schedule concept
Planning activities on agriculture are classified based on time horizons. For long-term plans, the area of land required must be determined. Moreover, the type of crop to be planted and the cropping schedule must be determined [5]. After the decision is made, the next step is to determine the short-term technical and operational planning decisions including harvest decisions such as how to allocate transportation equipment, labor, scheduling packaging and processing in manufacturing, or the number of harvests per period so that performance can be significantly improved [6]. Production scheduling in the agricultural industry starts from scheduling planting crops, harvesting scheduling to post-harvest activities, especially for vegetable commodities (horticulture) because these commodities have a relatively short life cycle (perishable). So that the commodity is easily damaged or its quality will decrease over time [7]. The timeline of activities in agricultural production starts from a seedling at the beginning of the period based on the demand at the beginning of each period. the harvest process is carried out at the end of the period. Because of the perishable durability, plants harvested in one period are used to meet demand in the same period [7]. The figure 1 represent the timeline of activities in agricultural production [7].

![Figure 1. Timeline of agriculture production.](image)

The scheduling method used in the agricultural production process is the MRP (material requirement planning) concept. MRP is a system to avoid the lack of raw materials in the production process. MRP has two objectives, the first objective is to determine the material needed in the production process and maintain priority at this time. In order to determine the amount of material needed, the company must have an inventory of the right type of material and with the amount in accordance with the production needs to meet the demand at the right time. In manufacturing, MRP is useful for determining the components needed to meet the master production schedule and based on the lead time to calculate the period of time the component must be available. MRP must determine what will be ordered (what to order), the amount that must be ordered (how much to order), the time
of order (when to order), and when to send (when to schedule delivery). The goal of maintaining current priorities is to be used at the time of request, and supply of components changes every day. Customers change the number of orders.

2.2 Crop rotation
Plant rotation is important in organic agriculture because it provides the main mechanism for making the soil fertile (good quality), controls pests, and minimizes diseases that attack the plants. Good crop rotation requires strategic planning because lack of planning can cause serious problems, such as accumulation of soil-borne diseases or soil nutrient imbalances. Crop rotation also helps limit pest populations because it can disrupt the life cycle of pests by changing their habitat [8]. In the process of making a crop rotation schedule there are several things that must be considered, the first is, plants that belong to the same botanical family should not be planted sequentially in the same area. The crop that belongs to the same botanical family should not be planted on adjacent area in the same period (adjacency constraint). The second thing that must be consider in the crop rotation schedule is fallow period. Fallow period is the period in which the soil is left overgrown with weeds to improve the soil structure, then the soil is loosened again to be planted with new plants [3][9].

2.3 Adjacency constraint
The adjacency constraint is important in making a planting schedule that considers the crop rotation. The length of crop rotation period is predetermined by the farmer. When the planting period has finished, it will repeat the planting rotation schedule that has been previously formed. Adjacency constraint is the constraint to guarantee that crop which belong to the same botanical family is forbidden to plant on the adjacency planting area. The planting area is divided into several land parcels which can be represented by a planar graph connected G (V, A) where the set of vertices V corresponds to the land parcels and there are edges (u, v) ∈ A if the plots u and v have the same boundaries. Two plots are categorized as adjacent if they share the boundaries [2]. Figure 2.3 shows the planting area divided into 5 and shows related graphs [2].

Based on Figure 2, adjacent land parcel have lines connecting the plots. For example, to land parcel 1 adjacent to land parcels 2, 3, 4, and 5, for land parcels 2 adjacent to land parcels 1, 3, 5 and so on. So that plants that are included in one botanical family may not be planted together on the land parcels 2, 1, 3, and 5. Plants belonging to one botanical family may be planted simultaneously on land parcels 2 and 4 or 3 and 5 while plants that are not included in one botanical family may be planted close together in the same period.

3. Structure of the model
In this section we discuss about the model of planting schedules for organic vegetables by considering crop rotation rules in order to avoid pest attack.
3.1 Formulation model

The purpose of the mathematical model is to determine the cropping schedules in order to maximize land occupation. There are 4 types of vegetables to be planted: Red Lettuce, Romain, spinach, and Pokchoy. Red Lettuce and Romain belong to the same botanical family so that they should not be planted sequentially in the same land parcel. Each vegetable has a different planting period. Table 1 shows the subscript indices used in the model; in turn, Tables 3 summarize the decision variables and the parameters respectively.

Table 1. Subscript indices.

| Subscripts | Variation |
|------------|-----------|
| List of crops (i) | i=1,2,…,n |
| Period (j) | j=1,2,…,T |
| Land parcels (k) | k=1,2,…,K |

Table 2. Decision variables and parameters.

| Symbol | Description |
|--------|-------------|
| x_{ijk} | 1, if crop i is cultivated during period j in plot k, 0 otherwise |
| t_{i} | Duration of planting crops i, including the time estimated for preparing the soil and harvesting |
| T | Number of periods in each rotation (unit time specified) |
| K | Number of land parcels in the planting area |
| F(p) | Set of crops of botanical family p |

The objective function of the model is maximization land occupation [2].

\[
\text{Max } Z = \sum_{i=1}^{n} \sum_{j=1}^{T} \sum_{k=1}^{K} (t_{i} \times x_{ijk})
\]

Subject to:

\[
\sum_{i=1}^{n} \sum_{j=1}^{T} \sum_{k=1}^{K} x_{ijk} \leq 1, \quad j = 1,…,T, \quad k = 1,…,K
\]

(2)

\[
\sum_{i \in F(p)} \sum_{r=0}^{T-1} x_{(j+r)k} \leq 1, \quad p=1,…,f; \quad j = 1,…,T, \quad k = 1,…,K
\]

(3)

\[
\sum_{i \in F(p)} \sum_{r=0}^{T-1} \left[ x_{(i,j+r)k} + x_{(i,j+r)u} \right] \leq 1, \quad p=1,…,f; \quad j = 1,…,T
\]

(4)

\[
x_{ijk} \in \{0,1\}, \quad i = 1,…,n, \quad j = 1,…,T, \quad k = 1,…,K
\]

(5)

For Eq. 2, Eq. 3 and Eq. 4 if \((j + r) > T\), substitute \((j + r)\) for \((j + r - T)\). Eq. 1 is objective function of this model to maximization of land during one rotation period [2]. Eq. 2 ensures that two crops cannot occupy the same place. If crop i is being cultivated in land parcel one for some period, no other crop can be planted on that land parcel in that period. Eq. 3 ensures that crops included in one botanical family cannot be planted sequentially in the same land parcel. Eq. 4 is a constraint to ensure that crops of the same family cannot be grown at the same time in adjacent plots. Eq. 5 is the binary constraint [2].
3.2 Numerical experiment
To evaluate this model we conduct numerical experiment, considering a cropping area divided 3 land parcels with spatial configuration as illustrated in figure 3.

| Land Parcels 1 | Land Parcels 2 | Land Parcels 3 |
|----------------|----------------|----------------|

**Figure 3.** Land parcels.

To evaluate this model we conduct numerical experiment, considering a cropping area divided 5 land parcels with spatial configuration as illustrated in Figure 3. The length of each rotation is 3 months. The unit of time is one week. We selected 4 crops from 2 botanical families. Crops characteristics data are shown in the table 3.

| Vegetables   | Family       | Seedling time | Planting time |
|--------------|--------------|---------------|---------------|
| Red Lettuce  | Asteraceae   | 4 Weeks       | 5 Weeks       |
| Romain       | Amaranthaceae| 4 Weeks       | 7 Weeks       |
| Horenso      | Brassicaceae | 4 Weeks       | 5 Weeks       |
| Pakchoy      |              | 4 Weeks       | 6 Weeks       |

**Table 3.** Crops characteristic.

| Land Parcels | Periods (week) |
|--------------|----------------|
|              | 1  2  3  4  5  6  7  8  9  10  11  12 |
| Land Parcels 1 | RL  RL  0   RL  RL  RL  RL  RL  0   RL  RL  RL |
| Land Parcels 2 | H    0    H   H    H   H    H    0    H    H    H |
| Land Parcels 3 | RL  RL  RL  RL  0   RL  RL  RL  RL  0   RL |

**RL = Red Lettuce**  
**H = Horenso**

**Figure 4.** Optimal crop rotation scheduling for 3 land parcels.

By using LINGO 11 professional software, the model was solved. The model was run on a microcomputer provided with 1.99 GHz intel processor and 3.9 GB of memory RAM. The diagram in Figure 4 shows an optimal crop rotation scheduling for 3 land parcels during 3 months. According to constraint number one, the land parcels are only used by one crop. If crop i is planted in one land parcel another crop cannot planted in that land parcel until crop i is harvested. According to the results, the farmer have to plant Red Lettuce in period 10 then harvest in period 2 at land parcel 1. Horenso is planted in period 3 in land parcels 2, in period 9 in land parcels 2.

Based on the objective function to maximize land occupation, the value of land occupation is 30. Land parcel 1 is empty in period 3 and 9. This vacant land cannot be planted because the duration of vacant land is less than the planting time for each plant. This outcome highlights the advantage of the proposed model, and the crop rotation constraint ensures that crop is included in one botanical family so that the crops to plant are Red Lettuce and Horenso. According to the optimization result, the farmer should choose Horenso and Red Lettuce. By growing this one, the farmer can produce more compared to the Romain and Pakchoy within the same period. This is proven, if Romain is selected to plant in land parcel 2, the farmer only can produce Romain only once. Moreover Romain is not selected to plant because it cannot be planted adjacent to Red Lettuce. As explained before, it has 8 day-planting time, so if Romain is planted in period 3, it must be harvested in period 10 while in
period 4 in land parcel 1 it starts planting Red Lettuce so that it does not meet the constraints of adjacency.

4. Conclusion
Agriculture supply chain has been a matter of great interest in recent years. People began to realize the importance of healthy lifestyle. They choose to consume organic products. This resulted in an increased demand for organic products such as organic vegetables. In this paper we have presented a 0-1 linear optimization model to determine a crop rotation scheduling for cropping area divided into three land parcels. Each crop has planting times of different length. The problem is concerned with organic vegetable production which considers crop rotation rule and adjacency constraints for crops of the same family. The rotation has the same length in all land parcels. The objective function is to maximize land parcels occupation. The model show disadvantages that suggest some future research lines for example not all types of plants are selected for planting. Based on the computational result, the farmers only plant Red Lettuce and Horenso for one rotation period. If during that period there are demands for Romain and Pakchoy, then the farmer cannot fulfill them. Thereby, future research has to consider demand in production planning.

5. References
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