Computers and Electronics in Agriculture 119 (2015) 12–18

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Crop rotation model for contract farming with constraints on similar profits

Jing Li [a,*], Daniel Rodriguez [b], Dongqing Zhang [a], Kaiping Ma [a]

[a] *Faculty of Engineering, Nanjing Agricultural University, Nanjing 210031, China*
[b] *Queensland Alliance for Agriculture and Food Innovation (QAAFI), The University of Queensland, Toowoomba 4350, Australia*

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 28 September 2015
Accepted 7 October 2015

Keywords:
Contract farming
Crop rotation
Heuristic algorithm
Perishable products

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.

* Corresponding author. Tel./fax: +86 02558606710.
E-mail address: phdlijing@njau.edu.cn (J. Li).

http://dx.doi.org/10.1016/j.compag.2015.10.002
0168-1699/

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 $r = 1, \ldots, R_j$.