Chapter 2.4

A Linear Optimization Approach for Increasing Sustainability in Vegetable Crop Production

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ABSTRACT

This chapter is concerned with a set of optimization problems associated to crop rotation scheduling in the context of vegetable crop production according to some ecological criteria: no crop of the same botanic family is planted in sequence, green manure and fallow periods must be present in any schedule. A core mathematical model called the crop rotation scheduling model is proposed to represent these ecological criteria together with specific technical constraints associated to the growing of vegetable crops. Three optimization problems based on crop rotation schedules are written in detail in this chapter. For each problem, the authors present a general modeling framework and a solution methodology based on a technique known as column generation, which iteratively builds crop rotation plans for a number of plots. Some extensions are also presented, with the aim of incorporating additional characteristics found in production field conditions. This chapter ends with a brief discussion on a set of computational experiments and some suggestions for future research.

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INTRODUCTION

Large monoculture-based production systems have been present in Brazil since sugar cane was grown for sugar production in the 16th – 18th centuries. Furthermore, it became more important in the sixties and seventies. Although these systems are able to produce food at low prices, they are also associated with many social and environmental problems. Indeed, besides depending on extensive use of highly soluble mineral fertilizers, pesticides and fossil energy, large monocultures need a small number of employees and usually exclude small family growers due to the dependence on large amounts of capital. This has raised concerns about the economical, environmental and social sustainability of these food production system. In response to these concerns, alternative production models such as 'Natural', 'Organic', and 'Biodynamic' agricultures have attracted attention. Implementing these models has been boosted by private initiatives, such as the promotion of specific fairs and distribution strategies, as well as governmental incentives in the form of regulations and guidelines for organic production in the country.

The main cornerstone of more sustainable models in crop production is crop diversification and the introduction of biological processes in the system. Various agricultural and ecological studies demonstrate that the increase in crop species diversity leads to beneficial effects, such as better exploitation of productive resources, less pest damage, a higher control of spontaneous weeds and an increase in production stability (Altieri, 1995; Gliessman, 2000).

Biological processes are fundamental for maintaining ecological-based crop production. Among the important processes that should be stimulated, we can cite nutrient cycling, nitrogen biological fixation and the processes associated with the thriving of spontaneous vegetation at specific times and places. Crop diversification associated to biological processes in cropping systems allows for the conservation of productive resources, as well as less dependence on industrial inputs, such as fertilizers and pesticides. Moreover, they might reduce the production costs and result in social benefits, such as a decrease in grower's vulnerability to the market prices and a better distribution of grower's income and food for the population throughout the year. One of the most widespread strategies for enhancing crop diversification over time is crop rotation. In these production systems, a sequence of different crops is cultivated in the same field in a finite time interval and this production sequence is repeated indefinitely. Besides the mentioned potential benefits, crop rotation helps to protect soil from eroding and makes it possible to use the land in another period during the year.

Among the ecological criteria and biological methods that can be used to define rotation plans, one might list the following (Gliessman, 2000):

a. avoid the growth of a crop immediately after a crop from the same botanical family has been harvested as many herbivores and pathogens only attack crops from a specific botanical family;
b. include green manure crops (usually a leguminous) for biological nitrogen fixation; and
c. include fallow periods, in which the spontaneous vegetation is left to thrive for a given period of time, thus contributing to the biological control of insects and improving soil biological, chemical and physical characteristics.

In this chapter, we focus on the scheduling of vegetable crop rotation. In this context, one must consider that vegetable crops embed many different species and cultivars, they present very different cropping times and a high specific cropping season due to their sensibility to climatic conditions. Vegetable crops are also more susceptible to pest attacks. Moreover, it is common practice to cultivate many different crops in the same area throughout the year. These characteristics make the rotation planning using ecological criteria (a)–(c) a complex task, which is why the use of support software is very useful, if not essential. In addition, for commercial reasons, vegetable

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