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Invited Review

Application of planning models in the agri-food supply chain: A review

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Abstract

The supply chain of agricultural products has received a great deal of attention lately due to issues related to public health. Something that has become apparent is that in the near future the design and operation of agricultural supply chains will be subject to more stringent regulations and closer monitoring, in particular those for products destined for human consumption (agri-foods). This implies that the traditional supply chain practices may be subject to revision and change. One of the aspects that may be the subject of considerable scrutiny is the planning activities performed along the supply chains of agricultural products. In this paper, we review the main contributions in the field of production and distribution planning for agri-foods based on agricultural crops. We focus particularly on those models that have been successfully implemented. The models are classified according to relevant features, such as the optimization approaches used, the type of crops modeled and the scope of the plans, among many others. Through our analysis of the current state of the research, we diagnose some of the future requirements for modeling the supply chain of agri-foods.

Keyword: OR in agriculture

1. Introduction

The supply chain practices of agricultural food products are currently under public scrutiny. This is the result of several factors, such as the national attention given to recent cases of fresh produce contamination (van der Vorst, 2006), the changing attitudes of a more health conscious and better informed consumer who wants to have precise information about the farming, marketing, and distribution practices used to bring the agricultural products into the shelves of the neighborhood supermarket. This scrutiny will undoubtedly translate into additional regulations and market driven standards that will affect the design and operation of an already complex supply chain. This complexity is particularly critical in the case of perishable agricultural commodities where the traversal time of the products through the supply chain and the opportunities to use inventory as a buffer against demand and transportation variability are severely limited. This complexity is compounded when the supply chain encompasses two or more countries. Thus, the opening of domestic markets to international competition throughout the world will undoubtedly result in shifting the focus from a single echelon, such as the farmer, to the efficiency of the overall supply chain. In order to meet these new challenges, it is necessary to take a critical look at the current supply chain practices to determine the best strategies to accommodate the new global conditions. In particular, it is necessary to investigate if there exist better ways to design and operate a supply chain that is increasingly globally integrated. In this paper we focus primarily on planning models used in the different aspects of the supply chain of agricultural food products obtained from crops, or agri-food products. This review does not include the supply chains of other products such as cattle, meats, and other agricultural products not directly related to crops.

The term agri-food supply chains (ASC) has been coined to describe the activities from production to distribution

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that bring agricultural or horticultural products (Aramyan et al., 2006) from the farm to the table. ASC are formed by the organizations responsible for production (farmers), distribution, processing, and marketing of agricultural products to the final consumers.

The supply chain of agri-foods, as any other supply chain, is a network of organizations working together in different processes and activities in order to bring products and services to the market, with the purpose of satisfying customers' demands (Christopher, 2005). What differentiates ASC from other supply chains is the importance played by factors such as food quality and safety, and weather related variability (Salin, 1998). Other relevant characteristics of agri-foods include their limited shelf life, their demand and price variability, which makes the underlying supply chain more complex and harder to manage than other supply chains.

This paper gives an assessment of the state of the art in the area of planning models for the different components of agri-food supply chains. Fig. 1 presents the factors used to dissect and organize this review. For instance, from the perspective of storability of the products, we make the distinction between those papers whose main focus is on perishable products from those that focus mostly on non-perishable products. From the perspective of the scope; we divide the papers into strategic, tactical, and operational planning. From the perspective of modeling uncertainty, we divide the papers into deterministic and stochastic. In a second level of the classification, we make a further categorization using the particularities of the modeling approaches used. For instance, we divide the deterministic models into those based on linear programming, dynamic programming, etc. We also divide the papers using stochastic modeling approaches into stochastic programming and stochastic dynamic programming.

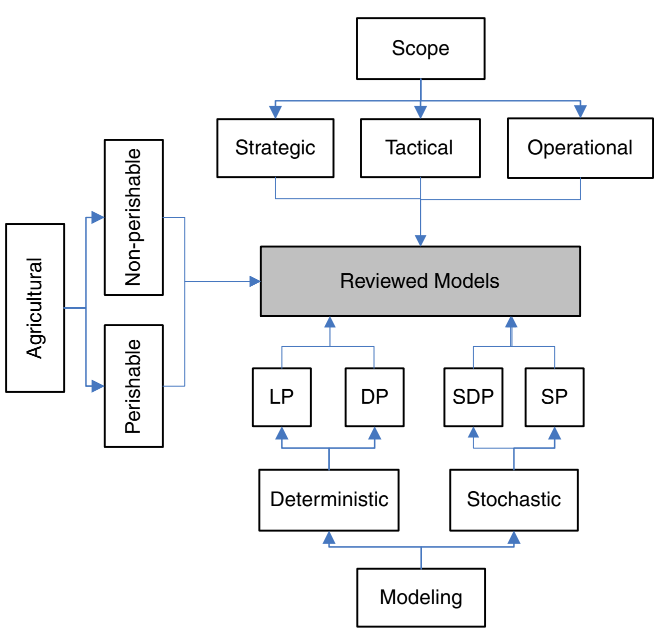

Fig. 1. Supply chain literature and its relation with our review.

The papers not fitting exactly one of these categories appear in more than one group or, for those papers not fitting any of the categories; they are grouped in a special category presented at the end of the classification.

1.1. Scope of the review

We are aware of at least three previous literature reviews in areas related to the topic of planning models of agricultural supply chains; the earliest was performed by Glen (1987), and the latest by Lowe and Preckel (2004). Glen performed an exhaustive search of the literature (previous to the year of 1985) covering crop and livestock production models. The review by Lowe and Preckel focused on the main modeling approaches used in crop planning in the context of agribusiness. Their review included some of the relevant papers covered in Glen (1987), but also some papers that were published after Glen's review. Although Lowe and Preckel's review is not extensive, it highlights some potential areas for future research in the area. Another review that focused on the topic of location analysis applied to agriculture was compiled by Lucas and Chhajed (2004). This review covers applications related to location of warehouses and processing plants from the year 1826 to the year 2000. In their paper, Lucas and Chhajed recognized the complexity and challenges of strategic production–distribution models applied to the agricultural industry, and the need to consider uncertainty in the planning models. These authors also emphasize the emerging use of these models by large corporations.

Our intention in this paper is to complement and expand the previous works by identifying the works that either were not covered or were published after these reviews. Another objective is to frame the literature in the context of supply chain planning. In this paper we take a similar approach to that of Lowe and Preckel's by focusing on those papers aimed at the production and distribution of crops. We also aim to perform an extensive search of those papers that have been published from the year 1985, the year of Glen's review, to the present. As it was the case in the previous reviews, we do not cover macroeconomic models designed to plan crop production for entire regions or countries; instead we focus on those models targeted to be used by a single user, which may be a farmer or a company. The underlying reason for this approach is to look at the ASC planning problem from the perspective of the individual farmers, or group of farmers, facing an increasingly integrated and more complex production–distribution system. Most of the models addressed in this review come from journals in the agricultural sciences, supply chain, and operations research literature.

1.2. Plan for this research

The organization of this paper is as follows: we first present (Section 2) some background about the importance of agriculture and the fresh produce industry. Section 3 presents a brief description of the supply chain planning framework. In Section 4 we present supply chain planning models that have been developed for non-perishable agri-food products. Section 5 presents those supply chain planning models used in perishable agri-foods. Sections 4 and 5, in addition to identify and classify the planning models, also present some salient examples of the models and the planning approaches that have been used on specific problems. Those papers not fitting the classification scheme used in Sections 4 and 5 are presented in Section 6. Finally in Sections 7 and 8, we provide a summary of the review and identify some existing gaps in the literature that we believe should be addressed in the future.

2. Background

Contrary to common belief, the supply chain of agricultural products continues to be important, in terms of consumption and monetary value. For instance, Kinsey (2001) estimates that in the year 2000, the food and agricultural sector (not accounting its auxiliary services) made up over 9% of the US gross domestic product (GDP). He shows that the contribution to the GDP of some agricultural sectors is actually expanding. It has been reported that the US agricultural market has maintained a steady growth in production fueled by the internal demand. However, the main future growth in demand for agricultural products is expected to be generated by developing nations, which are actively increasing their consumption of proteins, fruits, and vegetables (Boehlje et al., 2003).

Fresh produce is one of the most dynamic sectors of the industry (Huang and Sophia, 2004). For example, the US market for fresh agri-foods represents nearly a quarter of all US food expenditures, with annual consumption of over a $100 billion in products related to fruits and vegetables (Epperson and Estes, 1999). Statistics from the United Sates Department of Agriculture (USDA, 2007) suggest that the per-capita consumption of fresh vegetables has been steadily increasing since the early 1980s, while the per capita consumption of traditional crops such as wheat and other grains have increased at a much slower pace and, for the last few years, it has actually decreased. The largest portion of the reported increases in consumption has been attributed to population growth, but also to market changes, such as the increasing public awareness of the benefits of healthier diets and to the higher incomes among the US population (McLaughlin et al., 1999). This increased demand for fresh products and an expectation of their year-around availability has in turn fueled the expansion of the underlying supply chains to include overseas production units such as winter produce from Mexico, Chile and other South American countries. The same trend has been observed in Europe were the norm is to find that the winter fresh produce sold in Northern Europe is produced in Spain, Turkey, North African countries, and beyond. These changes in demand and distribution patterns are expected to continue or even accelerate in the near future, thus making it necessary to look for ways to improve the current supply chain practices. In particular, the improvements should consider the new challenges imposed by the changing demand in agri-foods, and the new realities of the industry, which involves a global marketplace and more strict food safety regulations.

The structure of global market for agri-foods and the associated supply chains is not static. On the contrary, it is currently undergoing a drastic transformation. For instance, the profile of the typical player in the agri-food supply chain is changing from family based, small-scale, independent firms to one in which larger firms are more tightly aligned across the production and distribution value chain (Boehlje, 1999). The sophistication needed to successfully compete in these emerging supply chains makes it more likely that some of the concepts of supply chain planning and coordination that have been successfully applied in the manufacturing sector can be adapted to fit the agri-food supply chains. For instance, the academic and practice-oriented literature related to improvements of non-agricultural supply chains is ample (see for instance Vidal and Goetschalckx, 1997; Sarmiento and Nagi, 1999; Min and Zhou, 2002; Meixell and Gargeya, 2005). But implementing supply chain practices that have been effective in other fields, to the ASC is not easy, since the supply chain of agri-foods is characterized by very long lead times, as well as significant supply and demand uncertainties (Lowe and Preckel, 2004). These issues are even more complex for fresh products, where producers also face additional marketing uncertainties and a shorter life of the product. Thus, in order to adequately plan the operations in the supply chain of fresh products; it is necessary to formulate specific planning models that incorporate issues such as harvesting policies, marketing channels, logistics activities, vertical coordination, and risk management (Epperson and Estes, 1999).

An additional reason for the lack of planning models for the ASC has been the fragmented nature of the industry, in which advanced planning systems have not been easily adapted, implemented and maintained (McCarl and Nuthall, 1982). Lately, however, the new level of consolidation being observed in the fresh produce industry has resulted in more logistical activities performed directly by the producers, such as packaging, distribution, and final delivery of the products to the customers (Kader, 2001). These recent developments have increased the need for more sophisticated planning strategies and tools in this industry.

The present review aims at determining current state of the art in models and strategies for planning the ASC, and at the identification of the research gaps as a first step to the development of the solutions needed by the agricultural logistics industry.

3. Supply chains, supply chain planning and modeling approaches

We have identified two main types of ASCs, the first one is the supply chain of fresh agri-foods, and the second one is the supply chain for non-perishable agri-foods. Fresh products include highly perishable crops such as fresh fruits and vegetables whose useful life can be measured in days, non-perishable products are those that can be stored for longer periods of time such as grains, potatoes, and nuts. In the present review fresh products are of particular interest due to their added logistical complexity, their limited shelf life, and the renewed interest of the general public on the safety of these products.

3.1. Scope of decision-making in supply chain planning

Planning in supply chain of agri-foods usually involves several levels of hierarchical decisions. These decisions can be classified as strategic, tactical or operational, depending on their effects to the overall supply chain (Simchi-Levi, 2003; Chopra and Meindl, 2003). In the present research we review those supply chain planning models focused on strategic, tactical, and operational decision for the agri-food supply chain. We place special attention to those models dealing with coordination of tactical decisions such as production and distribution.

3.2. Decisions in supply chain planning

Planning is an activity that supports decision-making by identifying potential alternatives and making the best decisions according to the objectives of planners (Fleischmann et al., 2005). Supply chain planning (SCP) is comprised, at the highest level, of three main decision-making functional processes: production planning, inventory control and physical distribution (Beamon, 1998). Fleischmann et al. (2005) divides the supply chain activities into four functional areas: procurement, production, distribution and sales. These functional areas play an important part in the architecture of advanced planning systems for commercial packages (Stadler, 2005). Although these tasks have traditionally been modeled independently, there is a consensus in the supply chain literature that two or more of these processes should be modeled together for improving the overall supply chain performance (Chandra and Fisher, 1994).

In the context of the ASC, we have identified four main functional areas: production, harvest, storage, and distribution. Decisions made in production include those related to cropping, such as the land to allocate to each crop, timing of sowing, and the determination of resources required for growing the crops. During harvest, some of the decisions that need to be made include the timing for collecting the crops from the fields and the determination of the level of resources needed to perform this activity. Some other decisions made at harvest include the scheduling of equipment, labor, and transportation equipment. Sometimes these decisions also involve the scheduling of the packing or processing plant. The third function is storage, which includes the inventory control of the agri-foods, which is required when the products need to be stored before or during their distribution. Some storage-related decisions also include the amount to store and sell in each planning period and how to position the inventory along the supply chain. Finally, the distribution function involves moving the product down the supply chain to deliver it to the consumers. The decisions associated with distribution include selecting the transportation mode, the routes to use and the shipping schedule to deliver the product.

3.3. Modeling approaches in SCP

From a modeling perspective, the models for supply chain planning can be classified as deterministic or stochastic, according to the certainty of the value of the parameters used (Min and Zhou, 2002). We further refine this classification according to the main mathematical techniques used for finding solutions to these models. In those cases where all of the model's parameters are assumed deterministic, the researchers have traditionally used approaches such as linear programming (LP), dynamic programming (DP), mixed integer programming (MIP), and goal programming (GP). Otherwise, stochastic modeling approaches are used, these include stochastic programming (SP), stochastic dynamic programming (SDP), simulation (SIM), risk programming (RP).

We are aware of alternative modeling approaches for modeling agri-food related activities, which we do not cover in the present review. In general these approaches are not as commonly used for applications in the ASC, but there are applications in related areas of agricultural research in which these modeling approaches are useful. One example is the use of multi-objective and multi-criteria decision-making models, which have been applied to subsistence farms and agricultural policy planning. The interested reader in multi-criteria decision-making is referred to the work of Hayashi (2000), who presents a comprehensive list of articles on the topic of multi-criteria agricultural decision making. Another example is the use of models to predict plant growth and the timing of their maturity, which have been applied to estimate production yield as a function of time. For a detailed description of these models the reader is advised to consult the reviews by Marcelis et al. (1998) and van Ittersum et al. (2003).

4. Planning models for ASC of non-perishable products

In this section we present those works dealing with models for the planning of activities in the supply chain of non-perishable agri-foods. The complete list of the research papers covered is presented in Table 1. This table presents the leading authors and the publication year of the paper. The second column gives a brief description of the papers and their main objective(s). In the remainder of this section we classify these papers according to their planning scope, the functional nature of the decisions being modeled and the modeling approaches used. In order to better illustrate the different classifications we briefly describe one or more

Table 1
List of models non-perishable agricultural products

Model	Main objective of the paper
Torkamani (2005)	Evaluate prospective technology options using SP with the aim of maximizing the farmer's utility (exponential utility maximizing objective)
Kobzar et al. (2005)	Develop a RP model for capturing joint stochastic distributions (parametric and non-parametric) using a mean–variance objective function
Apaiah and Hendrix (2005)	Design a supply chain network for growing, harvesting, transporting and processing of a pea-based product using a MIP that minimizes total cost
Jiao et al. (2005)	Develop a harvest schedule for a sugar cane farms using a LP model that maximizes the sugar content in the crops for a harvest season
Biswas and Pal (2005)	Plan seasonal crops within a year, using a fuzzy program with the objective of increasing utilization of land, labor, production and profits
Visagie et al. (2004)	Determine farm planning strategies (crop and livestock) with a MIP that maximize the profit earned, given the level of risk selected
Jones et al. (2003)	Design a plan for planting decisions for a two period SP problem for a corn seed producer with variable yield with the objective of reducing cost
Recio et al. (2003)	Develop a farm plan that includes scheduling field tasks and analyzing investments with the objective of minimizing costs using a MIP model
Vitoriano et al. (2003)	Prepare a plan for cropping tasks with a LP, satisfying precedence and time window constraints with the objective of minimizing costs
Higgins (2002)	Schedule the roster for harvest of a sugar cane region using MIP with the objective of reducing costs in transportation and in the processing plant
Maatman et al. (2002)	Develop a SP model for planning production and consumption of a farmer for a given rainfall, with the objective of minimizing shortages
Gigler et al. (2002)	Design a DP model for planning the decisions of multi-echelons agri-chains, to satisfy demand at the minimum total chain cost
Glen and Tipper (2001)	Plan the introduction of improved cultivation systems using a MIP model for semi-subsistence farmers with the purpose of increasing discounted return
Lien and Hardaker (2001)	Analyze the farmers response to different type of subsidies in whole-farm, and their attitude towards risk through a SP with utility maximizing objective
Ekman (2000)	Determine the best combination of equipment and crop mix with the objective of maximizing revenue using a SP model
Schilizzi and Kingwell (1999)	Estimate the impact of price and yield uncertainty on the introduction of crops using SP, with the objective of maximizing expected utility of a farmer
Raju and Kumar (1999)	Plan irrigation and production tasks with a LP model to find the best compromise between net benefits, agricultural production and labor employed
Higgins et al. (1998)	Schedule harvesting and replanting operations with a LP model, considering available processing capacity with the objective of maximize net revenue
Abdulkadri and Ajibefun (1998)	Generate crop plan alternatives that are close to the optimal decisions for farmers with different objectives and using a LP model
Sumanatra and Ramirez (1997)	Develop a plan for multi-crop water allocation and intra-seasonal stochastic irrigation scheduling using DP and SDP models to maximize revenues
Lazzari and Mazzetto (1996)	Develop of a model for selecting and scheduling the machinery for a multicrop farm using search techniques for minimizing the cost
Torkamani and Hardaker (1996)	Design a utility efficient non-linear SP model used for analyzing the economic efficiency of farmers with several utility maximizing functions
Burton et al. (1996)	Determine the production policy of double cropping and crop rotations with a MOTAD objective (maximizing revenue and minimizing low returns)
Nevo et al. (1994)	Design a crop plan with an expert systems and a LP model with the objective of maximizing profits
Duffy and Taylor (1993)	Analyze long-term farm planning decisions under provisions of 1990 farm bill using a SDP model with the objective of maximizing expected present value
Kaiser et al. (1993)	Determine the potential impact of climate change using a SP model that maximizes revenue under different simulated scenarios
Dobbins et al. (1992)	Develop a LP model for planning the production, harvest, storage and marketing of crops and livestock, with the objective of maximizing revenue
Adesina and Sanders (1991)	Design a SP model applied to a sequential decision-making under weather uncertainty for selecting cereal technologies that maximize profits
Nanseki and Morooka (1991)	Evaluate economic performance of farmers using a SP model with 3 risk preferences (max utility, max probability and chance constraint)
Alocilja and Ritchie (1990)	Develop a simulation tool for maximizing profit and minimizing yield risk, by planning sowing date, fertilizer treatment and plant population
Turvey and Baker (1990)	Determine the relation of farm programs to the farmer's hedging decisions with futures and options. By using SP with utility maximizing objective
Bin Deris and Ohta (1990)	Develop a production system that minimizes machine demand in a two-stage cost minimizing application using LP and DP
Perry et al. (1989)	Design a multi-period MIP model to identify the participation in government programs and crop mix with the objective of maximizing net present value

(*continued on next page*)

Table 1 (*continued*)

Model	Main objective of the paper
Clarke (1989)	Determine the cropping pattern that maximizes the return from the farm, applied to a farm in Bangladesh using a LP model
Kaiser and Apland (1989)	Determine production and marketing plans for two crops using a SP model with the objective of maximizing profit and reduce profit deviation
Lambert and McCarl (1989)	Develop a discrete SP for selecting among marketing alternatives with the objective of maximizing revenues
Turvey et al. (1988)	Design a RP model for providing useful alternatives to the variance–covariance quadratic programming method
Tan and Fong (1988)	Determine cropping decisions for a perennial crops, with the objective of maximizing revenue with MOTAD and using a LP model
Glen (1986)	Design a plan for an integrated crop and beef production with internal production of feed stuff, using a LP model for maximizing revenue
El-Nazer and McCarl (1986)	Develop a LP model to design and determine the optimal long-run rotation of crops with the objective of maximizing revenue with risk aversion
Butterworth (1985)	Develop a MIP model for whole farm plan with crop, livestock and labor decisions with the objective of maximizing revenues
Stoecker et al. (1985)	Design of an application of LP and DP models for determining production, irrigation, drilling and water distribution decisions for maximizing revenues

representative papers for each classification. In selecting these papers we favored those that were motivated by a concrete need and offered evidence of a successful implementation.

4.1. Planning scope for ASC of non-perishable products

Table 2 presents the papers for non-perishable agri-foods organized according to the planning scope being addressed. The papers are classified as strategic (S), tactical (T) or operational (O). The fourth column of Table 2 shows whether the papers provide evidence that the described models were implemented and used (Y/Y); just applied to a case study, but not to a specific real life situation(Y/N); or not applied at all (N). As it can be observed in the table, the reported models that have been successfully applied to the planning the ASC are a minority. This same pattern has been reported in other reviews of agricultural models (Higgins et al., 2007). For this reason we highlight in our review those models that have been successfully applied to the planning of different aspects of the ASC.

The next column of Table 2 identifies the targeted user of the model. We identify this user as the decision maker (DM). The decision maker can be a farmer, external advisor, planner, or a centralized decision maker in the supply chain (SC). We define the planner as a decision maker that is in charge of a large operation, such as large farmers, cooperatives or corporations. Usually this type of planner requires more sophisticated tools and strategies than a small of medium size farmer. The reason for the inclusion of this additional classification dimension is to provide an assessment of the level of technical sophistication required for the application of the planning models, which increases from the farmer, at the lowest level, to the centralized decision maker, at the highest level of the classification.

4.1.1. Models for strategic planning in ASC of non-perishable products

In this section we discuss in more detail strategic models aimed at the ASC with a particular emphasis on those that deal with farming decisions. The papers reviewed cover a wide range of strategic decisions such as equipment selection, selection of farming technology, financial planning, design of supply networks, reservoir management, evaluation of perennial crops, and crop rotation strategies. In terms of their objective functions, these models include profit and revenue maximization, utility maximization, net present value, and cost minimization. In the remainder of this section we discuss some representative examples of these papers.

From the list of articles in Table 2, there are only a few models aimed at purely strategic decisions. For instance, Ekman (2000) presents an example of strategic planning applied to technology selection. The paper describes an SP model for selecting the best mix of equipment and tillage schedule for an individual farm with the purpose of maximizing revenue. The model uses discrete probability distributions to represent the available working days. The distributions are used to determine the optimal amount of equipment required to meet tillage schedule. The results presented indicate that deterministic models underestimate the capacity requirements for unfavorable-weather years. The main contribution of this work is the selection of machinery investment with uncertain constraints (time available for tillage) given by the stochastic nature of the weather.

Tan and Fong (1988) present an LP model to select the best crop mix for a perennial crop plantation. The objective is to maximize the revenue and to consider risky outcomes by penalizing negative returns, also known as mean absolute deviation (MOTAD). One of the main considerations in evaluating perennial crops is the determination of the multiple periods in which the model has to be evaluated, and the corresponding uncertainty in the prices of the crops. The researchers use the net present value of the mean absolute deviation to evaluate the alternative crops. An efficient frontier is developed with the different potential plans from which the decision makers can select according to their level of risk. The main contribution of this paper is the development of a methodology for making long term decisions under uncertainty.

Table 2
Planning scope and decision variables for non-perishable agricultural products

Model	Planning scope					Decision variables					
	S	T	O	A	DM	P	H	D	I	SCM	Other decisions considered
Torkamani (2005)	X	X		Y/N	Advisor	X				1	Labor and financial
Kobzar et al. (2005)		X		Y/N	Planner	X				1	Risk reduction
Apaiah and Hendrix (2005)	X	X		N	SC	X	X	X		3	Production at plant
Jiao et al. (2005)		X		Y/Y	Planner		X			1	
Biswas and Pal (2005)		X		Y/N	Advisor	X				1	
Visagie et al. (2004)	X	X		Y/N	Farmer	X				1	Livestock planning
Jones et al. (2003)		X		Y/Y	Planner	X				1	
Recio et al. (2003)		X	X	Y/Y	Advisor	X				1	Scheduling of activities
Vitoriano et al. (2003)	X	X		N	Planner	X				1	Modeling approach
Higgins (2002)			X	Y/Y	Planner		X			1	Reduce variability at plant
Maatman et al. (2002)		X		Y/Y	Advisor	X			X	1	Consumption and purchase
Gigler et al. (2002)		X		N	SC	X	X	X	X	3	
Glen and Tipper (2001)	X	X		Y/N	Advisor	X				1	Selection fallow system
Lien and Hardaker (2001)		X		N	Planner	X				1	Subsidies, labor
Ekman (2000)	X			Y/N	Farmer	X				1	Equipment investment and tilling schedule
Schilizzi and Kingwell (1999)		X		Y/N	Advisor	X				1	Crop rotations
Raju and Kumar (1999)		X		Y/N	Advisor	X				1	Planning of irrigation, labor
Higgins et al. (1998)		X	X	Y/N	Planner		X			1	Replanting decisions
Abdulkadri and Ajibefun (1998)		X		Y/N	Farmer	X				1	Generate alternative plans
Sumanatra and Ramirez (1997)		X	X	Y/N	Advisor	X				1	Irrigation scheduling
Lazzari and Mazzetto (1996)	X			Y/N	Advisor					1	Equipment sizing/scheduling
Torkamani and Hardaker (1996)		X		Y/N	Planner	X				1	Utility functions
Burton et al. (1996)	X	X		N	Advisor	X				1	Crop rotations and labor
Nevo et al. (1994)		X		N	Farmer	X				1	
Duffy and Taylor (1993)	X	X		N	Planner	X				1	Participation on program
Kaiser et al. (1993)	X	X		N	Farmer	X	X			1	Tilling schedule
Dobbins et al. (1992)		X	X	Y/Y	Advisor	X			X	1	Activities schedule
Adesina and Sanders (1991)		X		Y/N	Advisor	X				1	Purchasing and consumption
Nanseki and Morooka (1991)		X		Y/N	Planner	X				1	Labor requirements
Alocilja and Ritchie (1990)		X		Y/N	Advisor	X				1	Sowing date and fertilizer use
Turvey and Baker (1990)	X	X		Y/N	Planner	X				1	Financial and hedging
Bin Deris and Ohta (1990)			X	Y/N	Advisor	X				1	Scheduling of machines
Perry et al. (1989)	X	X		Y/N	Farmer	X				1	Program participation
Clarke (1989)		X		N	Advisor	X				1	Crop selection and rotation
Kaiser and Apland (1989)		X		Y/N	Farmer	X	X		X	1	Tillage and marketing
Lambert and McCarl (1989)		X		Y/N	Advisor			X	X	1	Utility function
Turvey et al. (1988)		X		Y/N	Advisor	X				1	
Tan and Fong (1988)	X			Y/N	Planner	X				1	Assign crops to soil type
Glen (1986)		X		Y/N	Advisor	X			X	1	Livestock decisions
El-Nazer and McCarl (1986)	X			Y/N	Advisor	X				1	Design of crop rotations
Butterworth (1985)		X		Y/N	Advisor	X				1	Livestock an labor
Stoecker et al. (1985)	X	X		Y/N	Farmer	X				1	Irrigation and aquifer

S: strategic, P: production variables/decisions, T: tactical, H: harvesting variables/decisions, O: operational, D: distribution variables/decisions, A: application of the models, I: inventory variables/decisions, DM: decision maker for which the model is designed, SCM: echelons of the supply chain.

We close this discussion about strategic modeling by describing a paper for modeling the economic benefits of irrigation development over a depleting aquifer (Stoecker et al., 1985). The problem is formulated as an LP problem that makes short term crop mix decisions (one year plan), which is combined with a DP approach that defines the long-term cropping plans by carrying over the effects of the yearly decisions. The main objective of the model is to maximize the net present value of multi-period revenue. The decision variables in the model include system variables such as crop production, drilling policy, area developed for irrigation, and water allocation. The main contribution of the model is to simultaneously determine the optimal discrete capital expenditure patterns for both single period and multi-period groundwater utilization.

4.1.2. Models for tactical planning in ASC of non-perishable products

Tactical models for non-perishable agri-foods handle short to medium term decisions in farm planning, such as cropping plans, harvesting, and planting policies. Accordingly, the papers presented in Table 2 deal with crop allocation, drilling policy, participation on government programs, water allocation, scheduling of tillage, labor requirements, harvesting, marketing, financial, and post-harvesting decisions. The objective functions of these models include traditional one-dimensional objective functions such as profit maximization, cost minimization, and production maximization. Sometimes the models also include alternative objectives such as risk reduction while increasing profit, investment hedging, and multi-objective criteria. Examples of papers dealing with tactical models that have been successfully implemented are presented next.

Jiao et al. (2005) present a harvest-scheduling model for a region in Australia with multiple independent sugar cane fields. The paper presents an LP model for determining the amount of crops to harvest along the season with the objective of increasing the amount of sugar obtained. The model also restricts the harvest decisions to assure fairness to the farmers in the region. The main contribution of the paper is the development of a statistical analysis that predicts sugar content and the integration of the statistical analysis to the optimization model. This model has been converted into a software tool, which is currently used by more than 20 growers in several regions of Australia.

A second example of a tactical model is given by the work of Maatman et al., 2002. This model helps a subsistence farmer to determine strategies for the production, consumption, selling, storing, and purchasing of crops. The problem is modeled as a two-stage SP, where the first-stage decisions involve what and how much to produce given that a certain amount of rain is observed. In the second-stage decisions (post-harvest), the farmer decides the consumption, storage, selling, and purchasing of the crop. The main objective of this model is the minimization of food shortages for the farmer and his family. The researchers claim that their approach is simple to apply; given the limited number of options and scenarios available to the farmers. They also report that the use of this model has influenced agricultural policies in Burkina Faso and allowed to test alternative production methods adapted to the characteristics of the farmers.

4.1.3. Models for operational planning in ASC of non-perishable products

Regarding the models related to operational planning (Table 2), we can observe that there are fewer papers in the area of operational planning than in the area of tactical planning. This difference may reflect the importance of tactical over operational planning for non-perishable products. Most of the operational models presented are concerned with determining harvesting plans, equipment scheduling, water allocation, and land preparation.

The work of Recio et al. (2003) is an example of the models that include tactical and operational decisions. This work embeds a mixed integer program (MIP) into a decision support systems (DSS) that provides detailed plans for farmers' activities such as crop selection, scheduling of field tasks, investment analysis, machinery selection and other aspects of the production process. The objective of the model is the minimization of the costs incurred by farmers during the cropping season. The model has been successfully used as part of extension services in Spain to provide recommendations about crops profitability.

The second example is a model that deals exclusively with operational decisions (Higgins, 2002). In this work, models are developed to deal with operational decisions for scheduling harvesting operations. The main objective of this work is to minimize the costs incurred while meeting market demand constraints. The planning problem presents two main issues, how to efficiently harvest the product, and how to reduce the operational costs at a processing plant. Other byproducts of the model include obtaining a more reliable transportation, a constant daily supply of crops; reducing capital expenditures and reducing the cost of scheduling mechanical harvesters. The author indicates that the successful application of this model resulted in significant cost savings for the sugar cane industry of Australia.

4.2. Planning decisions for ASC of non-perishable products

The second part of Table 2 presents the classification of papers for non-perishable agri-foods according to the activity of the supply chain they target. The main activities in ASC involve the planting (P), harvesting (H), storing (I), and distributing (D) crops to the customers downstream in the supply chain. This table also presents the field "SCM", which provides information about how many echelons of the supply chain are considered in the models. For example, if only the decisions of the farmer are considered, it is said that only one echelon is covered by the model. However, if decisions affecting the farmer and distributor are considered, then two supply chain echelons are being modeled. The last column of Table 2 presents succinct information on additional planning decisions addressed by the models. Examples of such decisions include financial and purchasing considerations, capacity planning, crop rotation, irrigation, and fertilizer use. In the following sections we discuss in more detail some of these models, particularly those that are used for planning the production and distribution of crops.

4.2.1. Production models of non-perishable products

From the list of models presented in Table 2, we can observe that production (P) related decisions are the most common of the models presented. Usually production decisions are related to the timing and the amount to plant of each crop, as well as to the rotation of the crops along several time periods. Most of these models are designed to plan the production from the perspective of a single participant of the supply chain, such as determining the production of a single farm.

One example of production models is the work presented by Dobbins et al. (1992). These authors evaluate crop production alternatives using an LP model. The LP model includes planting, harvesting, processing, and the storage of crops. The objective is to maximize revenues by preparing an optimal cropping plan for the year. The resources considered in the model include land, labor, machinery, and other constraints, such as processing, storage, and institutional constraints. At the time that the paper was written, the model had been successfully used for approximately 25 years, which included periodic maintenance and additions to keep up with the needs of the farmers.

A second example of production related models is given by the work of Schilizzi and Kingwell (1999). These authors investigate the impact of price and yield uncertainty in cropping decisions for a farm in Western Australia. The objective is to maximize the expected utility function of the farmers. The SP model includes decision variables such as crop rotation, crop selection, and land allocation. These decisions take into consideration constraints related to the soil type, crop rotation, available crops, expected yield, the farmer's risk attitudes and the weather patterns. Of particular importance is the effect of the weather on production, which is modeled through a set of discrete weather conditions with a corresponding probability of occurrence. The models presented include the use of farmer's specific utility functions and the modeling of weather uncertainty.

4.2.2. Production–distribution models of non-perishable products

Different functions in the ASC have been traditionally modeled independently. This is mostly due to the added complexity of developing and finding solutions for integrated multi-echelon models (Thomas and Griffin, 1996). This is particularly true when the echelons being modeled include those for production and distribution activities. Integrated models, although challenging to develop and solve, offer potential cost saving benefits. For instance, Chandra and Fisher (1994) report savings of up to 20% when integrated decision models are used. In agriculture, judging at the relative few applications that consider production and distribution decisions in the same model, this integration has also been difficult to achieve. However, while we did not find evidence that any of the models had been implemented in a real operation; the integrated models found in the literature document the potential high benefits of using such models in the planning of ASC.

An example of an integrated model is given by the work of Apaiah and Hendrix (2005). These authors designed a network model for growing, harvesting, transporting and processing a pea-based product. The supply chain modeled is divided into three phases: production (growing and harvesting), ingredient preparation (milling and concentration) and product processing. These phases are connected by transportation links using different transportation modes. The objective is to minimize the overall costs of the supply chain, which is composed of all the production and transportation activities required to obtain the final product. The problem is modeled using an LP formulation that when solved gives the amount of peas to produce at each growing location, the amount of peas to transport from the growing areas to the plants, the amount of pea concentrate to process at the plant, the quantity of concentrate to transport to the product processing facilities, and the products to process at each facility. One of the benefits of the model is that it provides an estimate of the costs involved in the operation of a new product line.

4.3. Modeling approaches in ASC of non-perishable products

The modeling approaches used in agricultural planning are presented in Table 3. These include stochastic programming (SP), linear programming (LP), dynamic programming (DP), stochastic dynamic programming (SDP), and mixed integer programming (MIP). According to the results reported in the literature, some of the approaches have been applied more successfully to the planning of ASC than others. For instance, the papers based on LP (Dobbins et al., 1992; Higgins, 2002) and SP models (Jones et al., 2003) have a good record of rendering successful applications.

The most popular modeling approach in agricultural planning has been LP. The extended use of LP models for planning agricultural activities is surprising given the high level of uncertainty present in the estimation of the parameters of the models such as yield, profit, etc. However, the popularity of LP can be explained by the simplicity of use and the flexibility of LP models to capture a large variety of decisions, such as crop scheduling, resource assignment, selection of production methods, and investment decisions (Hazell and Norton, 1986).

An example of LP modeling is provided by Vitoriano et al. (2003). This model is used to plan farm resources and to schedule the different activities required for growing the crops. The overall objective of the model is to minimize total costs. The model considers time windows, precedence and resource constraints to restrict the scheduling of production activities in the farm. The paper considers two modeling approaches, one that partitions time into discrete units, and a second one that uses a continuous time horizon. The former is preferred for short term planning horizons, while the latter is used for long planning horizons with loose time windows. For a more general perspective on the developments of LP modeling in agricultural planning the reader is referred to Hazell and Norton (1986) and Dent et al. (1986).

Some authors have modified traditional LP models to account for the uncertainty present in most farming activities. The effects of uncertainty are particularly important if farmers are risk averse, which it has been traditionally assumed in the economics literature (Hardaker et al., 1991). The modeling of uncertainty and risk attitudes in the objective function has been called risk programming. The formulation of objective functions includes the mean–variance (E–V), minimization of the total absolute deviations (MOTAD), utility maximization and other formulations. We are aware of at least two previous reviews related with RP, the first one, by Hardaker et al. (1991),

Table 3
Modeling approaches used for planning non-perishable agricultural products

Model	LP	SP	DP	SDP	MIP	Other aspects
Torkamani (2005)		X				Nonlinear SP
Kobzar et al. (2005)	X					Risk programming
Apaiah and Hendrix (2005)	X					
Jiao et al. (2005)	X					Regression analysis
Biswas and Pal (2005)						Fuzzy goal programming
Visagie et al. (2004)					X	Risk programming
Jones et al. (2003)		X				
Recio et al. (2003)					X	Decision support systems
Vitoriano et al. (2003)	X				X	
Higgins (2002)					X	Tabu search
Maatman et al. (2002)		X				
Gigler et al. (2002)			X			
Glen and Tipper (2001)	X				X	
Lien and Hardaker (2001)		X				Time series
Ekman (2000)		X				
Schilizzi and Kingwell (1999)		X				
Raju and Kumar (1999)	X					MCDM and constraint prog.
Higgins et al. (1998)	X					
Abdulkadri and Ajibefun (1998)	X					Modeling to generate alternatives
Sumanatra and Ramirez (1997)			X	X		
Lazzari and Mazzetto (1996)						Search methods
Torkamani and Hardaker (1996)		X				
Burton et al. (1996)	X					
Nevo et al. (1994)	X					Expert systems
Duffy and Taylor (1993)				X		Time series
Kaiser et al. (1993)		X				Simulation and time series
Dobbins et al. (1992)	X					
Adesina and Sanders (1991)		X				
Nanseki and Morooka (1991)		X				
Alocilja and Ritchie (1990)						Simulation
Turvey and Baker (1990)		X				Utility functions
Bin Deris and Ohta (1990)	X		X			
Perry et al. (1989)					X	
Clarke (1989)	X					
Kaiser and Apland (1989)		X				Time series and regression
Lambert and McCarl (1989)		X				Time series and regression
Turvey et al. (1988)	X					Risk programming
Tan and Fong (1988)	X					Multiple objectives and MOTAD
Glen (1986)	X		X			
El-Nazer and McCarl (1986)	X					MOTAD
Butterworth (1985)					X	
Stoecker et al. (1985)	X		X			

presents a list of programming models for farm planning under uncertainty, with particular focus on RP models. The second, by Backus et al. (1997), reviews several aspects of farm decision-making under risk, including utility functions, risk preferences and modeling approaches that have been applied in RP problems.

The quest for more realistic modeling alternatives has popularized the use of stochastic programming. Examples of the use of stochastic programming in agricultural planning include the models developed by Jones et al. (2001, 2003). The authors model the production of crops to obtain seeds for a seed-corn company, with two sequential production periods under random yields and uncertain demand. The decision variables include the amount of crops to be produced in a first period planted in spring and harvested in late summer (North America), and the production in the second period harvested in winter (South America) to satisfy an uncertain annual seed demand of the spring of the following year. The objective of the problem is to maximize the expected gross margin given the costs of production incurred and expected yields at the two-stages. The authors report that the use of the SP model and the application of the proposed planning methodology resulted in increasing the profit margins of the company by 24%.

Also popular in the agricultural planning literature is the use of DP (Stoecker et al., 1985) and SDP (Sumanatra and Ramirez, 1997). These models have traditionally been used in multi-period settings, where the decisions made in the time period being analyzed have consequences over several periods into the future. The decisions considered in the models reviewed include decisions such as irrigation planning, and the long term planning of crops (Duffy and

Taylor, 1993). The reader interested in specific details for developing DP models for agricultural problems is referred to Taylor (1993).

Additional modeling approaches in agricultural planning include the use of simulation for estimating the growth and yield of crops (Alocilja and Ritchie, 1990), fuzzy programming (Biswas and Pal, 2005), and search methods to find useful solutions (Lazzari and Mazzetto, 1996). Other tools have been used in combination with LP, SP and DP, such as time series analysis (Lien and Hardaker, 2001), utility function elicitation (Turvey and Baker, 1990), decision support systems (Recio et al., 2003) and expert systems (Nevo et al., 1994).

5. Planning models for ASC of fresh products

The second part of our review covers those papers that deal with fresh or perishable agri-foods. The complete list of reviewed models for fresh agri-foods is presented in Table 4. This table includes the main objectives of the papers and their corresponding authors. Comparing Tables 4 and 1, we can observe that there are fewer articles dealing with perishable agri-foods than with non-perishable ones. However, given the increasing economic importance of perishable agri-foods and the renewed interest on food safety, we expect that the number of papers published in this area will increase in the near future. In fact, as it can be seen in Table 4, most of the papers that focus in perishable products have been published recently. In the following sections, we will dissect these works using the same criteria presented in Section 4.

5.1. Planning scope for ASC of fresh products

Table 5 organizes the papers in terms of the planning scope of the models presented. The models in the papers can be classified into strategic (S), tactical (T), and operational (O) categories. Because of its implications for ASC planning, the table also identifies whether the model presented include a shelf life feature (SL). However, as it can be observed from Table 5 only a few papers explicitly model the shelf life of agri-foods. The fifth column of Table

Table 4
List of models for fresh agricultural products

Model	Main objective of the paper
Ferrer et al. (2008)	Determine a plan for the optimal scheduling of the harvest of wine grapes using a LP model with the objective of minimizing operational and grape quality costs
Widodo et al. (2006)	Design of a DP model to integrate production, harvest and storage of perishable items with growth and loss functions for maximizing the demand satisfied
Caixeta-Filho (2006)	Development of a LP that links chemical, biological and logistics constraints to the quality of the fruit to harvest, with objective of maximizing revenue
Kazaz (2004)	Design a two-stage SP to determine the olive trees to contract in the season for an oil producer with uncertain yield and demand, for maximizing revenue
Allen and Schuster (2004)	Determine the optimal rate of harvesting and capital investment (capacity) using a nonlinear program, to reduce losses by weather and overcapacity
Rantala (2004)	Design a production–distribution model for the supply chain of a seedlings with the objective of minimizing costs
Itoh et al. (2003)	Design a model for crop planning with uncertain values, described with fuzziness and randomness, with the objective of maximizing minimum value of revenue
Caixeta-Filho et al. (2002)	Develop a LP model for maximizing the expected gross revenue of a greenhouse by designing an appropriate marketing and planting plan
Berge ten et al. (2000)	Develop a whole farm model to compare between different farming technologies before empirical work starts. With economic and environmental goals
Darby-Dowman et al. (2000)	Design of a SP model for determining the optimal planting plans for a vegetable crop with the help of weather scenarios, with a revenue maximizing objective
Romero (2000)	Determine an efficient cropping pattern by considering the risk of the producers with a multi-objective (max revenue, min variability) model
Leutscher et al. (1999)	Design of a production model with tactical and operational decisions with the objective of increasing profitability
Stokes et al. (1997)	Develop optimal production and marketing decisions for a nursery producing ornamental plants using SDP with revenue maximizing objective
Aleotti et al. (1997)	Develop a SP model that optimizes revenue by changing the capacity of food preservation facilities and considering the uncertainties in crop markets
Miller et al. (1997)	Determine a plan for production and harvesting of a packing plant with a LP and fuzzy programs with the objective of minimizing costs
Hamer (1994)	Determine a planting and harvesting plan for fresh crops using a LP model with the objective of maximizing profits
Purcell et al. (1993)	Develop a RP decision model for landscape land production, with the objective of maximizing returns for a given level of risk aversion
van Berlo (1993)	Determine sowing, harvesting and production plans using a LP model with the objective of minimizing costs across the logistical chain
Annevelink (1992)	Determine a plan for the location of pot-plants inside a greenhouse with the objective of minimizing costs using heuristics and genetic algorithms
Saedt et al. (1991)	Develop a plan for a pot-plant greenhouse with two models, one LP for future plans and one MIP for transition plans, with the aim of maximizing revenue

Table 5
Planning scope and decision variables for fresh agricultural products

Model	Planning scope						Decision variables					
	S	T	O	SL	A	DM	P	H	D	I	SCM	Other decisions considered
Ferrer et al. (2008)		X	X	X	Y/N	Planner		X			1	Labor and routing
Widodo et al. (2006)		X	X	X	N	SC	X			X	2	
Caixeta-Filho (2006)		X			Y/N	Planner		X			2	
Kazaz (2004)		X		X	Y/N	Planner	X	X			1	Purchase from other source
Allen and Schuster (2004)	X				Y/Y	Planner	X	X			1	Capacity planning
Rantala (2004)	X	X			Y/N	SC	X		X	X	2	Open/close facilities
Itoh et al. (2003)		X			N	Farmer	X				1	
Caixeta-Filho et al. (2002)		X	X		Y/Y	Farmer	X	X			1	
Berge ten et al. (2000)	X	X			Y/N	Advisor	X				1	Technology selection
Darby-Dowman et al. (2000)		X			Y/N	Farmer	X	X			1	Capacity decisions
Romero (2000)		X			N	Planner	X				1	
Leutscher et al. (1999)		X	X		N	Farmer	X				1	Operational policies
Stokes et al. (1997)		X			Y/N	Farmer	X				1	Selling or retain
Aleotti et al. (1997)	X	X			Y/N	Farmer		X	X	X	1	Preservation technology
Miller et al. (1997)			X		Y/N	Planner		X		X	1	
Hamer (1994)		X			Y/N	Farmer	X				1	Variety selection
Purcell et al. (1993)		X			Y/N	Advisor	X				1	
van Berlo (1993)	X	X			Y/N	Farmer	X	X		X	2	Processing schedule
Annevelink (1992)			X		N	Farmer	X				1	Spatial location
Saedt et al. (1991)		X	X		Y/Y	Farmer					1	Transition planning

S: strategic, P: production variables/decisions, T: tactical, H: harvesting variables/decisions, O: operational, D: distribution variables/decisions, A: application of the models, I: inventory variables/decisions, DM: decision maker for which the model is designed, SCM: echelons of the supply chain.

5 provides information about the extent of the application of these models (A). This column shows whether the papers provide evidence that the described models were implemented and used (Y/Y); just applied to a case study, but not to a specific real life situation (Y/N); or not applied at all (N). As it can be seen from the table, only a few works are motivated and fully applied to a real operation. Finally, the sixth column of the table identifies the targeted user of the models; which we labeled as the decision maker (DM). In the subsequent subsections we dissect the models presented in Table 5 using the same criteria previously used in Section 4. We also discuss some representative examples of models for each classification criteria. In the selection of papers to discuss we favored those that had been successfully applied to solve a concrete and real problem.

5.1.1. Models for strategic planning of ASC of fresh products

The strategic models for perishable agri-foods, shown in Table 5, cover several types of decisions, such as the design of supply networks, financial planning, capacity, and technology selection. Some of the most common objective functions of these models include profit/revenue maximization and cost minimization. Most of the models identified that cover strategic decisions also include some aspects of tactical planning. In the examples presented next we discuss two models, one that covers exclusively strategic level decisions and another one that covers both strategic and tactical aspects of planning.

Allen and Schuster (2004) developed a model for calculating the capacity and rate of harvest required for the production of grapes. The objective of the model is to minimize the losses in crops, caused by weather, and to minimize overinvestment costs of installing excess capacity. A major contribution of the paper is the use of nonlinear programming to reduce the risk of uncertain weather. The benefits reported from the use of this model include $2 million in capital avoidance from harvesting equipment and improved risk assessment for the incorporation of new crop areas.

Berge ten et al. (2000) developed a model for a farm to compare the potential performance of alternative farming technologies. The objective of the model is to select those technologies that give the best tradeoff between economic and environmental goals. The authors present a case study of the methodology using a problem that is modeled as a multiple-goal linear program for planning the optimal crop rotation for flower bulb farming. The objective function of the model is to maximize farm gross margin, and to minimize the use of pesticides and fertilizers. The strategic decisions included the selection of growing technology and the tactical decisions included the selection of crop rotations.

5.1.2. Models for tactical planning of ASC of fresh products

Tactical planning models are the most popular applications for fresh ASC (Table 5). Some of the decisions presented in these models include crop scheduling, harvest planning, crop selection, and labor capacity. We now present two tactical planning models that have been implemented, and have provided significant benefits to the farmers, attesting of the potential benefits of these types of models in ASC.

The first example is the work of Caixeta-Filho et al. (2002). These authors use an LP model for planning the production of flowers in a Brazilian greenhouse. The main decision variable is the number of flowers to produce in each specific greenhouse at a particular time period. The model includes decisions for planting and harvesting in several periods of the year. Some of the constraints of the model include the amount to harvest and plant for each period. The objective of the model is to satisfy the demand of customers while maximizing revenue. The LP model is embedded in the planning software of the greenhouse company, thus giving the decision makers and supervisors the tools for planning the operations of the company. The reported benefits of using this model are additional sales and profits, with a 32% increase in the farmers' profit margin.

Another application of tactical planning to greenhouse production is provided by Saedt et al. (1991), who develop a production planning model for a pot-plant greenhouse. The model handles two types of plans, one for future production and a transition plan to move from current state of the greenhouse to one that meets the future production needs. The future and transition production plan is determined with the help of an LP model. The decisions included in the model are production scheduling, determination of labor and space needs. The benefits obtained from the implementation of this model include increasing the net profits by about 10%.

5.1.3. Models for operational planning in ASC of fresh products

In this section, we present the papers for fresh ASC that focus on short-term or operational planning. Among the operational decisions considered in these models are harvesting, scheduling of production activities, intermediate storage and packing planning. Comparing the number of operational models for perishable products shown in Table 5 with those for non-perishable commodities shown in Table 2, we can observe that there is a greater emphasis on short-term planning in the production of perishable products. The differences between the models for fresh and non-perishable crops support the idea that the operational decisions in the management of highly perishable products are extremely important. The particular characteristics of operational models for the fresh ASC are illustrated next through the description of some of the papers presented in Table 5.

Miller et al. (1997) develop two models for harvesting and packing fresh tomatoes, one using an LP formulation and a second one using a program obtained by adding fuzzy type constraints to the model. Some of the decisions included in the model are the quantity to harvest per period and the inventory to keep for the next period. The objective is to minimize the cost of operation in the harvesting and packing operations.

A second example of operational planning dealing with production scheduling in a pot-plant greenhouse is given by the work of Annevelink (1992). This model takes the information of a tactical crop mix plan, and develops an operational plan for the spatial allocation of pots in each production period. The objective of the model is to minimize costs and to increase the utilization of a greenhouse. The model is solved in an iterative way by solving tactical and operational models, with the help of heuristics such as clustering heuristics and genetic algorithms that provide good working solutions.

5.2. Planning decisions for ASC of fresh products

In the second part of Table 5, we present the different decisions variables of the models reviewed. These include production (P), harvesting (H), distribution (D), and storage (I). When comparing Tables 2 and 5, it is evident that the papers reviewed are clustered around production and harvesting decisions with distribution and storage falling behind. It is also evident from the table that few models combine these decisions, to develop production–distribution or harvesting–distribution models. Comparing Tables 2 and 5, we notice that Table 5 contains a higher number of papers dealing with harvesting decisions. This may be the result of the short shelf life of the products and the lack of mechanized equipment for harvesting these crops. Other decisions in the models include labor planning, capacity planning, spatial location, technology selection, purchase decisions, and processing schedule.

5.2.1. Production models for fresh products

Production decisions are the most popular in the models presented in Table 5. Models dealing with production planning for greenhouses are particularly prolific. Production decisions include determining the amount, mix and timing for planting each crop, and the scheduling of resources such as labor and transportation. Some of the common objectives of these models include the minimization of costs and maximization of profits subject to demand constraints.

Kazaz (2004) presents an SP model for a Turkish company producing olive oil. The company has the option of leasing the olive trees to grow the olives or to buy the olives in the open market at a higher price. The planning model consists of two-stages, where the decisions at each stage depend on the stochastic distribution of demand and the uncertain yield of the olive trees. In the first-stage the company determines the amount of trees to lease, and in the second-stage, based on the yield and the prices of olives in the open market, the company determines the amount of olive oil to produce and olives to buy from the farmers. The objective of the model is to maximize the expected profit subject to demand and the sales price of the olive oil.

van Berlo (1993) presents a model to plan and coordinate the production and supply of raw materials from the field to a processing plant. The targeted operation is a vertically integrated vegetable processing industry. The coordination is performed with the use of a linear goal programming model that satisfies several competing objectives that include the minimization of the cost of sowing, optimization of the utilization of the processing plant, and meeting the market's demand. This model considers not only the planning of activities at the farm level but also the supply of these agri-foods to a processing plant down the supply chain and the planning of production at the plant. The motivation of the model is to coordinate the production and harvest activities to meet market's demand in terms of quantity and quality.

5.2.2. Production–distribution models for fresh products

The number of models designed for supporting production–distribution decisions is still small compared to the total number of papers reviewed. We found only two examples supporting production–distribution decisions, none of which had been fully implemented. We believe that this lack of production–distribution applications will change as the industry materializes the potential benefits of including the shelf life of the products in this type of models and the other benefits that have been reported in other segments of the industry when using production–distribution planning (see Section 4.2.2).

Rantala (2004) presents an MIP model for designing the integrated production–distribution plans for the seedling supply chain of a finnish nursery company. Some of the decisions included in the model are the total number of seedlings to be produced and transported from nurseries to cooled warehouses, or transported directly to customers, or transported from warehouses to customers. The model also includes capacity constraints and capacity-related decisions. The main objective of the model is to minimize the total cost of producing and transporting the products needed to meet customers demand.

Aleotti et al. (1997) provides a second example of production–distribution models. He describes an MIP formulation for selecting the best design for the post-harvest handling of fresh vegetable crops between the harvest and the final market. The purpose of Aleotti's research is to maximize the benefits from capital investment in food-preservation facilities under conditions of uncertain production and demand. The uncertainty in the environment is modeled as an SP problem using a set of market and crop scenarios. The objective of the model is the maximization of the expected profit through the selection of the best combination of post-harvest processes.

5.2.3. Harvesting models for fresh products

The most common activities of the harvesting models reviewed included decisions related to the amount of product to harvest per period, how to transport the harvested product, how to allocate transportation equipment, and the scheduling activities of packing and processing plants.

The work by Ferrer et al. (2008) can be considered a good representative of the papers dealing with harvesting planning. This paper presents an MIP model for optimally scheduling the harvesting operations of wine grapes. The model considers the costs of harvesting activities and the loss of quality of the grapes for delaying harvesting. The decisions in this model include the amount of grapes to harvest from the different plots in each period, the routing of harvesting among plots and the number of workers to hire or lay off for each period of the harvesting season. One of the main contributions of this model is the representation of the quality loss in the objective function of the model.

A second paper dealing with a harvesting model (Caixeta-Filho, 2006) uses an LP formulation to link the pertinent chemical, biological and logistical restrictions to the quality of the fruit to be harvested. The model considers two potential objective functions, one that maximizes the number of boxes of fruit produced and another that maximizes total revenue. The second objective was considered a better objective for the case of an orange juice producer that schedules the harvest of several independent farmers. The decision variables of the model are the monthly amount of crop to harvest from a grove.

5.3. Modeling approaches in ASC for fresh products

The main modeling approaches used in the papers listed in Table 6 are LP, MIP, SP, DP and SDP. Other approaches used include growth simulation, nonlinear optimization, fuzzy programming, risk programming, goal programming and multi-objective programming. As it was the case in non-perishable agri-foods, the most popular modeling approach for fresh agri-foods, and the one with the most successful applications, is LP. We now describe some examples of the papers aimed at the planning of fresh agri-foods activities.

Hamer (1994) uses an LP model to determine the best planting and scheduling decisions to assure a steady supply of Brussels sprouts over a long planning horizon. The author assumes the demand and quality of the product is known in advance and that there exists a way to estimate the distribution of the yield for different crops. The main objective of the model is to satisfy the market demand and to maximize profit, subject to factors such as scheduling of transplanting, direct drilling, grading, packaging, seeding, land preparation, growing, and harvesting.

An extension of Hamer's model is presented by Darby-Dowman et al. (2000). The model uses the results of Hamer's model as an input for an SP model. The main contribution of this paper is the introduction of stochastic behavior and a utility function to minimize the risk incurred by the grower, resulting in a robust production plan. The decision variables for the model are the amount of land allocated to each crop, the timing of the sowing, the amount of product to harvest, sell and purchase to satisfy the demand of the customers. The yield of the products is assumed uncertain, due to the weather variability. The weather-yield relationship is formulated using 31 weather scenarios. The results from the experiment indicate that using a stochastic model rendered more robust plans than just using deterministic models.

Widodo et al. (2006) present a different approach for integrating the production, harvesting and inventory planning of flowers through the use of growth and loss func-

Table 6
Modeling approaches used for planning fresh agricultural products

Model	LP	SP	DP	SDP	MIP	Other aspects
Ferrer et al. (2008)	X				X	Relaxation heuristic
Widodo et al. (2006)			X			Growth and loss functions
Caixeta-Filho (2006)	X					
Kazaz (2004)		X				Nonlinear optimization
Allen and Schuster (2004)						Nonlinear optimization
Rantala (2004)	X				X	
Itoh et al. (2003)	X					Fuzzy programming
Caixeta-Filho et al. (2002)	X					
Berge ten et al. (2000)	X					Multi-objective programming
Darby-Dowman et al. (2000)		X				
Romero (2000)	X					Risk programming
Leutscher et al. (1999)	X					Simulation and regression
Stokes et al. (1997)				X		
Aleotti et al. (1997)		X			X	
Miller et al. (1997)	X					Fuzzy programming
Hamer (1994)	X					Decision support system
Purcell et al. (1993)	X					Risk programming
van Berlo (1993)	X					Goal programming
Annevelink (1992)	X					Genetic algorithm
Saedt et al. (1991)	X					

Table 7
Other agricultural supply chains planning models

Model	Main objective of the paper
Schepers and van Kooten (2006)	Plan the value chain of fresh fruits (producer, trader and retailer) using systems dynamics with the objective of maximizing total revenue
Higgins and Laredo (2006)	Develop an IP model for harvesting and transporting crops, together with the rationalization of railroads with the objective of minimizing total cost
Higgins et al. (2004)	Develop a framework for integrating harvesting and transportation decisions in the Australian sugar value chain to minimize costs
Higgins (1999)	Schedule harvest date and crop cycle, considering transportation and capacity restrictions using an IP model that maximizes the net revenue
Tijskens and Polderdijk (1996)	Develop a model for estimating the quality of harvested products affected by temperature, chilling injury, and different levels of initial quality
Porteus (1993b)	Plan the use of new technologies, demand management, and sensitivity analysis to improve the performance of a cranberry packing plant
Porteus (1993a)	Develop a tactical plan for capacity and staffing decisions for improving the efficiency of a cranberry packing plant using queuing models

tions. They use a DP model to deal with periodical harvests subject to periodical flowering for maximizing the level of demand coverage per period. The objective is the minimization of the loss caused by premature harvesting, and the loss from transporting and storing products at the retailer's site. The main decision variable is the amount of product to be harvested at each harvesting period.

Stokes et al. (1997) presents an SDP model for managing a nursery, with two interesting features, the consideration of after-tax profits and the uncertainty of profit. The problem is to arrive to an optimal marketing and production plan for a nursery that produces ornamental plants. The nursery considered, produces different sizes of crops. The crops increase their value with growth, but this growth also results in higher operating costs. The states of the model are the production area dedicated to each type of crop, a possible carry-over loss, and the net income obtained. The decisions include the determination of the size and the timing of the crops to sell. The risks faced by the producers include cost, and yield uncertainty. These risks are assumed to be reflected in the stochastic behavior of the prices obtained.

6. Other related models

As part of the literature review, we found other papers that although related to agricultural planning, do not directly fit the classification scheme used in this paper. Table 7 presents a list of these papers with the intention of informing the interested reader of additional contributions in the planning of ASC.

7. Conclusions

Different conclusions can be drawn from the previous review. One is that the use of integrated planning models in the ASC is still very limited. While we believe that these models would be useful in the modeling of all the agri-food products, they would be particularly useful for perishable crops. Although integrated models are inherently more complex, than those dealing with a single planning aspects, the potential benefits of these models usually outweigh the added complexity. This is particularly true in planning the coordination of production and distribution activities for large and medium size companies (Boehlje, 1999). The need for integrated models is reinforced by Perosio et al. (2001) who recognize the increasing importance of grower/shippers who are in charge of not only producing the crops but also of their distribution. The importance of these growers in the ASC is expected to expand as more retailers and processors continue to buy directly from producers, bypassing the traditional wholesalers and intermediaries (Kaufman et al., 2000). For these growers the use of integrated models to better plan their activities might represent substantial savings and increased efficiencies.

A second finding that can be drawn from the reviewed papers is that planning models dealing with perishable products very often fail to incorporate realistic stochastic, and shelf life features present in the different echelons of the supply chain. Perhaps the reason for this lack of more realistic scenarios is the added complexity of finding solutions for the resulting models. In the few cases that reality-based stochastic features were introduced into the models the results justified the added complexity of the model (Jones et al., 2003; Allen and Schuster, 2004). Most troubling is the lack of shelf life features in the majority of the models developed for planning perishables agri-foods, since these features are essential for maintaining the quality and freshness of perishable products.

We also found that there are a limited number of models dealing with operational planning. This paucity of applications is evident in the case of integrated models that aim at planning more than one aspect of the ASC. Given the thin profit margins observed by the producers, efficient operational planning could make the difference between a successful and an unprofitable operation. The relevance of operational models is even more accentuated in the case of perishable crops because of the critical impact of their limited shelf life on harvesting and transportation decisions.

Finally, judging by the numbers of published papers, we concluded that the focus of agricultural planning has been mostly on non-perishable products. However, we also detected a change in this trend since most of the papers aimed at perishable products have been developed in the last six years. Perhaps the lack of research on perishable products was due to the perceived less importance of these crops over the traditional or program crops such wheat, corn and cotton. However, there is a new reality since the current markets for fresh products are very dynamic and even evolving faster than traditional crops (Huang and Sophia, 2004). The ever increasing demand of consumers for healthy products and the more stringent regulations in the handling of fresh products will undoubtedly create the need for improving the current supply chain planning practices. Judging from the publication trends, we believe that this need is already being reflected in the papers reviewed and we expect that the research activity in the area will increase significantly in the near future.

8. Identification of gaps in the literature and call for research

In closing, we would like to give an assessment of the gaps in the existing literature on planning models of the ASC. In order to identify these gaps we take two different approaches. The first approach is to compare and contrast the existing research and research trends in planning models for ASC to those related planning activities within the manufacturing supply chains, a sector considerably more research-mature than that of ASC. The second approach is to assess the future needs of the industry based on projecting the current trends of the industry into the future.

Regarding the first approach, we believe that the state of the art in models for planning ASC are still lagging behind the research aimed at some manufacturing supply chains, such as electronics and automotive manufacturing. Researchers in manufacturing supply chains are currently developing models for designing supply chain networks for local and international markets (Goetschalckx et al., 2002; Meixell and Gargeya, 2005), coordinating the activities of companies in the supply chain (Sarmiento and Nagi, 1999; Thomas and Griffin, 1996), planning transportation operations and developing information management systems (Stadler and Kilger, 2005; Helo and Szekely, 2005). Of particular relevance is the research on supply chain coordination, which identifies the activities and polices to be pursued by the different supply chain participants to obtain the maximum benefit of the entire supply chain (Kouvelis et al., 2006; Chen and Paulraj, 2004). Evidence of these coordination-needs in ASC, is the development of programs such as efficient consumer response and other supply chain coordination initiatives that have been championed by retailers. Among the preferred tools for supply chain coordination, has been the use of contracts, which includes policies for buying, selling, delivering, and pricing of products. Similar contracting arrangements have also been gaining popularity in ASC, but still there is a need to research their design and effects for the particular characteristics of the agricultural markets (MacDonald et al., 2004). Other areas of expertise in manufacturing supply chains are internal logistics, which include the activities within a single firm that are necessary for the efficient flow of services and goods (CLM, 2006). An evident gap is the lack of models applied to the distribution of perishable products, such as those developed in the inventory literature (Goyal and Giri, 2001).

Regarding the identification of future needs based on industry trends, we can mention the industry consolidation and the vertical integration of the supply chains. The consolidation of the agri-food industry has evolved from the need for economies of scale, strategic positioning, risk management and market control (Boehlje, 1999). On the other hand, vertical integration has been motivated by a host of technological, regulatory and financial reasons, in addition to changes in consumer preferences, such as increased quality and product safety (Hobbs and Young, 2000). These trends have motivated new initiatives in ASC, such as traceability, quality certifications, food safety, and quick response just to name a few of the latest developments in the industry (Bourlakis and Weightman, 2004). Some of these trends and efforts sometimes are lumped together under the term "Agroindustrialization of Operations." This indicates that there are now more similarities between manufacturing supply chains and ASC than ever before (Reardon and Barret, 2000). In response to these challenges some potential innovations can be identified. For instance, we believe that there is a need for models that include more realistic features, such as uncertain information, logistics integration, risk modeling, regulatory environment, quality and security of products. In particular, we have identified the need for stochastic models for the tactical planning of perishable and non-perishable agri-foods. Stochastic models can be used to plan the production of crops, and to make these plans robust to uncertainty. We envision the extension of these models to incorporate other risk reduction alternatives, such as the use of contracts, financial and real options as diversification strategies. Such models can aid the growers to make more holistic decisions, in terms of risk and expected revenues. Although some of these risk reduction issues have been modeled in the past, they have not considered market, production, distribution and the uncertainty of the models' parameters.

Other potential contributions include operational models which integrate production and distribution decisions. The need for such logistical models has promoted the emergence of the field of "Agribusiness Logistics", which studies the impact of logistical issues in ASC (Biere, 2001). The importance of Agricultural Logistics issues is particularly evident in the case of perishable products where the limited shelf life of the product requires a very careful planning of the transportation and inventory decisions to reduce the deterioration of the products and preserve their value. In our opinion, there is a particularly a conspicuous lack of adequate models for planning operational decisions for production/harvest and distribution for perishable crops. The development of these models is an immediate need not only for the benefit of industry but also for the benefit of the final consumer.

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References

Abdulkadri, A., Ajibefun, I.A., 1998. Developing alternative farm plans for cropping systems decision-making. Agricultural Systems 56 (4), 431–442.

Adesina, A.A., Sanders, J.H., 1991. Peasant farmer behavior and cereal technologies: Stochastic programming analysis in Niger. Agricultural Economics 5, 21–38.

Aleotti, L.O., Araujo, R., Yahya, R., 1997. Selection of postharvest technology routes by mixed-integer linear programming. International Journal of Production Economics 49, 85–90.

Allen, S.J., Schuster, E.W., 2004. Controlling the risk for an agricultural harvest. Manufacturing & Service Operations Management 6 (3), 225–236.

Alocilja, E.C., Ritchie, J.T., 1990. The application of SIMOPT2: Rice to evaluate profit and yield-risk in upland-rice production. Agricultural Systems 33, 315–326.

Annevelink, E., 1992. Operational planning in horticulture: Optimal space allocation in pot-plant nurseries using heuristic techniques. Journal of Agricultural Engineering Research 51, 167–177.

Apaiah, R.K., Hendrix, E.M.T., 2005. Design of supply chain network for a pea-based novel protein foods. Journal of Food Engineering 70, 383–391.

Aramyan, C., Ondersteijn, O., van Kooten, O., Lansink, A.O., 2006. Performance indicators in agri-food production chains. In: Quantifying the Agri-Food Supply Chain. Springer, Netherlands (Chapter 5), pp. 49–66.

Backus, G.B.C., Eidman, V.R., Dijkhuizen, A.A., 1997. Farm decision under risk and uncertainty. Netherlands Journal of Agricultural Science 45, 307–328.

Beamon, B.M., 1998. Supply chain design and analysis: Models and methods. International Journal of Production Economics 55, 281–294.

Berge ten, H.F.M., van Ittersum, M.K., Rossing, W.A.H., van de Ven, G.W.J., Schans, J., van de Sanden, P.A.C.M., 2000. Farming options for the Netherlands explored by multi-objective modeling. European Journal of Agronomy 13, 263–277.

Biere, A., 2001. Agribusiness Logistics: An Emerging Field in Agribusiness Education, International Food and Agribusiness Management Association, Agribusiness Forum and Symposium, Sydney, Australia, <http://www.ifama.org/conferences/2001Conference/Papers/Area%20I/Biere_Arlo.PDF>.

Bin Deris, S., Ohta, H., 1990. A machine-scheduling model for large-scale rice production in Malaysia. Journal of the Operational Research Society 41 (8), 713–723.

Biswas, A., Pal, B.B., 2005. Application of fuzzy goal programming technique to land use planning in agricultural systems. Omega 33, 391–398.

Boehlje, M., 1999. Structural changes in the agricultural industries: How do we measure, analyze and understand them? American Journal of Agricultural Economics 81 (5), 108–1041.

Boehlje, M., Fulton, J., Gray, A., Nilsson, T., 2003. Strategic Issues in the Changing Agricultural Industry, Purdue University, Department of Agricultural Economics, CES-341.

Bourlakis, M.A., Weightman, P.W.H., 2004. Food Supply Chain Management. Blackwell Publishing, Oxford, UK.

Burton, R.O., Crisostomo, M.F., Berends, P.T., Kelley, K.W., Buller, O.H., 1996. Risk/return analysis of double-cropping and alternative crop rotations with and without government programs. Review of Agricultural Economics 18, 681–696.

Butterworth, K., 1985. Practical application of linear/integer programming in agriculture. Journal of the Operational Research Society 36 (2), 99–107.

Caixeta-Filho, J.V., van Swaay-Neto, J.M., Wagemaker, A.P., 2002. Optimization of the production planning and trade of lily flowers at Jan de Wit Company. Interfaces 32 (1), 35–46.

Caixeta-Filho, J.V., 2006. Orange harvesting scheduling management: A case study. Journal of the Operational Research Society 57 (6), 637–642.

Chandra, P., Fisher, M.L., 1994. Coordination of production and distribution planning. European Journal of Operational Research 72, 503–517.

Chen, I.J., Paulraj, A., 2004. Understanding supply chain management; critical research and theoretical framework. International Journal of Production Research 42 (1), 131–163.

Chopra, S., Meindl, P., 2003. Supply Chain Management: Strategy, Planning and Operation. Pearson Education, Inc., Upper Saddle River, New Jersey.

Christopher, M., 2005. Logistics and Supply Chain Management. Prentice Hall, London.

Clarke, H.R., 1989. Combinatorial aspects of cropping pattern selection in agriculture. European Journal of Operational Research 40, 70–77.

Council of Logistics Management (CLM), 2006. <http://www.clm1.org>, Consulted on November.

Darby-Dowman, K., Barker, S., Audsley, E., Parsons, D., 2000. A two-stage stochastic programming robust planting plans in horticulture. Journal of the Operational Research Society 51, 83–89.

Dent, J.B., Harrison, S.R., Woodford, K.B., 1986. Farm Planning with Linear Programming: Concept and Practice. Butterworths.

Dobbins, C.L., Preckel, P.V., Han, Y., Doster, D.H., 1992. An application of linear programming to planning crop systems. In: Proceedings of fourth International Conference on computers in Agricultural Extension Programs, January 28–31, Orlando, FL.

Duffy, P.A., Taylor, C.R., 1993. Long-term planning on a corn-soybean farm: A dynamic programming analysis. Agricultural Systems 42, 57–71.

Ekman, S., 2000. Tillage system selection: A mathematical programming model incorporating weather variability. Journal of Agricultural Engineering Research 77 (3), 267–276.

El-Nazer, T., McCarl, B.A., 1986. The choice of crop rotation: A modeling approach and case study. American Journal of Agricultural Economics, 127–136.

Epperson, J.E., Estes, E.A., 1999. Fruit and vegetable supply-chain management, innovations, and competitiveness: Cooperative Regional Research Project S-222. Journal of Food Distribution 30, 38–43.

Fleischmann, B., Meyr, H., Wagner, M., 2005. Advanced planning. In: Supply Chain Management and Advanced Planning: Concepts Models, Software and Case Studies. Springer, Berlin, Germany (Chapter 4).

Ferrer, J.C., MacCawley, A., Maturana, S., Toloza, S., Vera, J., 2008. An optimization approach for scheduling wine grape harvest operations. International Journal of Production Economics 112 (2), 985–999.

Glen, J.J., 1986. A linear programming model for an integrated crop and intensive beef production enterprise. Journal of the Operational Research Society 37 (5), 487–494.

Glen, J.J., 1987. Mathematical-models in farm-planning – a survey. Operations Research 35 (5), 641–666.

Glen, J.J., Tipper, R., 2001. A mathematical programming model for improvement planning in a semi-subsistence farm. Agricultural Systems 70, 295–317.

Gigler, J.K., Hendrix, E.M.T., Heesen, R.A., van den Hazelkamp, V.G.W., Meerdink, G., 2002. On optimization of agri chains by dynamic programming. European Journal of Operational Research 139, 613–625.

Goetschalckx, M., Vidal, C.J., Dogan, K., 2002. modeling and design of global logistics systems: A review of integrated strategic and tactical models and design algorithms. European Journal of Operational Research 143, 1–18.

Goyal, S.K., Giri, B.C., 2001. Recent trends in modeling of deteriorating inventory. European Journal Of Operational Research 134 (1), 1–16.

Hamer, P.J.C., 1994. A decision support system for the provision of planting plans for Brussels sprouts. Computers and Electronics in Agriculture 11, 97–115.

Hardaker, J., Pendey, S., Patten, L., 1991. Farm planning under uncertainty: A review of alternative programming models. Review of Marketing and Agricultural Economics 59 (1), 9–22.

Hayashi, K., 2000. Multicriteria analysis for agricultural resource management: A critical survey and future perspectives. European Journal of Operational Research 122, 486–500.

Hazell, P.B.R., Norton, R.D., 1986. Mathematical Programming for Economic Analysis in Agriculture. Macmillan Publishing Company, New York, NY.

Helo, P., Szekely, B., 2005. Logistics information systems: An analysis of software solutions for supply chain co-ordination. Industrial Management & Data systems 105, 5.

Higgins, A.J., 1999. Optimizing cane supply decisions within a sugar mill region. Journal of Scheduling 2, 229–244.

Higgins, A.J., 2002. Australian sugar mills optimize harvester roster to improve production. Interfaces 32 (3), 15–26.

Higgins, A.J., Laredo, L.A., 2006. Improving harvesting and transport planning within a sugar value chain. Journal of the operational Research society 57, 367–376.

Higgins, A.J., Muchow, R.C., Rudd, A.V., Ford, A.W., 1998. Optimising harvest date in sugar production: A case study for the Mossman mill region in Australia. Field Crops Research 57, 153–162.

Higgins, A., Thorburn, P., Archer, A., Jakku, E., 2007. Opportunities for value chain research in sugar industries. Agricultural Systems 94, 611–621.

Higgins, A., Antony, G., Sandell, G., Davies, I., Prestwidge, D., Andrew, B., 2004. A framework for integrating a complex harvesting and transport system for sugar production. Agricultural Systems 82, 99–115.

Hobbs, J.E., Young, L.M., 2000. Closer vertical co-ordination in agri-food supply chains: A conceptual framework and some preliminary evidence. Supply Chain Management 5 (3), 131–142.

Huang, Sophia W., 2004. Global Trade Patterns in Fruits and Vegetables, United States Department of Agriculture, Agriculture and Trade Report No. WRS-04-06.

Itoh, T., Hiroaki, I., Teruaki, N., 2003. A model of crop planning under uncertainty in agricultural management. International Journal of Production Economics 81–82, 555–558.

Jiao, Z., Higgins, A.J., Prestwidge, D.B., 2005. An integrated statistical and optimization approach to increasing sugar production within a mill region. Computers and Electronics in Agriculture 48, 170–181.

Jones, P.C., Lowe, T.J., Traub, R., 2001. Matching supply and demand: The value of a second chance in producing seed corn. Review of Agricultural Economics 24 (1), 222–238.

Jones, P.C., Lowe, T.J., Traub, R., 2003. Managing the seed-corn supply chain at Sygenta. Interfaces 33 (1), 80–90.

Kader, A.A. (Eds.), 2001. Postharvest Technology of Horticultural Crops, University of California Division of Agriculture and Natural Resources, Publication 3311, pp. 5–30.

Kaiser, H.M., Apland, J., 1989. DSSP: A model of production and marketing decisions on a Midwestern crop farm. North Central Journal of Agricultural Economics 11 (1), 105–115.

Kaiser, H.M., Riha, S.J., Wilks, D.S., Rossiter, D.G., Sampath, R., 1993. A farm-level analysis of economic and agronomic impacts of gradual climate warming. American Journal of Agricultural Economics 75, 387–398.

Kaufman, P., Handy, C., McLaughlin, E.W., Park, K., Green, G.M., 2000. Understanding the dynamics of produce markets: Consumption and consolidation grow. US Department of Agriculture-Economic Research Service, Market and Trade Economics Division, Agricultural Information Bulletin No. 758, August.

Kazaz, B., 2004. Production planning under yield and demand uncertainty with yield-dependent cost and price. Manufacturing & Service Operations Management 6 (3), 209–224.

Kinsey, J.D., 2001. The new food economy: Consumers, farms, pharms and science. American Journal of Agricultural Economics 83 (5), 1113–1130.

Kobzar, O.A., van Asseldonk, M.A.P.M., Huirne, R.B.M., 2005. Whole-farm planning under risk: Application of alternative risk programming techniques to support portfolio-decisions in Dutch agriculture. In: Agricultural Economics Society Annual Conference, University of Nottingham, England.

Kouvelis, P., Chambers, C., Wang, H., 2006. Supply chain management research and production and operations management: Review, trends, and opportunities. Production and Operations Management 15 (3), 449–469.

Lambert, D.K., McCarl, B.A., 1989. Sequential modeling of white wheat marketing strategies. North Central Journal of Agricultural Economics 11 (2), 157–169.

Lazzari, M., Mazzetto, F., 1996. A PC model for selecting multicropping farm machinery system. Computers and Electronics in Agriculture 14, 43–59.

Leutscher, K.J., Renkema, J.A., Challa, H., 1999. Modeling operational adaptations of tactical production plans on pot plan nurseries: A simulation approach. Agricultural Systems 59, 67–78.

Lien, G., Hardaker, J.B., 2001. Whole farm planning under uncertainty: Impacts of subsidy scheme and utility function on portfolio choice in Norwegian agriculture. European Review of Agricultural Economics 28 (1), 17–36.

Lowe, T.J., Preckel, P.V., 2004. Decision technologies for agribusiness problems: A brief review of selected literature and a call for research. Manufacturing & Service Operations Management 6 (3), 201–208.

Lucas, M.T., Chhajed, D., 2004. Applications of location analysis in agriculture: A survey. Journal of the Operational Research Society 55, 561–578.

Maatman, A., Schweigman, C., Ruijs, A., van der Vlerk, M.H., 2002. Modeling farmer's response to uncertain rain fall in Burkina Faso: A stochastic programming approach. Operations Research 50 (3), 399–414.

MacDonald, J., Perry, J., Ahearn, M., Banker, D., Chambers, W., Dimitri, C., Key, N., Nelson, K., Southard, L., 2004. Contracts, Markets, and Prices: Organizing the Production and Use of Agricultural Commodities, United States. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 837.

Marcelis, L.F.M., Heuvelink, E., Goudriaan, J., 1998. Modelling biomass production and yield of horticultural crops: A review. Scientia Horticultusrae 74, 83–111.

McCarl, B.A., Nuthall, P., 1982. Linear-programming for repeated use in the analysis of agricultural systems. Agricultural Systems 8 (1), 17–39.

McLaughlin, E.W., Green, G.M., Park, K., 1999. Changing Distribution Patterns in the US Fresh Produce Industry: Mid/Late-70s to Mid/Late-90s, Department of Agricultural, Resource, and Managerial Economics, Cornell University, Ithaca, NY 14853, June.

Meixell, M.J., Gargeya, V.B., 2005. Global supply chain design: A literature review and critique. Transportation Research Part E 41, 531–550.

Miller, W.A., Leung, L.C., Azhar, T.M., Sargent, S., 1997. Production planning for fresh tomato packing. International Journal of Production Economics 53, 227–238.

Min, H., Zhou, G., 2002. Supply chain modeling: Past, present and future. Computers & Industrial Engineering 43, 231–249.

Nanseki, T., Morooka, Y., 1991. Risk preference and optimal crop combinations in upland Java, Indonesia: An application of stochastic programming. Agricultural Economics 5, 39–58.

Nevo, A., Oad, R., Podmore, T., 1994. An integrated expert system for optimal crop planning. Agricultural Systems 45, 73–92.

Perosio, D.J., McLaughlin, E.W., Cuellar, S., Park, K., 2001. Supply chain management in the produce industry. Produce Marketing Association, Newark, Delaware, 22–32.

Perry, G.M., McCarl, B.A., Rister, M.E., Richardson, J.W., 1989. Modeling government program participation decisions at the farm level. American Journal of Agricultural Economics 71 (4), 1011–1020.

Porteus, E.L., 1993a. Case analysis: Analyses of the national cranberry cooperative – 1. Tactical options. Interfaces 23 (4), 21–39.

Porteus, E.L., 1993b. Case analysis: Analyses of the national cranberry cooperative – 2. Environmental changes and implementation. Interfaces 23 (6), 81–92.

Purcell, D.L., Turner, S.C., Houston, J., Hall, C., 1993. A portfolio approach to landscape plant production and marketing. Journal of Agriculture and Applied Economics 25 (2), 13–26.

Raju, K.S., Kumar, D.N., 1999. Multicriterion decision-making in irrigation planning. Agricultural Systems 62, 117–129.

Rantala, J., 2004. Optimizing the supply chain strategy of a multi-unit finish nursery. Silva Fennica 38 (2), 203–215.

Reardon, T., Barret, C.B., 2000. Agroindustrialization, globalization, and international development: An overview of issues, patterns, and determinants. Agricultural Economics 23, 195–205.

Recio, B., Rubio, F., Criado, J.A., 2003. A decision support system for farm planning using AgriSupport II. Decision Support Systems 36 (2), 189–203.

Romero, C., 2000. Risk programming for agricultural resource allocation. Annals of Operation Research 94, 57–68.

Saedt, A.P.H., Hendriks, T.H.B., Smits, F.M., 1991. A transition planning method applied in a decision support system for pot-plant nurseries. European Journal of Operations Research 52, 142–154.

Salin, V., 1998. Information technology in agri-food supply chains. International Food and Agribusiness Management Review 1 (3), 329–334.

Sarmiento, A.M., Nagi, R., 1999. A review of integrated analysis of production–distribution systems. IIE Transactions 31, 1061–1074.

Schilizzi, S.G.M., Kingwell, R.S., 1999. Effects of climatic and price uncertainty on the value of legume crops in a Mediterranean-type environment. Agricultural Systems 60, 55–69.

Schepers, H., van Kooten, O., 2006. Profitability of 'ready-to-eat' strategies: Towards model assisted negotiation in a fresh-produce chain. In: Quantifying the Agri-Food Supply Chain. Springer, Netherlands (Chapter 9).

Simchi-Levi, D., 2003. Designing and Managing the Supply Chain: Concepts, Strategies, and Case Studies. McGraw-Hill, New York, NY.

Stadler, H., 2005. Supply chain management and advanced planning-basics, overview and challenges. European Journal of Operational Research 163, 575–588.

Stadler, H., Kilger, C., 2005. Supply Chain Management and Advanced Planning: Concepts Models, Software and Case Studies. Springer, Berlin, Germany.

Stoecker, A.L., Seidmann, A., Lloyd, G.S., 1985. A linear dynamic programming approach to irrigation system management with depleting groundwater. Management Science 31 (4), 422.

Stokes, J., Mjelde, J., Hall, C., 1997. Optimal marketing of nursery crops from container-based production systems. American Journal of Agricultural Economics 79, 235–245.

Sumanatra, J., Ramirez, J.A., 1997. Optimal stochastic multi-crop seasonal and intraseasonal irrigation control. Journal of Water Resources Planning and Management 123 (1), 39–48.

Tan, L.P., Fong, C.O., 1988. Determination of the crop mix of a rubber and oil palm plantation – a programming approach. European Journal of Operations Research 34, 362–371.

Taylor, C.R. (Ed.), 1993. Applications of Dynamic Programming to Agricultural Decision Problems. Westview Press, Boulder, CO.

Thomas, D.J., Griffin, P.M., 1996. Coordinated supply chain management. European Journal of Operations Research 94, 1–15.

Tijskens, L.M.M., Polderdijk, J.J., 1996. A generic model for keeping quality of vegetable produce during storage and distribution. Agricultural Systems 51 (4), 431–452.

Torkamani, J., Hardaker, J.B., 1996. A study of economic efficiency of Iranian farmers in Ramjerd district: An application of stochastic programming. Agricultural Economics 14, 73–83.

Torkamani, J., 2005. Using whole-farm modeling approach to assess prospective technologies under uncertainty. Agricultural Systems, 138–154.

Turvey, C.G., Driver, H.C., Baker, T.G., 1988. Systematic and nonsystematic risk in farm portfolio selection. American Journal Agricultural Economics 70 (4), 831–835.

Turvey, C.G., Baker, T.G., 1990. A farm-level financial analysis of farmer's use of futures and options under alternative farm programs. American Journal of Agricultural Economics, 946–957.

United States Department of Agriculture (USDA), 2007. Fruits and Vegetables (farm weight): Per Capita Availability, 1970–2005, http://www.ers.usda.gov/Data/FoodConsumption/spreadsheets/fruitveg.xls.

van Berlo, M. Jules, 1993. A decision support tool for the vegetable processing industry; an integrative approach of market, industry and agriculture. Agricultural Systems 43, 91–109.

van der Vorst, J.G.A.J., 2006. Product traceability in food-supply chains. Acreditation and Quality Assurance 11, 33–37.

van Ittersum, M.K., Leffelaar, P.A., van Keulen, H., Kropff, M.J., Bastiaans, L., Goudriaan, J., 2003. On approaches and applications of the Wageningen crop models. European Journal of Agronomy 18, 201–234.

Vidal, C.J., Goetschalckx, M., 1997. Strategic production–distribution models: A critical review with emphasis on global supply chain models. European Journal of Operational Research 98, 1–18.

Visagie, S.E., de Kock, H.C., Ghebretsadik, A.H., 2004. Optimising an integrated crop-livestock farm using risk programming. Operations Research Society of South Africa 20 (1), 29–54.

Vitoriano, B., Ortuño, M.T., Recio, B., Rubio, F., Alonso-Ayuso, A., 2003. Two alternative models for farm management: Discrete versus continuous time horizon. European Journal of Operational Research 114, 613–628.

Widodo, K.H., Nagasawa, H., Morizawa, K., Ota, M., 2006. A periodical flowering-harvesting model for delivering agricultural fresh products. European Journal of Operational Research 170, 24–43.