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An expert system for predicting orchard yield and fruit quality and its impact on the Persian lime supply chain

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ABSTRACT

In recent years academics and industrials have shown an interest in agricultural systems and their complex and non-linear nature, aiming to improve production yield in the agricultural field. Innovative strategies and methodological frameworks are thus required to assist farmers in decision making for an efficient and effective resource management. In particular, this research concerns the structural problem of the Persian lime supply chain in Mexico, which still leads to low production yield over short time periods with heterogeneous fruit quality and also to the emergence of excessive middleman businesses arising from a fragmentation between orchard and exporting companies that constitute the first two links in the associated supply chain. Based on the Persian lime production cycle, an Expert System (ES) using Fuzzy Logic involving an inference engine with IF—THEN type rules is presented in this paper. A Mamdani model codifies the decision criteria related to agricultural practices for growing Persian lime in non-irrigated orchards. The ES allows the farmer to boost production in orchards by modeling application scenarios for agricultural practices. A case study based on an exporting company's fruit supply is discussed, in which the ES proves to be a useful tool to aid the decision making involved in the application of agricultural practices in the orchard. Results show an increase in production yield and fruit quality in the orchard, as well as a better synchronization between orchard and exporting companies, with a significant impact on inventory levels of fresh fruit in the link Persian lime exporting company.

1. Introduction

Mexican citrus fruit production is generally characterized by a low implementation of technology and good agricultural practices, which is partly related to low production yield and low fruit quality in non-irrigated orchards with an average yield of 14 t per hectare (t/ha), against 21 to 35 t/ha reported by the ten countries with highest productivity (FAO, 2009). The fresh fruit supply chain of Persian lime involves four stakeholders: (i) the growers of Persian lime; (ii) the companies that are dedicated either to fresh-fruit treatment or to juice-extracting for the post-harvest treatment of citrus fruit; (iii) the trading companies that put the product on the market and (iv) finally, the retailers who deliver the product to the final customer in a national or export market. A typical issue of this kind of supply chains in Mexican citrus fruit production concerns the exporting company's difficulty to supply Persian limes that meets market requirements both quantitatively and qualitatively; this explains the key role of farmers in the fresh fruit supply chain, since they are responsible for effectively managing the production process and fruit transport from the orchard to the fresh fruit exporting company.

The first link in the Persian lime supply chain is the citrus fruit cultivation area, consisting of several farmers who supply fresh fruit to the exporting companies. Two production systems can be distinguished either non-irrigated orchards (NIO) or irrigated orchards (IO). Farmers on NIOs basically apply agricultural practices and rely on mechanical equipment for their maintenance while IOs have irrigation systems, allowing higher production yield than on the same planting area in a non-irrigated orchard. In both production systems, chemical products are used and agricultural practices are implemented to increase production and improve fruit quality, which is classified according to two criteria for export, i.e. fruit size and color. Persian lime for export markets such as United States (USA), European Union (EU) and

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Japan (J) is packaged in boxes of 10, 20, and 40 lbs, all of which requiring the correct size and amount of limes per box. For this reason, suitable application of agricultural practices is significant considering how the producing orchard is the key supplier in the Persian lime supply chain, producing fruit with the right quality characteristics demanded by the exporting companies. In each production system, Persian lime production has three growth stages: Flowering, Fruit Set and Fruit growth. Flowering plays a critical role in the plant's reproductive cycle. Fruit Set refers to the process when a flower is set as a fruit. Finally, Fruit Growth is the phase when the fruit is harvested. The Flowering phase produces a production yield expressed in flower weight, which is significant in the next stage, Fruit Set, and is at the same time expected to produce fruit yield when eventually the ripened fruit is harvested. In every stage diverse agricultural practices and uncertain events determine yield for each growth stage, whether yield is maintained or reduced. Production dynamics emphasizes the importance of evaluating each development stage in the orchard as to estimate the production yield. The production yield and fruit quality of a production orchard can be uncertain, resulting in speculations about supply from the first to the second link of the Persian lime supply chain, which not only slows down the flow of fruit along the chain but also makes the chain more expensive due to factors beyond the orchard's production system such as middleman businesses or massive purchases of fruit, leading Persian lime exporters to stockpile fruit and generate high fresh-fruit inventories in the warehouse. The uncertainty of fruit supply has forced members of the first and second link of the supply chain to start looking for alternatives that increase productivity of producing orchards attempting to ensure a permanent supply and respond to customer's orders. Orchard production yield is closely related to the producer's economic profitability, so low productivity in the first link affects the supply chain in two ways: first, it has an impact on the producer as it reduces his harvesting profits, and second, it affects the second link, the exporting company, in a way that the company is now faced with the important challenge of ensuring supply and fruit quality demanded by the market.

In this context, this research is focused on Persian lime production in a non-irrigated orchard. The underlying idea is that the improvement of the orchard the management and of harvesting profits will allow for a better synchronization between the first two links of the supply chain, i.e. production in the orchard and citrus fruit exporting company. Improving this synchronization has the benefit that it reduces the economic consequences generated by the inventory of fresh fruit in the second link—exporting company. The article is organized as follows: Section 2 presents a literature review focused on the complex issue of agricultural supply chains. It presents various studies that have contributed to the concept of supply and to the improvement of the supply chain synchronization. Section 3 is a brief introduction to the Fuzzy Sets Theory and is dedicated to the Expert System design developed in this study with its validation process. In Section 4, a case study describes the effect on Persian lime supply chain synchronization between the first and the second link. Section 5 describes user perceptions concerning the expert system. Finally, Section 6 summarizes the main results of this study and suggests some perspectives.

2. Literature review and work position

Several studies have indicated that logistics systems ensure a continuous and uniform supply, and they can incur a high percentage of global production costs (Iannoni and Morabito, 2006), especially when perishable products are involved. In that case, the fresh products have to progress quickly through the supply chain and the time needed to use inventory as a buffer against demand variability is highly uncertain and short. Because of the need for an effective management of the agricultural supply chain, industrials and academics have become interested in collaborating even more closely with the stakeholders of the supply-chain. Taylor (2006) studies a series of agro-food chains, and concludes that demand variability of the final customer is found in all the analyzed chains. In some cases, the variability is the result of natural causes, such as seasonal consumption patterns or short-term fluctuation. In other cases, promotional activity is what creates significant uncertainty. The analysis of demand characteristics along the agro-food chains demonstrates a propensity for misalignment of demand and business activity rates due to issues such as demand amplification or production policies determined by factors other than demand, as for example lot size policy or variability in the supply of an agricultural product from its origin of production. In this respect, Bacarin et al. (2004) present a collaborative model for agricultural supply chains that supports negotiation, renegotiation, coordination and documentation mechanisms adapted to situations found in this kind of supply chain such as return flows. The model is supported by an architecture where chain elements are mapped to Web Services and their dynamics to service orchestration. Aiming to improve the coordination of the supply chain, Burer et al. (2008) and Carrillo et al. (2012), suggest optimization models based on negotiation, operating and operations strategies for each one of the agricultural supply-chain members. Canavari et al. (2010) examined how traceability is related to competitiveness in a fruit company. The authors support a hypothesis that states that traceability can be seen as a possible resource of the organization as a part of the information management in the supply chain. The article demonstrates that not only strategic, but also operative choices determine the way buyers and sellers along with chain members manage a single supply network. On the one hand, the authors highlight that traceability systems involve constraints of different kinds: economic, technological, available resources, legislation, laws and regulations – both external and internal – within the organization's area of competence. On the other hand, Coronado (2012) presents an association model for an agricultural products supply chain that describes different steps for implementing an association model between customer/supplier companies. The model seeks to establish an association level suitable for a relationship with suppliers, but not supplier selection. The model integrates fifteen companies' most valuable association experiences in customer/supplier relationships. It involves a process of aligning expectations and determines which level of cooperation is more productive. Ahumada et al. (2012) present a stochastic tactical planning model for the production and distribution of fresh agricultural products. The model incorporates the uncertainties encountered in the fresh product industry when developing growing and distribution plans due to the variability of weather and demand. The main motivation is to make tools available for producers to develop robust growing plans, while allowing flexibility to choose among different levels of exposure to risk. Catalá et al. (2013) present a strategic planning model for optimal restructuring of a pome (pears and apples) production farm concerning varieties and planting densities. The model decides the optimal investment policy for a given farm, maximizing the net present value of business while dynamically deciding its planting structure along a given time horizon under different financial scenarios. The model constraints impose restrictions on the activities to take into account risks and cultural practices. The mathematical model corresponds to a mixed integer linear programming problem, where integer decisions are related to the minimum reconversion land unit and funding requirements. As an approach towards coordinating the relationship between production and transformation, some investigations (González et al.,