Sweet cherries from the end of the world:

Options and constraints for fruit production systems in South Patagonia, Argentina

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Sweet cherries from the end of the world:

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PREFACE

Defending a PhD thesis is the last step in a long process of which the actual start is difficult to determine. I feel that start lays with my first visit to Wageningen, when I followed the International Course on Vegetable Production at the International Agricultural Centre, in 1999. I assisted to that course thanks to the institutional support of my superiors at INTA-EEA Santa Cruz, Héctor Espina and Eduardo Quargnolo, and with financial assistance through a fellowship from NUFFIC. During that training period in Wageningen, I decided to try to continue with an MSc and the generous recommendation letter of the coordinator of the course, Martien Beek, had probably some effect to obtaining another fellowship from NUFFIC to do so. One year later, in 2000, I started the MSc program in Production Ecology and one of the many friends that I made during that time was Santiago Dogliotti, an Uruguayan PhD student that was in the last phase of his program. The discussions with him on interests and approaches made me to decide following two modules of QUASI (Quantitative Analysis of Agro-ecosystems) course. That was the opportunity to meet Nico de Ridder and to propose him the idea of preparing a PhD thesis on development of the cherry sector in Patagonia. Nico suggested discussing the "proto-idea" with Herman van Keulen. Herman accepted to be my future promotor and Nico assumed a role as my co-promotor (later Pablo Peri joined us as Argentinean supervisor), and in just a few weeks, while finishing my MSc thesis (with Peter Leffelaar and Jan Goudriaan as supervisors), we developed a pre-proposal that was submitted to the sandwich-PhD fellowship program of the Wageningen University. The fellowship was initially awarded, but its formalization was delayed for several months, until I was notified that there were changes in the available budget, the number of fellowships was drastically reduced, and finally I was not among the selected candidates. Herman and Nico, Peter Leffelaar, as education coordinator, and Ken Giller, as chairman of the chair group Plant Production Systems (PPS), strongly appealed against the decision, and finally the fellowship was officially (re)awarded. Without their action, I would never have started the PhD program that I am finishing now. That support (institutional and financial) did not stop at that initial phase of the program, and I acknowledge Ken Giller for the financial support (complementing the sandwich fellowship) by PPS also during the last part of my PhD program, taking into consideration my personal situation. By then, my family expanded from two to four individuals, causing all sort of additional logistic and financial problems!

Once the PhD program started, many people contributed to the research and helped me in different ways, both at INTA and Wageningen. At INTA, I thank the Director of the *Estación Experimental Agropecuaria Chubut*, Rubén Micci, and the

Director of *Regional Patagonia Sur*, Carlos Paz, who allowed me in 2002 to start working in the group *Fruticultura* under a contract. That created the opportunity to meet people that helped me by sharing their knowledge and data, and by teaching me many practical issues of cherry growing. My acknowledgement in that regard goes to Belén Pugh, Francisco Onofre and Eduardo Pugh. Also private advisors, like Walter Dominguez, Juan Carlos Pujó and Claudia Mundet, were always open to share their experience and provide me field information. Many growers directly participated in and contributed to several aspects of the research by allowing me to conduct the experiments on their commercial farms. My thanks for that to Alejandro Catalano, Leopoldo Montes, Francisco Eylenstein, Oscar Collman and Norma Vitale, and also to all those that allowed to visit freely their farms to learn about their cherry production systems.

The discussions with my local supervisor Pablo Peri were very fruitful to set up the structure of the different chapters and to increase my self-criticism. Nico de Ridder, my Dutch supervisor, not only corrected my proposals and manuscripts, and took care of my academic training, but also was always ready to help in administrative, financial and personal matters. The effort he made for inter-integration of “his” students, inviting us to cook in his house, is an extra (not minor) reason for acknowledgement. Thanks also to his wife Rita, always happy to receive us. Herman van Keulen, my promotor, broke any possible paradigm with regard to formalities between a professor and a student. With him I deepened my capacity to criticize concepts and texts. After receiving back my first manuscripts “completely red”, I supposed that with time, his corrections would have been less dramatic arriving at the last chapters of my thesis. I was completely wrong! With Pablo, Nico and Herman, we developed a team capable to work in a very pleasant and motivating atmosphere, in which the discussions were open and the critics were always constructive. Thank all three of you very much!

Without the support of Marcel Lubbers and Frits Claassen, the chapter on farm-level optimization would have taken a much longer time and the result would not have been of the same quality. Thanks for your patience to teach me!

In the different parts of the research, many other colleagues, growers and assistants participated as co-authors, supplied information, provided personal communications or assisted in discussions. My acknowledgement to Javier Evans, Eduardo Estremador, Federico Perry, Nelson Hughes, Alejandro Curzel, Roberto Torres, César Iwan, Matías Martínez, Martín Cerviño, Sandra Jara, Verónica Jara, Gustavo Buono, Fernando Manavella, Diego Bertoli, Liliana San Martino, Rosa Kofalt, Erica Colombani, César Sanz, Sandra Szlápelis, Antonio Pascale, Miriam Muñoz, Miguel Cárcamo, Norma Kikuchi, Ariel Ñancucheo, Rubén Astorquizaga,

Dolores Raffo, Enrique Sánchez, Luis Iannamico, Ana Laura Torres, Ana Gómez, Federico Guerendiain, Santiago Behr and Horacio Tapia. Horacio helped me with most of the artwork of this thesis, including the cover design, which is based on a paint of my sister Silvia. Thanks also to the students that contributed directly or indirectly to this thesis: Mariana Vallés, Mariana Gigena, Wilbert van Wijk, Marieke Veltman, Marlies van Leeuwen and Richard van Oorschot.

I am very grateful for the institutional support received from INTA. Specifically, I want to thank Jorge Salomone, Rubén Micci, Carlos Paz, Rafael Castellanos and Roberto Iglesias assisting me in going through the procedures that allowed me to follow this program.

Research is impossible without assistance from the secretaries and administration personnel. Among many others, my special thanks to Rosana Minor, Inés Battro, María del Carmen Gatti, Vilma Jones, Andrés Navarro, Mario Romero, Víctor Andrada, Juan Llancamán, Pablo Caimi, Pablo and Adrián Marchese, and David Humphrays, all at INTA, and to Ria van Dijk, Charlotte Schilt and Gijsbertje Berkhout at PPS. Also thanks to Antonio Valente, Dorethe Kuijpers and the others from TUPEA for their help. My gratitude goes also to Claudius van de Vijver, coordinator of the C.T. de Wit Graduate School PE&RC, for his openness and flexibility to fit an education plan in a sandwich program, something that is not always easy.

The time in Wageningen would not have been so nice without the many friends I made during the different periods that I spent there: Maylin Ramirez, Jorge Pereda, Karely, Peter Asibey Bonsu, Morestaff Chibanda, Grettel Amador and Rodolfo Yglesias, José Treviño, Ximena Chavez Espinoza, Alejandra Mora Vallejo, Olavo, Marineide, Paola and Natalia, Anneke Polderdijk, Florence van Houtte, Hana Abi Tarabay, Giorgos Kritsotakis, Santiago Dogliotti and Gabriela, Ernesto Bastidas and Manon, Patricio Parra, Lucas Seghezzo, Adriana Álvarez, Mateo and Natalia, Mariana Rufino, Erwin Kalis, Robin and Ivan, Tatiana and Aart, Kazbek Toleubayev, Marcos Malosetti and Roxina Soler, Carola Cortés, Adriana Salcedo and Benoit Gorguet, Jaime Luján Zilbermann and Mariana Wongtschowsky, Luis Jarrín, Santiago López Ridaura and Rebeca, Daniela Chavez, Assefa Abegaz, and Pablo Tittonell and Simone. I also had a very nice time with my student mates in Haarweg. Besides Pablo, also Fernando Funes, Bongani Ncube, Shibu Muhammed Ebrahim, Senthilkumar Kalimuthu, Chrispen Murungweni, Mai van Trinh and Benjamin Kibor.

Finally, I want to thank my family. First my father Julio, not physically present to enjoy this moment, but I still feel his unconditional support and motivating advices in the professional arena, mixing his double role of father and colleague. To my mother, Catalina, who thought me the importance of perseverance towards attaining a goal with her life example. My special thanks go to my children, Adriano and Micaela, just because existing, which is motivating enough…, and to Gabriela, my unconditional partner.

Contents

1

General introduction

CHARACTERIZATION OF PATAGONIA

Argentina is a large country (2,791,810 km^2), with a relatively low population density (40 million inhabitants). Patagonia is the southern (Fig. 1) and least populated region, covering 28.2% of the total area with 4.5% of the population (1.9 inhabitants km^{-2}) (Naumann, 1999). The region is environmentally heterogeneous with abundant natural resources and a large variety of ecosystems (DHV Swedforest, 1998), in which the semi-desert climate is dominant.

Patagonian climate

Information on climatic conditions in Patagonia is scarce, due to lack of an active and well-distributed network of meteorological stations (DHV Swedforest, 1998). The climate can be characterised as temperate or cold-temperate, however, with average temperatures of the coldest month rarely below 0 °C. However, absolute minimum values are below –20 °C in the Southern half, at higher latitudes, and close to the Andes in the West. The annual amplitude of mean monthly temperatures varies between 16 °C in the centre-North of Río Negro Province and 5 °C in the extreme South of the region (Paruelo *et al*., 1998).

Rainfall is not strictly seasonal (Laya, 1981), but a high proportion of total rainfall falls in winter, and generally in small events (Soriano, 1992). The difference between humid and dry years depends on the number of events exceeding 10 mm. The

Fig 1. Location of the Patagonian provinces (grey area) of Argentina. From North to South: Neuquén, Río Negro, Chubut, Santa Cruz and Tierra del Fuego.

N-S Andes mountain range presents an orographic barrier for the humid masses of air coming from the Pacific Ocean. These masses of air heat up and loose most of their water as they move through the Andes and into the continent. In Chubut province, the gradient in annual rainfall with distance to the Andes is 7 mm km^{-1} for the first 60 km (Paruelo *et al*., 1998). Therefore, Patagonia can be divided in two sectors: the Andes and the plateau (Coronato and Bisigato, 1998).

The Patagonian plateau is characterised as arid, with annual rainfall below 500 mm (and mostly below 200 mm) (León *et al.*, 1998; Naumann, 1999), concentrated in winter and early spring (May to August) (León *et al.*, 1998).

Between 65 and 75% of the wind direction observations are from West-Southwest. In the centre-West of Chubut the speed is between 15 and 22 km h^{-1}, with maximum values between September and January and minimum values in winter. The winds coming from the West and those of polar origin both are characterized by low humidity (Beltrán, 1997).

The valleys of the plateau

The Patagonian plateau is characterised by a severe precipitation deficit, defined as the difference between annual rainfall and annual potential evapotranspiration (Naumann, 1999), and therefore agricultural development has been limited mostly to extensive sheep ranching, with wool for export as the main product. This sector flourished since the beginning of the European colonisation of inland Patagonia at the end of the 19^{th} century (DHV Swedforest, 1998; Golluscio e*t al*., 1998). However, inappropriate management (continuous grazing of large fields at fixed stocking rates) resulting in rangeland degradation, accompanied by the fall in international prices of wool since the 1970's, forced many farms to close, or at least drastically reduce livestock numbers. The combination of rangeland degradation and the unfavourable economic context made animal husbandry non-sustainable in large areas of Patagonia (Golluscio *et al*., 1998).

The valleys, cutting the plateau from West to East, represent just a small fraction of the area, but the cities are concentrated in these valleys and they have a great impact on regional agriculture, thanks to the possibility of using irrigation. In the main irrigated valleys (some with good levels of infrastructure and services), agriculture is generally limited to semi-intensive activities, such as grazing of pastures by sheep and beef cattle, and alfalfa cultivation (sold as hay for winter feeding to the sheep farms of the steppe); in addition, crops like wheat and potato are cultivated, as well as fruit orchards and vegetables.

Generally, the irrigation period is from October to April, coinciding with the lowest water levels of the rivers, so that not all available water can be utilised. To increase water extraction, it is necessary to build dams, at high costs and with strong environmental impacts, requiring studies on the side-effects of their construction (DHV Swedforest, 1998). Water is distributed through vast canal networks, and crops are gravitationally irrigated by furrow or flood irrigation, requiring carefully levelled fields, realized at considerable investments. Water rights belong to the state, which may entrust distribution control to cooperative irrigation companies. Water costs vary among valleys, but it is relatively inexpensive, as more water is available than can be applied to the available levelled land (Ferrari Bono, 1990).

The glacial and alluvial origin of soils in the Patagonian valleys results in considerable spatial heterogeneity over small distances, a characteristic that often has not been taken into account in land use planning, resulting in land degradation. It has been estimated that about 75% of the area of valleys and swamps is heavily degraded as a result of accumulation of sodium and salt, due to limited drainage capacity. The combination of inefficient distribution through permeable canals and excess irrigation on heavy clay soils, have resulted in reduced water table depths and increased salt contents, in some cases to levels that preclude further cultivation (Ravetta and Soriano, 1998).

SEARCH FOR ALTERNATIVE PRODUCTION SYSTEMS

Golluscio *et al*. (1998) have suggested that the declining sustainability of traditional animal husbandry in large areas of Patagonia is the central problem. The coming decades offer challenges for land managers, land planners and researchers (Aguiar and Sala, 1998). There is a need for identification and development of new, more profitable, crop(ping system)s, with better market opportunities, and to expand the area of irrigated cropping systems. To be successful, such crops must be competitive in a global market. For stimulating new crops and cropping systems, optimal use should be made of the comparative advantages, either in terms of environmental conditions, to target yield and quality (Ravetta and Soriano, 1998), or in terms of market conditions.

During the last decade, both the public and private sectors have been searching for new, technologically and economically feasible alternatives, that should be also environmentally sustainable. Efforts have been made to establish new activities, allowing farmers to adapt, transform or diversify existing production systems, with varying degrees of success. In Santa Cruz, a program for garlic production was initiated, including credit provision and plant health control. A similar approach (the so-called “Productive Revolution”) was followed in Chubut with several commodities, such as tulip bulbs, garlic, fox-skin and fruit-tree production. In general, these initiatives were based on inadequate understanding of the possibilities and limitations.

Fruit production is one of the most intensive and complex production sectors, highly demanding in labour, capital, technology and management. Sweet cherry (*Prunus avium* L.) production has been identified as one of the most promising activities, on the basis of its favourable production performance in the region and the identified marketing prospects, especially for the external market. Its high demand for labour is a positive characteristic for policy makers, considering that at the end of 2006 the level of unemployment and sub-employment in Argentina was 9 and 11%, respectively (INDEC, 2007).

FRUIT-TREE PRODUCTION SYSTEMS IN SOUTH PATAGONIA

North Patagonia (Neuquén and Río Negro Provinces), and in particular the upper valley of Río Negro, is a traditional region of fruit production. Here most of the Argentinean apples and pears are produced. However, in South Patagonia (Chubut, Santa Cruz and Tierra del Fuego Provinces), its development has been rather limited. Apple and pear production had some importance in the past, but is currently restricted to supply for the regional market, as it cannot compete with the main production areas. Walnut is grown on many farms of the lower valley of Chubut River (LVCHR), but in small numbers, with low technology and oriented to self-consumption or, at most, to local markets as an occasional and complementary income. Some small experiments with peach production in Los Antiguos have faced serious pest and disease problems, illustrating the importance of technical knowledge for growers and local technicians for developing new crops. Some growers have experimented with commercially interesting plum exports to Europe, along with cherries, but in very small quantities. Growers from the LVCHR, Los Antiguos, Sarmiento and Comodoro Rivadavia have been exporting sweet cherries to Europe for some time. Concurrently, provincial organisations and INTA (*Instituto Nacional de Tecnología Agropecuaria*) have been supporting the development of this crop through applied research and extension, convinced of the possibilities for its expansion and success.

However, diversification towards other fruit-tree crops has not really started, neither does policy promote it. Different fruit crops need packing facilities and labour at different times of the season, and they have similar commercial canals and logistic knowledge requirements. Hence, even though sweet cherry seems currently the most profitable crop in the region, other fruit crops might be interesting options to increase the use efficiency of the available resources, as income complements and for spreading of risk.

SCOPE FOR FRUIT-TREE PRODUCTION SYSTEMS

Many fruit-tree productions systems are possible; these systems can be characterised on the basis of their different components such as rootstock, cultivar, training system, tree spacing, irrigation system, frost control system and pest- and disease control method. Many of the system's components are highly inter-related. Some cultivars can only be combined with specific rootstocks (compatibility) and on the other hand, some rootstocks are adapted to specific soil types. Planting density and training system (and very often irrigation system) are strongly inter-related. Rootstock-cultivar combinations can play a role in reducing the vigour of the tree and therefore allow higher planting densities.

Traditionally, standard production systems, especially of sweet cherry, were established with vigorous cultivars at wide spacing (Parnia *et al*., 1986; Lang and Ophardt, 2000), producing large trees (Ystaas, 1989; Webster and Schmidt, 1996; Meland, 1998), which, however, were difficult to harvest and started to produce late (Bargoni, 1996; Meland and Hovland, 1996). Currently, in new orchard designs, aimed at improved economic viability, tree densities are invariably higher (Tadeusz, 1992; Webster, 1998), and combined with new training systems, cultivars and dwarfing rootstocks. The general objective is to produce smaller trees that start to produce earlier and require less labour (Meland and Hovland, 1996; Meland, 1998; Webster, 1998; Lang and Ophardt, 2000). Pruning, generally, is not a solution to reduce vigour, because severe pruning (especially in winter) stimulates vegetative growth and reduces yield potential (Parnia *et al*., 1986). The most effective and permanent tool to reduce vigour is the use of dwarfing rootstocks or fully compact scion cultivars (Webster, 1998), that, however, are not always available.

A management approach to maximizing yields is to aim for maximum light interception of the trees (Meland and Hovland, 1996) and to optimise the balance between vegetative and reproductive growth. With the use of small trees at high density, the orchard comes into bearing earlier, is easier to maintain and performs better economically. Tree density and earliness of production are strongly positively correlated. This relationship changes, however, when the trees start to occupy their allotted space within the row. Due to intra-specific competition, smaller differences in yield are expected in the long run (Meland, 1998).

Fruit-tree crops are perennial and the choice of production system is made at planting, in the context of financial (and other resource) constraints and unknown future prices of inputs and outputs, and the selection of the system has implications for yield and fruit quality, and ultimately profit (Hester and Cacho, 2003).

MODEL-BASED STUDIES

Agricultural development involves the introduction of new technologies that, at least potentially, should increase production and profit (Spharim and Seligman, 1983). Today, farmers have to meet the economic, technological and environmental requirements laid down by agro-industries, consumers and/or government regulations. Policy makers and extension workers need cost-efficient tools and close links to researchers to evaluate potential strategies and activities to increase farmers' income (Bernet *et al*., 2001) in an environmentally sustainable way.

Most of the work done in the past on selection and introduction of new crops in Patagonia has not been performed systematically, nor based on clear product/market requirements. Biological criteria were neither used, although enough information might have been available to identify the processes through which environmental conditions in the region restrict crop growth and yield. Formulation of clear objectives, based on solid criteria and a precise methodology should increase the opportunities in the development of new crops for Patagonia (Ravetta and Soriano, 1998).

Analysing fruit production systems and their alternative management options experimentally is generally not feasible, because of the length of time and the extensive resources required (Meinke *et al.*, 2001) and therefore a modelling approach is an attractive alternative. Models can have a different nature, depending on their purpose and the available knowledge about the processes involved. Mechanistic or explanatory models explain system behaviour on the basis of the underlying processes. On the other hand, models based on statistics and using correlations between observed variables are empirical or descriptive. In fruit production systems studies, different types of models can be useful to increase understanding of complex processes and to differentiate relevant from secondary factors, thus helping to prioritise research questions.

Some models can be linked when outputs of one are used as inputs in another. For instance, crop growth models can yield estimates of yield and fruit quality potentials that can be incorporated as target-values in Technical Coefficient Generators (TCG). Then, results of the TCGs can subsequently be used as input in exploratory land use models.

OBJECTIVE OF THIS THESIS

The main objective of this study is to assess constraints and opportunities for fruit production systems in South Patagonia (Chubut and Santa Cruz Provinces, Argentina). Emphasis is on sweet cherry, because this is currently the most important fruit-tree crop, while at the same time many important aspects, such as yield and quality potential, and frost damage risk, are poorly understood. Other fruit-tree crops have to be analyzed as well, because, although cherry production has positive effects through generating income and job opportunities, labour demand is highly seasonal and labour supply (in quantity and at acceptable quality level) is an important restriction. Moreover, under the present mono-cropping system, facilities and machinery, knowledge on logistics and marketing channels, are under-utilized.

This situation requires an exploratory land use study, allowing identification of the development options for Patagonian farms ('window of opportunities'), subject to the limitations imposed by resource availabilities and different (conflicting) objectives. The aim of this model should be to support strategic decision-making, such as 'when to plant', 'what to plant', 'with which technology', and 'how many hectares of each activity'. Sensitivity analyses provide a means to gain insight in the robustness of the land use solutions and in the consequences of present decisions on future possibilities. Exploratory studies are highly demanding in terms of quantitative information (technical coefficients for every single activity) and therefore automation of the calculations is needed.

OUTLINE OF THIS THESIS

Chapter 2 describes the sweet cherry production systems in South Patagonia on the basis of regional statistics about their main components, cultivars and rootstocks, training systems, irrigations systems and frost control systems. A rough estimate is given of the labour demand for harvesting the crop and current use and capacity of the packing facilities are summarized. Chapter 3 discusses various fruit quality definitions and meanings in different parts of the sweet cherry chain, the main quality characteristics and indicators, and the importance of heterogeneity in consumer demands. Key aspects to improve overall fruit quality in the sweet cherry chain are indicated. In Chapter 4, a "target-tree" approach to maximize gross value of product at farm gate is described and applied to sweet cherry orchards, integrating eco-physiological principles and price-fruit quality relationships. Chapter 5 presents a method for frost damage risk assessment in different sweet cherry production areas of South Patagonia and for estimating the potential impact of frost control systems on risk reduction. Lack or poor quality of data limited validation of the method, but the approach appeared useful in identification of the variables significantly affecting risk of frost damage. In Chapter 6, the technical coefficient generator (TCG) FruPat is presented, developed for quantification of the inputs and outputs for each year of the life cycle of a large number of fruit-tree activities by combining location, fruit-crop, soil quality, training system, irrigation system and frost control system. In Chapter 7, an explorative study using linear programming is presented. OPTIFROP (OPTImum FRuit Orchards in Patagonia) is a dynamic farm model capable of allocating, throughout the time horizon of the run, production activities to different land units, while optimizing different objective functions, subject to several constraints. The analysis includes trade-off curves between objectives and evaluation of impact of changes in time of external conditions (driving variables). Chapter 8 discusses the contribution of this thesis to the understanding of yield and quality potential (and their trade-offs) in sweet cherry, to the assessment of frost damage, one of its main production risk factors, and to the possibilities for transparent discussions among different stakeholders on the consequences of current decisions for future options, when designing alternative land use systems. The importance of this thesis for the consolidation of research and extension groups in South Patagonia is also highlighted.

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Sweet cherry production in South Patagonia, Argentina

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ABSTRACT

In South Patagonia, the total sweet cherry area has increased from 176 ha in 1997 to 578 ha at the end of 2006, of which 255 ha are located in Los Antiguos (46° 19' SL; 220 m a.s.l.), 161 ha in the Lower Valley of Chubut River (LVCHR) (43° 16' SL; 30 m a.s.l.), 99 ha in Sarmiento (45° 35' SL; 270 m a.s.l.), 30 ha in Esquel (42° 55' SL; 570 m a.s.l.) and 33 ha in Comodoro Rivadavia (45° 52' SL; 50 m a.s.l.). The most common varieties are 'Lapins', 'Bing', 'Sweetheart', 'Newstar', 'Stella', 'Sunburst' and 'Van' grafted on 'Mahaleb', 'SL64', 'Pontaleb', 'Colt' and 'Mazzard'. Trees are generally drip–irrigated, and planted at high densities, using training systems such as tatura, central leader and modified vase (2700, 1100 and 1000 trees ha^{-1}, respectively). Growers in Los Antiguos are more traditional, planting mainly in vase (400 to 1000 trees ha^{-1}) or as free standing trees (280 trees ha^{-1}) and irrigating by gravity (74% of the area). Only 4.4% of the area of Los Antiguos is frost protected, as growers strongly rely on the moderating effect of lake Buenos Aires. Frost control systems are absent in Comodoro Rivadavia, because the orchards that are already in the productive phase are located next to the sea, in an area with low frost risk. The frost-protected area is 66% in Sarmiento, 35% in Esquel and 61% in LVCHR. Cherry fruits are harvested from November (LVCHR) to the end of January (Los Antiguos and Esquel), and only for picking, the labour demand during the 2006/2007 season was 190,000 hours. In that season, 11 packinghouses exported 729 Mg (45% of the total production) to Europe. Most orchards have not yet reached their mature stage and new ones are being established. Therefore, fruit volumes will continue to increase and shortage of labour and packing facilities may become a constraint.

Keywords: Varieties; Rootstocks; Training systems; Frost control; Irrigation; Labour

INTRODUCTION

The Patagonian plateau is characterized by annual rainfall between 200 and 500 mm (León *et al.*, 1998; Naumann, 1999). Between 65 and 75 % of the time the wind blows from the W–SW, with maximum speed during the cherry growing season (between September and January) and minimum in winter (Paruelo *et al.*, 1998). Mean annual temperatures vary from 8.2 °C to 13.5 °C in the different growing areas, and at all locations the chilling requirements of cherries are easily satisfied. Soil heterogeneity, characterized by a wide range in texture is an important characteristic of the Patagonian valleys where cherries are grown. The main soil limitations are sodicity and/or salinity, insufficient drainage or shallow water tables. Apart from this, agro-ecological conditions in the valleys of South Patagonia (Fig. 1) are generally favourable for fruit production and various stakeholders are interested in development of the fruit sector, especially sweet cherry, seemingly the most profitable fruit crop. Moreover, labour demands are about 2000 h ha^{-1} $year^{-1}$ (Cittadini *et al.*, 2006), making it also attractive for policy makers in a country with a high unemployment rate.

In South Patagonia, the total sweet cherry area has increased from 176 ha in 1997 to 578 ha at the end of 2006 (Fig. 2), of which 255 ha are located in Los Antiguos (46° 19' SL; 220 m a.s.l.), 161 ha in the Lower Valley of Chubut River (LVCHR) (43° 16' SL; 30 m a.s.l.) (Sanz, 2005), 99 ha in Sarmiento (45° 35' SL; 270 m a.s.l.), 30 ha in Esquel (42° 55' SL; 570 m a.s.l.) and 33 ha in Comodoro Rivadavia (45° 52' SL; 50 m a.s.l.).

ORCHARD SYSTEMS

Varieties and rootstocks

The most common varieties are 'Lapins' and 'Bing' (28.9 and 23.7% of the trees, respectively), followed by 'Sweetheart' (11.3%) 'Newstar' (7.7%), 'Stella' (6.8%), 'Sunburst' (5.3%) and 'Van' (4.8%) (Fig. 3-A). During the nineties, variety selection was based on self-compatibility, but also on quality aspects explaining the importance of 'Bing' (a self-sterile variety, but with very good fruit quality) in all zones. Rootstocks are much less diverse and their selection was based on nursery convenience, rather than on growers' preferences. The most common rootstock is 'Mahaleb' (57.7% of the trees), followed by 'SL64' (20.2%) 'Pontaleb' (12.1%), 'Colt' (4.5%) and 'Mazzard' (3.0%) (Fig. 3-B).

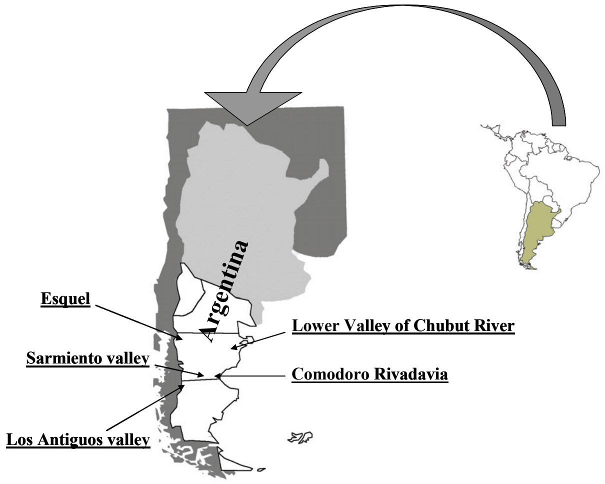

Fig. 1. Location of Patagonia (white area) and the main cherry production areas of the southern part.

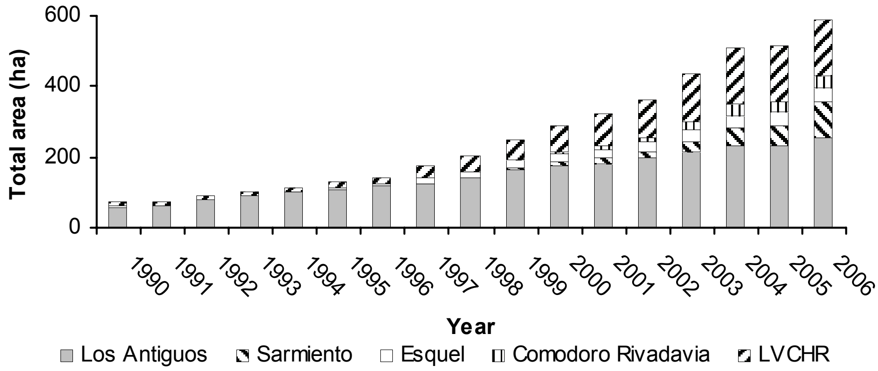

Fig. 2. Evolution of total area (ha) of sweet cherry orchards in the different production areas of South Patagonia, Argentina.

Training and irrigation systems

With the exception of those in Los Antiguos, practically all orchards are drip–irrigated and planted at high densities, using training systems such as tatura (V-shape), central leader and a modified vase (2700, 1100 and 1000 trees ha^{-1}, respectively) (Fig. 4). Growers in Los Antiguos are more traditional, training the trees mainly as traditional or modified vase (500 and 1000 trees ha^{-1}, respectively) or as free standing trees (280 trees ha^{-1}) (Muñoz, 2004) and irrigating by gravity (74% of the area). Yields of tatura systems have not yet fulfilled the expectations. Some tatura orchards have occasionally yielded 15 Mg ha^{-1} in LVCHR, but inconsistently. The reason could be the excessive

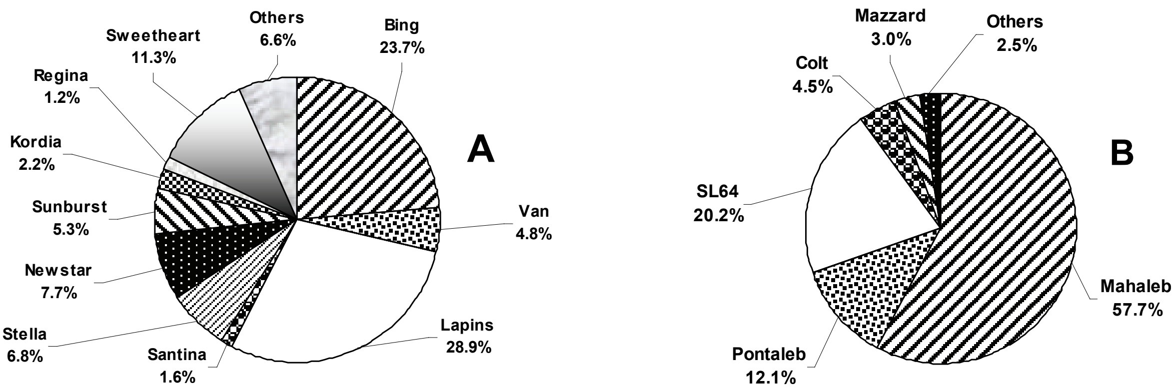

Fig. 3. Variety (A) and rootstock (B) distribution of sweet cherry trees (% of total number of trees) in South Patagonian orchards, Argentina.

care to control vigour (summer pruning and intentionally limiting water and nutrient supply), so that leaf area index (LAI) normally does not exceed 2.5. Commercial orchards in the same valley, but trained as vase or central leader (both approximately 1000 trees ha^{-1}) have attained an average of 10 Mg ha^{-1}. In Los Antiguos mean yields of adult free standing orchards are as low as 1.8 Mg ha^{-1} and in traditional or modified vase 4.5 and 5.5 Mg ha^{-1}, respectively. The main limitations to higher yields are design defects and management problems, such as inappropriate pruning, inefficient irrigation, uncontrolled spring frosts and pollination failures.

Wind protection

Windbreak barriers against strong winds are indispensable in all Patagonian valleys to allow establishment of commercial cherry plantations, although growers not always take this into consideration when planting. Sweet cherry has been defined as a very sensitive crop with respect to wind effects. High winds negatively affects cherry production, fruit quality and pollination effectiveness, and increase fruit abortion. The critical wind speed for cherry (defined as the mean wind speed during the growing period that causes a 10% reduction in crop yield) was 1.6 m s^{-1} (Peri and Bloomberg, 2002)[1]. Dense windbreaks (porosity less than 15%) of *Populus nigra* and *Salix* spp. have been used to protect cherry orchards. However, in recently developed areas,

[1] Beltrán (1997) reported wind speed between 4.2 and 6.1 m s^{-1} in the centre-West of Chubut Province (Chapter 1).

artificial (plastic) windbreaks have been installed until tree windbreaks reach an effective protected area.

Frost control systems

Considerable variability exists in the application of frost control systems among the different zones of South Patagonia. For example, only 4.4% of the orchards' area of Los Antiguos is frost-protected (sprinkling irrigation and mobile heating machines), as growers strongly rely on the moderating effect of lake Buenos Aires. However, in reality this effect is not sufficient to avoid frost damage and up to 70% losses have been recorded in un-protected orchards (Manavella and Guerendiain, 1998). Frost control systems are absent in Comodoro Rivadavia, because orchards that are already in the productive phase are located next to the sea, an area with low frost risk. The frost-protected area is 66% in Sarmiento (sprinkling irrigation and heaters), 35% in Esquel (mobile heating machines) and 61% in LVCHR (sprinkling irrigation). In this last location, the unprotected area comprises orchards that have not reached their mature stage yet.

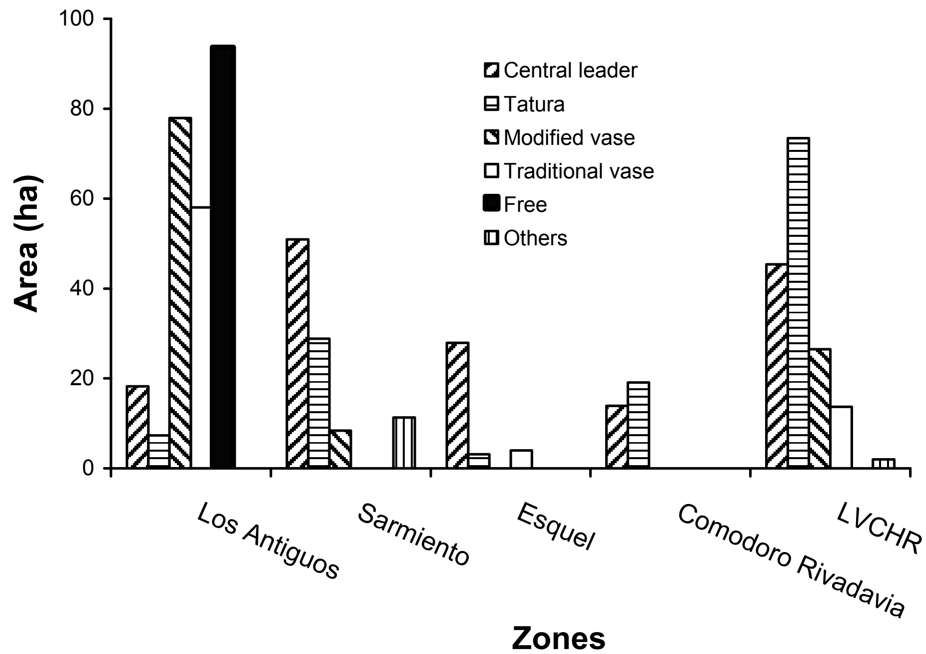

Fig. 4. Area per training system of sweet cherry orchards in the different production locations of South Patagonia, Argentina.

Table 1. Number of current packing facilities (season 2006/2007), present use and maximum processing capacity in the Lower Valley of Chubut River (LVCHR), Los Antiguos, Sarmiento, Comodoro Rivadavia and Esquel, in South Patagonia.

Production Area	Number of packing facilities	Current processing use (Mg)	Maximum[1] processing capacity (Mg)
LVCHR	5	1077	2110
Los Antiguos	2	350	1440
Sarmiento	2	52	130
Comodoro Rivadavia	1	123	200
Esquel	1	17	40
Total	11	1619	3920

[1] Working in 3 daily shifts

HARVEST AND POST-HARVEST

Cherry fruits are harvested by hand-picking from November (LVCHR) till the end of January (Los Antiguos and Esquel). The labour demand for this operation during the 2006/2007 season was approximately 190,000 hours. In that season, 11 packinghouses processed 1619 Mg (demanding another 175,000 hours of labour) and exported 45% (729 Mg) to Europe (during the 2003/2004 season 470 Mg were produced, from which 190 Mg were exported). Another 45% was sold as fresh fruit in the domestic market and 10% went to industry. All packinghouses use hydro-cooling, classification belts, grading machines and cooling rooms for storage. Their potential processing capacity (working in 3 daily shifts) is approximately 3920 Mg (Table 1). Main export destinies of the fruit have been England, Spain and other European countries. Transport always includes a cooled truck to Buenos Aires (where also the second class fruit is sold for the domestic market). From there, most fruit goes to Europe by air. However, some commercial pilots have used ship transport with promising results.

CONCLUSIONS

Sweet cherry production in South Patagonia is increasing. Potential for development of the cherry sector is high, based on a favourable climate, ample availability of land and water, and most importantly, because harvest and marketing is in “counter” season compared to the Northern Hemisphere. Most orchards have not yet reached their mature stage and new ones are being established. Therefore, fruit volumes will continue to increase and shortage of resources, specially labour, may become a constraint. The rapid growth of the cherry area can give the region an important position in the international context, but can also lead to shortage of packing facilities, labour, transport and sales capacity if not properly planned.

3

Sweet cherry quality in the horticultural production chain

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ABSTRACT

This article discusses the different quality definitions and meanings for different parts of the horticultural chain, the main quality characteristics and indicators, and the importance of heterogeneity of consumer wishes. Key aspects to improve overall fruit quality in the sweet cherry horticultural chain are indicated. Consumers do not behave uniformly and, next to consumer acceptance, other parameters have to be considered for the sweet cherry chain as a whole. The concept "quality" depends on the product itself and on the preferences of the consumer. It is often defined in terms of objective measures that relate to the consumers experience of eating quality. Cherry fruit quality is also determined by attributes that affect fruit marketing appeal and consumer satisfaction at consumption. The drivers behind the consumer's experience of eating quality may include colour, taste, texture and smell. These drivers can be assessed indirectly by measuring parameters related to this experience, such as sugar content, acid content, dry matter content, juiciness, firmness and volatiles content. These parameters change with ripening and fruit colour is the main indicator of maturity. Harvesting, handling, postharvest treatments, packaging, transport and fruit distribution involve a large number of mechanical operations that subject the produce to dynamic loads, mainly impacts, which are the main cause of pitting. To clarify the relationship between quality measurements and consumer acceptance, research on cherry quality attributes and on consumer preferences for different markets is needed. Future research should also include the effect of agricultural practices on fruit quality, using a systemic approach and considering the importance of each quality parameter on each link in the chain. The increasing interest in the nutraceutical effects of fruits and vegetables will require further specific research on sweet cherry. An integrated approach using a Quality Analysis and Critical Control Points system specifically designed for sweet cherry will require an in-depth understanding of the mechanisms affecting cherry quality throughout the horticultural chain.

Keywords: Firmness; Fruit size; Soluble solids content; Taste; Consumer acceptance; Health benefits

INTRODUCTION

The sweet cherry (*Prunus avium* L.) horticultural production chain consists of several parts: production, picking, cooling, selection, grading, packaging, transport, distribution and consumption. Quality of cherries may have a different meaning, depending on which part of the chain is considered. Consumer acceptance appears to be the most important overall characteristic of cherries (Crisosto *et al.*, 2006). However, consumers do not behave uniformly, being influenced by their cultural, historic, religious, demographic, economical and social background (Shewfelt, 2006), although Crisosto *et al.* (2003) reported that among American consumers, gender and ethnic group did not affect the decision to purchase sweet cherries. Besides consumer acceptance, other parameters have to be considered for the sweet cherry chain as a whole. For example, firmness is indispensable for reaching overseas markets (Glenn and Poovaiah, 1987; Guyer *et al.*, 1993) and regularly shaped cultivars are preferred for packinghouses because non-spherical fruits result in high percentages of under- and over-grading.

Quality of cherries is affected at each part of the chain. Management practices and decisions in the orchard can affect fruit quality at the point of sale. The choice of cultivar, for example, may limit fruit quality for the whole lifespan of the orchard. Similarly, nitrogen excess during the preharvest stage can reduce firmness and soluble solids content (SSC) (Crisosto *et al.*, 1995). Which factors affect consumer acceptance and how the different parts of the chain can help to satisfy consumer wishes are key aspects that should benefit all the participants of the chain. This article reviews the different quality definitions and meanings for different parts of the chain, the main quality characteristics and indicators, and the importance of heterogeneity of consumer wishes. An attempt is made to clarify key aspects to improve overall fruit quality in the sweet cherry horticultural chain.

QUALITY DEFINITION

Quality is an elusive concept, depending on the product itself and on the preferences of the consumer (Sloof *et al.*, 1996). Quality has many meanings, but is often defined in terms of objective measures that relate to the consumer's experience of eating quality (Walsh, 2006). Cherry fruit quality is also determined by attributes that affect fruit marketing appeal and consumer satisfaction at consumption (Predieri *et al.*, 2004). Consumers expect consistent presentation and eating quality (Peters, 1998). However, other quality dimensions should be considered, such as quality for handling, transport and storage, depending on which part of the chain is observed. For the sweet cherry chain as a whole, transport and storage quality are probably as important as eating quality, especially for overseas marketing.

Some major traits related to consumer purchase decision are based on visual appearance and include fruit size and colour, fruit and stem exterior freshness and absence of defects and injuries (Drake and Fellman, 1987). Predieri *et al.* (2004) mentioned that the most important physical properties of sweet cherries are skin colour, fruit size, fruit and stem exterior freshness, and absence of defects and injuries as the basis for consumer purchase decisions. However, theses parameters comprise only part of quality definition.

The drivers behind the consumer's experience of eating quality may include colour as a maturity indicator, taste, texture and smell. These drivers can be assessed indirectly by measuring parameters related to this experience, such as sugar content, acid content, dry matter content, juiciness, firmness and volatiles content (Walsh, 2006). Taste is largely determined by a balance between the sugar and the acid content, while aroma, which is often related to fruit overall appreciation, was not indicated by consumers as having major importance in the case of cherry (Mattheis *et al.*, 1992).

For the consumer, food safety is also, implicitly or explicitly, part of the quality definition. Because the chain involves processes, standardisation and external certifications are widely implemented in order to guarantee quality or safety. Food safety and product quality can be controlled during the production process and in the supply chain through the development and implementation of food safety and quality standards such as Euro-Retailer Produce Working Group – Good Agriculture Practices (EUREP-GAP), Hazard Analysis and Critical Control Points (HACCP), International Food Standard (IFS), British Retail Consortium (BRC) or Good Hygienic Practice (GHP) (Kosson, 2006).

QUALITY FOR GRADING, PACKING, TRANSPORT AND DISTRIBUTION

A growing demand for high quality fresh fruit and vegetables has revealed a worldwide problem concerning the mechanical damage of products that reach consumers through the distribution chain. Harvesting, handling, postharvest treatments, packaging, transport and fruit distribution involve a large number of mechanical operations that subject the produce to dynamic loads, mainly impacts (Bielza *et al.*, 2003). This aspect is especially valid for cherries, which as a result of their high sensitivity to impacts, manifests pitting (Patten *et al.*, 1983). Pitting is the development of depressions on the surface of the cherry that occurs after the fruit has been mechanically damaged, causing shearing and damage to cells in the flesh of the cherry. Pitting is a long-time problem in the fresh market cherry industry (Patten *et al.*, 1983). Many factors influence the incidence of mechanical damage in fruit handled on a grading line. This makes difficult to address damage estimation from an analytical point of view (Thompson *et al.*, 1995). The sensitivity of cherries to pitting is largely a function of fruit firmness. Firm cherries resist impact and compression pressures better than soft cherries. Unfortunately, factors governing cherry fruit firmness are not completely understood (Patten *et al.*, 1983).

Sweet cherry fruit is a very perishable commodity, because both the fruit and the stem consist largely of air and water, and the water is lost rapidly. Temperature and relative humidity (RH) of the environment are the external factors affecting the difference between fruit and atmosphere on vapour pressure (Yaman and Bayoindirli, 2002). Kupferman (1986) found that after 48 h at 10 °C, weight loss of cherries was approximately 1.5% and 3.5% at a RH of 100% and 52%, respectively. Moreover, Patterson and Kupferman (1983) reported weight loss to be four times higher on stems than on fruits. Cherries decay rapidly after harvest as a consequence of their high respiratory rate, which constitutes the main problem for successful transport and marketing (Mozetič *et al.*, 2004; Mozetič *et al.*, 2006)

CHERRY QUALITY INDICATORS

Fruit taste is related to sweetness, flavour and firmness, although these parameters change with each cultivar and may include other traits such as titratable acidity (TA) and the SSC/TA ratio (Guyer *et al.*, 1993). Fruit colour is the main indicator of maturity (Mozetič *et al.*, 2004; Usenik *et al.*, 2005) and it is important to establish the relationship between skin colour and SSC to identify the skin colour that cherries should be harvested at to ensure consumer acceptance (Crisosto *et al.*, 2002). In general, fruit weight, SSC, and SSC/TA ratio increases (Crisosto *et al.*, 1993), and firmness decreases (Mitcham *et al.*, 1998), as cherry skin colour changes from full light red to full dark red. Lack of firmness is associated to surface pitting (Toivonen *et al.*, 2004). Therefore, overripe cherries would be more sensitive to pitting.

Although Guyer *et al.* (1993) suggested that it is difficult to identify a single physical or chemical parameter to be used as an overall acceptability index for cherry cultivars, they indicate that firmness has the highest potential to be an objective overall index. Neven and Drake (2000) proposed to evaluate quality as a combination of objective (fruit and stem colours, firmness, SSC, TA) and subjective (defects such as pitting and bruising) parameters, complementing these evaluations using laboratory personnel to rate fruits and stems individually for overall appearance on a scale from 1 to 3 (1= best; 3= worst). For a specific market, time of the year and packaging type, quality could be indirectly associated with the price that the consumer is willing to pay for a product (Omeg and Omeg, 2005). In this context, another important quality parameter is the size of the cherries (Drake and Fellman, 1987). According to 2002 market summary retailers reports, fruit of 24 mm of diameter and larger had positive response from consumers (Omeg and Omeg, 2005).

Worldwide, but especially in developed countries, there is an increasing interest for food not only tasty and safe, but also producing additional health benefits. Fruits have been shown to contain high levels of antioxidant compounds, providing protection against cancer and heart diseases (Wang, 2006). Nutraceutical effects have specifically been reported for cherries (Mozetič *et al.*, 2004; 2006). The major polyphenolic groups in cherries are anthocyanins and hydroxycinnamic esters (Chaovanalikit and Wrolstad, 2004). One of the characteristic aspects of the maturation of red fruits is the change of the initial green colour to a red, violet or blackish colour, caused by accumulation of anthocyanins and chlorophyll degradation (Tudela *et al.*, 2005). Tannins and chlorogenic acid are known to affect both the flavour and astringency of fruits (Guyer *et al.*, 1993).

QUALITY FOR CONSUMER ACCEPTANCE

Consumers from different countries or regions demand different combinations of cherry quality attributes. Even within a given country or region different market segments exhibit varying preferences (Shewfelt, 2006). For example, lack or damage of the stem is usually considered as an indicator of low quality cherries. However, for some markets, stem-less cherries are marketed as a different product obtaining similar prices as cherries with stem. The commercial designation “Picota” embraces four traditional late varieties of sweet cherry (‘Ambrunés’, ‘Pico Limón’, ‘Pico Negro’ and ‘Pico Colorado’) from the Jerte valley (Spain) harvested without stems. Picotas account for approximately 60% of the cherry harvest in this production area (35,000 tonnes) (Alique *et al.*, 2005).

Appearance is a primary criterion in making purchasing decisions, with colour contributing more to the assessment of quality than any other single appearance factor (Kays, 1999). North American consumers would buy cherries based on dark skin colour: the darker the skin colour the higher the percentage of consumers that would buy them. However, fruit liking at consumption has been determined on SSC (Crisosto *et al.*, 2003). In a study conducted in Norway, it was shown that dark and large fruits were preferred (Lyngstad and Sekse, 1995). UK consumers prefer sweet, juicy, large dark full red or black cherries, with a glossy appearance (Wermund and Fearne, 2000), while in Japan, cherry colour was found to be the most important parameter for consumer acceptability (Miller *et al.*, 1986).

Visual characteristics are very important for cherry, since the consumer's decision to buy has been found to be based on fruit skin colour (full bright red for cv. 'Brooks'; mahogany for cv. 'Bing') (Crisosto *et al.*, 2003). Cliff *et al.* (1996) included seven appearance characteristics (colour intensity, colour uniformity, speckles, size, stem length, external firmness and "visual" liking) and seven flavour/texture characteristics (flesh firmness, flesh colour intensity, juiciness, sweetness, sourness, flavour intensity and "flavour/texture" liking). Uniformity of colour and fruit size have been the most useful parameters for predicting visual liking, with the first having the highest importance, whereas the best for flavour/texture liking were sweetness and flavour intensity variables.

In general, full dark red cherries have higher consumer acceptance than full bright red cherries. However, as skin colour darkens, postharvest life decreases (Crisosto *et al.*, 1993; Crisosto *et al.*, 1997). TA can also affect consumer acceptance, but only when SSC is low (Crisosto *et al.*, 2003). The ratio SSC/TA has been found to be related to the perception of sweetness, sourness or cherry flavour by trained judges (Crisosto *et al.*, 2002). High TA negatively affected consumer acceptance in the American market if SSC was below 16% and 13% for 'Brooks' and 'Bing' cherries, respectively, while consumer acceptance was high for both cultivars with SSC exceeding 16%, irrespective of TA (Crisosto *et al.*, 2003). Kappel *et al.* (1996) found that the SSC/TA ratio yielding the highest sensorial appreciation was between 1.5 and 2, with SSC being between 17 and 19%. Cliff *et al.* (1996) found that among a number of markets oriented to high quality cherries, flavour intensity and sweetness were the most important attributes for flavour/texture liking. Kappel *et al.* (1996) suggested a minimum of 15% SSC, but preferably 17–19%, and emphasised the importance of the balance between sweet and sour, in agreement with Guyer *et al.* (1993). For example, low sugar and high acid contents result in a sour taste, while low acid and high sugar contents result in a bland taste (Dolenc and Štampar, 1998).

SWEET CHERRY CHAIN: WHAT CAN BE DONE ABOUT QUALITY?

Work aimed at understanding the effect of cultural practices and the storage period on consumer acceptance levels during the maturation/ripening changes may be beneficial in developing improved cherry production and handling practices (Crisosto *et al.*, 2003). A more widespread use of sensory evaluation panels can orient production and marketing toward the identification of reliable production systems and areas, and to the selection of a reduced number of top quality cultivars in order to guarantee elevated quality levels to satisfy consumers (Predieri *et al.*, 2004). Below, an overview of factors that affect the quality of sweet cherry for the whole chain is provided.

Orchard management

Firm fruit are produced from trees with adequate vigour and good light penetration throughout the canopy. This can be arranged by yearly pruning (Patten *et al.*, 1983) and a low fruit to leaf area ratio (Patten *et al.*, 1983; Whiting and Lang, 2004). Mean fruit weight and SSC of the fruit will also be affected by the fruit to leaf area ratio (Roper *et al.*, 1987; Proebsting, 1990; Flore and Layne, 1999; Whiting and Lang, 2004). Increasing the plant density may lead to reduction in fruit size and quality, especially SSC, indicating a progressive competition between trees (Eccher and Granelli, 2006). For a specific cultivar, the fruit to leaf area ratio of the current season is the most important factor affecting fruit weight (Proebsting, 1990; Flore and Layne, 1999), while management in preceding years has a minor influence (Whiting and Lang, 2004). Leaf area per fruit itself is not important, but represents the production potential through its photosynthetic capacity, and a high value is essential for production of high-quality sweet cherries (Roper *et al.*, 1987). The shape of the tree, and therefore the training system, affects the light distribution (Cavallo *et al.*, 2001) and consequential the canopy photosynthetic rate (Proietti *et al.*, 2000). For the same leaf area per tree, a better light distribution may contribute to increased carbohydrate supply to sink organs, allowing bigger fruits. Drake and Fellman (1987) reported that the fruit weight of ‘Rainer’ varieties depended not only on maturity level but also on inter- and intra-tree fruit location, with fruit from the top and exterior of the tree crown averaging higher weight at the earlier harvest dates.

As indicated by Kappel *et al.* (1996) cultivars should be carefully chosen, especially with regard to fruit size. Irrigation and nutrition should be balanced according to demands to avoid firmness and SSC reductions (Crisosto *et al.*, 1995). Planting density and training systems allowing an even light distribution and avoiding over-cropping are key aspects to obtain high quality sweet cherries.

Harvest date

The choice of the harvest date has probably the largest impact on cherry quality and fruit colour seems to be the best indicator to decide it. Cherry fruits exhibit important biochemical and morphological changes during maturation, including increase in colour intensity and sugar content (Tudela *et al.*, 2005). Fruit colour (Mozetič *et al.*, 2004; Tudela *et al.*, 2005; Usenik *et al.*, 2005) and SSC (Mattheis *et al.*, 1992) are the main indicators of maturity. When examining the relationship between soluble solids and fruit maturation level, Guyer *et al.* (1993) found SSC increases of 15–19% over a three-week harvest period, with similar patterns in four cultivars (Hedelfingen, Ulster, Sam and Emperor Francis).

Simčič *et al.* (1998) found that sugars approach maximal values during the period of rapid colour change. The dynamics of skin colour changes might be used as a non-destructive method for determining optimal harvest date. Mitcham *et al.* (1998) also found significant relations between skin colour and SSC. However, it needs to be taken in account that maturity of fruit varies within and between trees. Fruit colour and soluble solids levels decrease with delay in flower anthesis and fruit location progressing from the top to the base of the plant (Patten *et al.*, 1986). Fruit colour can be assessed with a colorimeter or in an empirical way, in the field, with a colour chart.

Early harvest may affect not only biochemical characteristics, but also size, since it has been found that during the last two weeks of sweet cherry development, fruit total dry weight increased 3-fold (Keller and Loescher, 1989), although at a decreasing rate towards ripening.

Postharvest

The extension of the postharvest life of sweet cherry depends on three factors: (1) reduction in desiccation, (2) slowing down the physiological processes of maturation and senescence and (3) avoiding the onset and rate of microbial growth. To control these three factors, the main tools are refrigeration and controlling the RH (Yaman and Bayoindirli, 2002). The optimum temperature for harvest and handling of cherries is between 10 and 20º C (out of this temperature range more pitting is observed), while the optimum storage temperature is 0 ºC (Young and Kupferman, 1994), with a RH of 90 to 95% (Bernalte *et al.*, 1999).

Hydrocooling prolongs shelf-life more than air cooling. The positive effect of hydrocooling is probably due to the fact that cooling is faster, more even, and that the fruit are washed and can therefore be disinfected with sodium hypochlorite in the process, slowing down the decay associated with loss of quality and the development of fungal diseases (Alique *et al.*, 2005). Complementary techniques such as controlled or modified atmosphere and coatings can be used to reduce the respiration rate. The reduction of ascorbic acid loss in coated cherries was due to the low oxygen permeability of sucrose polyester coating which lowered the activity of the enzymes and prevented oxidation of ascorbic acid. The effect of low temperature significantly reduced the ascorbic acid loss (Yaman and Bayoindirli, 2002), showing that coating and refrigeration are complementary techniques.

CONCLUSIONS AND FUTURE RESEARCH ON CHERRY QUALITY

Although quality has different meanings for different stakeholders (producers, distributors, consumers, etc.) consumer acceptance seems to be the most important factor to be considered. Several parameters can be used to estimate indirectly consumer acceptance, but independent of consumer liking, firmness is a key aspect for marketing cherries overseas. Colour is related to many other parameters, such as SSC, TA and firmness, and is therefore the main tool to determine harvest date. However, there is no optimum colour for all conditions. Information at the orchard level is needed to determine which harvest colour should be used for specific markets and distribution channels. Decisions that affect productivity and fruit quality during the whole orchard life, such as the choice of the cultivar, the training system and the planting density, require an exhaustive evaluation of the current and future demands for quality standards.

Quality deterioration during classification, grading and packing can be reduced by using proper (currently available) technology, especially hydrocooling and efficiently designed grading machines. Storage and distribution need to control temperature and RH, and modified atmosphere is an important complement.

The use of systems for quality management, such as QACCP (Quality Analysis and Critical Control Points) would allow immediate discrimination between food safety aspects and quality aspects thereby enabling regulatory agencies with jurisdiction to audit for compliance with public health requirements (Peters, 1998). Developing and improving QACCP protocols for sweet cherry by linking the requirements of the protocol with the aspects that really affect cherry quality would be a benefit to all the participants of the chain, but specific research is needed to understand better how cherry quality is defined and how it can be improved.

There is a consensus with regard to consumer acceptance being the most important aspect of cherry quality and that the quality of a product is largely defined by intrinsic properties (Tijskens and Polderdijk, 1996). However, acceptance differs among consumers of different market segments and these differences have to be considered when defining optimum quality attributes. Research including physical and chemical analyses, but also consumer panels at different markets, may help to clarify this. Future research should also include the effect of agricultural practices (e.g. fertilisation, irrigation, pruning, bloom or fruit thinning, hormonal treatments, etc.) on fruit quality, using a systemic an global approach (Tijskens *et al.*, 2006) and considering the importance of each quality parameter on each link of the chain.

The increasing interest in developed countries for food producing additional health benefits suggests that nutraceutical effects of cherries will be an important direction for future research, allowing differentiating fruit to be produced under specific conditions or with regard to other competing fruit.

4

Designing a “target-tree” for maximizing gross value of product in Patagonian sweet cherry orchards

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ABSTRACT

A “target-tree” approach to maximize gross value of product (GVP; US\$ ha^{-1}) at farm gate was developed and applied to sweet cherry orchards, integrating eco-physiological information, model estimates and expert knowledge. During the 2003/04 growing season, the effect of the ratio of Fruit Number to Leaf Area (FNLAR; fruit m^{-2} LA) on Mean Fruit Weight (MFW; g fruit^{-1}) was analyzed at both spur and whole-tree level, for different combinations “training system–cultivar” (Experiment 1). During the 2004/05 season, the effect of FNLAR on MFW, soluble solids content (SSC), titratable acidity (TA) and firmness (F), was evaluated at whole-tree level in a ‘Bing’/‘Mahaleb’ orchard (Experiment 2). In Experiment 1, there were no significant interactions between training system and cultivar for the effect of FNLAR on MFW at spur and whole-tree level. No significant differences were observed between vase and tatura-trellis training systems. The R^2–values for the relationships per cultivar were higher at whole-tree level than at spur level. At both spur and whole-tree level, ‘Lapins’ had the highest Y-intercept and ’Van’ the lowest. At spur level, no differences among cultivars were detected in their sensitivity to increments in FNLAR, but at whole-tree level ‘Van’ showed less sensitivity than ‘Lapins’ and ‘Bing’. In Experiment 2, MFW, TA and SSC decreased linearly with increasing FNLAR (P<0.05). Firmness showed the same tendency, but the relationship was not significant (P=0.082). Minimum fruit quality thresholds define the suitable market for the fruit (export, domestic or industry), with their associated price ranges. In addition, in both the domestic and export markets, price depends mainly on fruit size. FNLAR determines fruit quality (and indirectly fruit price), but in combination with MFW and LAI, also yield. GVP is calculated as the product of yield and fruit price. The combination ‘Bing’/‘Mahaleb’ on vase was used to illustrate parameter estimation (LAI and FNLAR) for a “target-tree” in Patagonian orchards, using the results of Experiment 2. Under these conditions, a LAI of 3.07 is required to intercept 75% of PAR at harvest. With these parameters, and considering “price-fruit quality” relationships based on expert knowledge, maximum GVP was obtained with 80 fruit m^{-2} LA and a yield of 18.25 Mg ha^{-1}. Although this example is limited to a single combination of cultivar and training system in a specific location, the methodology can be applied to other situations, provided reliable relevant eco-physiological information is available.

Keywords: Ideotype; LAI; Fruit number to leaf area ratio; Fruit size; Fruit quality; Fruit price; Prunus avium

INTRODUCTION

In the valleys of South Patagonia (between lat. 42°S and 46°S), the total area under sweet cherry (*Prunus avium* L.) has increased from 176 ha in 1997 to 578 ha at the end of 2006. In the 2006/2007 season, 11 packinghouses processed more than 1600 tons, of which 45% was exported to Europe, 45% was sold as fresh fruit in the domestic market and 10% sold to industry. Fruit production will continue to increase, as most orchards have not yet reached their mature stage and new ones are being established, climatic conditions are favourable, land and water are amply available, and most importantly, harvest and marketing are in the winter season on the Northern Hemisphere. However, economic performance has not always been satisfactory due to low yields and/or lack of fruit quality. In commercial orchards, fruit yield and price define the gross value of product (GVP; US\$ ha^{-1}) for growers:

$$GVP = Yield \bullet P_f \qquad [1]$$

where Yield is expressed in kg of cherry fruit per hectare and P_f is the price at farm gate (US\$ kg^{-1}). Yield can be calculated as:

$$Yield = MFW \bullet FNLAR \bullet LAI \qquad [2]$$

where, MFW is mean fruit weight (kg $fruit^{-1}$); FNLAR fruit number to leaf area ratio (fruit ha^{-1} LA) and LAI leaf area index (ha ha^{-1}).

Empirical evidence indicates that low yields in Patagonian orchards can be associated with low LAI or with low fruit number, resulting in low FNLAR. LAI is the main determinant of intercepted PAR (photosynthetically active radiation), the main driver of photosynthesis (Lappi and Stenberg, 1998) and total dry matter production of crops (Patrick, 1988; Wagenmakers, 1994).

As P_f depends on fruit quality, highest GVP usually is not obtained at the highest yield due to the negative relation between yield and fruit quality. Fruit weight can be manipulated through cultivar selection, training system and management practices, such as irrigation regime, nutrient supply, etc. For a specific variety, FNLAR of the current year is the most important factor affecting inter-annual variation in fruit weight (Proebsting, 1990; Flore and Layne, 1999), while management in preceding years has a minor influence (Whiting and Lang, 2004). Leaf area (LA) per fruit itself is not important, but represents the production potential through its photosynthetic capacity, and a high value is essential for production of high-quality sweet cherries (Roper and Loescher, 1987). However, higher availability of sugars may result in higher fruit-set (Marcelis and Heuvelink, 1999), with the associated increase in FNLAR, negatively affecting MFW. Training system affects light distribution (Cavallo *et al.*, 2001) and therefore canopy photosynthetic rate (Proietti *et al.*, 2000). For the same LA per tree, a better light distribution may contribute to increased carbohydrate supply to sink organs, allowing higher MFW.

Although individual fruit weight is the main quality characteristic determining fruit price, also colour, firmness (F), soluble solids content (SSC) and titratable acidity (TA) are important quality characteristics for cherry. The relationships between FNLAR on one hand and MFW (Proebsting, 1990; Flore and Layne, 1999; Whiting and Lang, 2004), SSC (Roper and Loescher, 1987) and F (Facteau *et al.*, 1983), on the other, are negative.

Using relationships between the different quality parameters and the fruit to leaf area ratio in trees, "target trees", i.e. trees with matching LAI and FNLAR, maximizing GVP at farm gate, for different "price-fruit quality" relations can be defined. Such trees should intercept enough light to support high yields, but without excessive shading that could compromise fruit quality and future production. Management practices, i.e. that promote tree vigour (e.g. winter pruning, irrigation, N-fertilisation), weaken the tree (e.g. summer pruning) or affect fruit set (e.g. hormonal treatments, boron application, beehive density and frost protection) can then be tuned to attain orchards with target trees.

Specification of a 'target tree' can be considered conceptually equivalent to specifying the requirements of a crop ideotype in plant breeding (Donald, 1968), that has been described as 'the use of physiological approaches in crop breeding' (Sedgley, 1991), and aimed at tailoring of plants for increased production. In particular, the target tree resembles the 'market ideotype' defined by Donald (op. cit.), as 'the ideotype that is characterized by desirable characteristics at the end-point, i.c. the quality characteristics of the desired product such as bread-making quality of the grain'. To our knowledge, this approach has not been applied to perennial crops; hence the theory needs further elaboration for this purpose.

The objective of this study was to develop an integrated model ("target-tree") to maximize gross value of product at farm gate, based on experimental eco-physiological information (relationship between fruit quality and FNLAR), expert knowledge ("price-fruit quality" relationships) and estimated relationships between light interception and LAI.

MATERIALS AND METHODS

To study and quantify the relationship between FNLAR and fruit quality, two experiments were performed in a sweet cherry orchard of South Patagonia, Argentina.

Experiment 1

The first experiment was conducted at both, spur and whole-tree level (Cittadini *et al.*, in press[a]). The study was carried out during the 2003/04 growing season in two commercial orchards, one trained as tatura-trellis (1872 tree ha^{-1}) and the other as vase (966 tree ha^{-1}). Both orchards were planted in 1997 in the lower valley of the Chubut river (lat. 43°16’S; long. 65°25’W), with cultivars ‘Bing’, ‘Van’ and ‘Lapins’, grafted on the rootstock ‘Mahaleb’.

Routine horticultural care for commercial fruit production was provided, including irrigation, fertilization, wind-, weed-, pest- and disease control, and winter pruning. These growing conditions were considered optimal and were therefore not a factor in the experiment. Ten trees from each combination “training system–cultivar” were randomly selected for measurements.

From each tree, all leaves and fruits of six 2-year-old spurs were harvested. Each spur was harvested when more than 80% of the fruits on that spur attained commercial colour (no. 3 on the colour chart from the *Centre Technique Interprofessionnel des Fruits et Legumes*, CTIFL). Each spur leaf was measured with a Hewlett Packard Scan Jet 4C to the nearest 0.1 cm^2, using the “Image Tool 3.0” (UTHSCSA, 2002). All fruits per spur were weighed and counted to calculate MFW and FNLAR.

All leaves on each experimental tree were counted at fruit harvest over the maturation period (7 days for each cultivar), determined on the basis of fruit colour. Random samples of 60 leaves per tree were collected and mean area per leaf determined as described at spur level. LA per tree was calculated from the number of leaves and its mean area and used to calculate LAI for each tree on the basis of tree density. Total yield per tree was measured and MFW determined from a random sample of 50 fruits per tree. Number of fruits per tree and FNLAR were calculated from yield per tree and MFW. The sampled fruits were also used to analyze the relationship between fruit size (mm of equatorial diameter) and MFW for the three cultivars.

Interception of photosynthetically active radiation (PAR) was calculated as (Goudriaan and van Laar, 1994):

$$I_a = (1 - \rho_c) \bullet (1 - \exp(-K \bullet CLF \bullet LAI)) \bullet 100 \qquad [3]$$

where I_a is intercepted PAR (%); ρ_c a reflection coefficient set to 8% (Goudriaan and van Laar, 1994); K the light extinction coefficient, set to 0.6 (Jackson, 1980) and CLF a clustering factor (between 0 and 1) that was calculated with a sub-model (J. Goudriaan, Group Plant Production Systems, Wageningen University, *pers. comm.*) to correct for the row structure of the crop (inputs for this sub-model are LAI, height of the trees (H), and width of the crown (W) and the path (P)).

At both spur and whole-tree level, for each combination "training system–cultivar", simple linear regression analyses were performed with GenStat 6.1 (Payne, 2002), using FNLAR as independent variable and MFW as dependent variable. Equations were compared to detect differences (P<0.05) in slopes and Y-intercepts. When either training system or cultivar had no significant effect on the relationship, that factor was removed and a new analysis was performed.

Experiment 2

This experiment was performed during the 2004/05 season to study the relationship between fruit quality and FNLAR on trees of near-optimal LAI (Cittadini *et al.*, in press[b]). As during the period of reproductive growth, both, growth of individual fruits and vegetative growth can be stimulated at low FNLAR values (Grossman and DeJong, 1994; Marcelis and Heuvelink, 1999), the effect of FNLAR on mean shoot growth (MSG) and trunk cross sectional area increment (TCSAI) was also analyzed.

The study was conducted in the same commercial orchard of experiment 1, with 'Bing' trees grafted on rootstock 'Mahaleb' (966 tree ha^{-1}) and trained as vase. Based on data from the same orchard that showed a positive relationship between LAI at harvest and TCSA (cm^2) at bud-break (data not shown), a lower threshold for TCSA = 78 cm^2 was defined. Therefore, eighteen trees with TCSA > 78 cm^2 at bud-break were selected. Routine horticultural care, similar to that in Experiment 1 was provided, and therefore growing conditions can also be considered optimal.

Fruits were harvested with colour no. 4 on the CTIFL colour chart, because no. 3, as used in Experiment 1, was considered sub-optimal with regard to SSC and TA, and in this experiment, firmness was high enough to allow the 3-day delay. Weight may change over that period and therefore, the equations of the two experiments to estimate MFW have to be compared with caution. All leaves on each of the experimental trees were counted, and 1% was sampled at random. MFW was estimated from a random sample of 100 fruits per tree. Mean leaf area, LA per tree, LAI, PAR interception, total yield per tree and FNLAR were calculated as described for Experiment 1 at whole-tree level.

The fruit sample was also used to estimate F (Durofel index: 0 to 100), TA (ml NaOH) and SSC (%). F was measured non-destructively with a durometer[1], TA was measured by adding 10 ml of sample juice to 90 ml of distilled water and titrating with 0.1 N sodium hydroxide (NaOH) to the final point of pH 8.2, and SSC was measured on fruit juice with a refractometer[2].

Simple linear regression analyses were performed with GenStat 6.1 (Payne, 2002), using FNLAR (fruit m^{-2} LA) as independent variable and MFW (g $fruit^{-1}$), TA (ml NaOH), SSC (%), SSC/TA, F (Durofel index), MSG (cm) and TCSAI (cm^2) as dependent variables, to detect significant relationships (P<0.05).

RESULTS AND DISCUSION

Experiment 1

MFW as a function of FNLAR did not show interactions (P>0.05) between training system and cultivar, neither at spur nor whole-tree level. Significant differences (P>0.05) were neither found between vase and tatura-trellis training system at either level (data not shown). Therefore, training system was not considered in the further analyses.

In contrast, at spur level, 'Lapins' showed the highest and 'Van' the lowest Y-intercept value, but the rate of decrease in MFW with increasing FNLAR was the same for the three cultivars (Table 1).

At whole-tree level, mean LAI of individual trees was 2.5 (standard deviation: 0.9), with an estimated PAR interception (Eq. [3]) of 69%. Multiple regression analysis, using LAI of individual trees and FNLAR as explanatory variables, showed no significant effect of LAI on mean fruit weight (P=0.863, data not shown). For all three cultivars, MFW decreased with increasing FNLAR (Fig. 1). Coefficients of determination for the relationship between MFW and FNLAR were higher at this level than at spur level (Table 1). 'Lapins' had the highest Y-intercept and 'Van' the lowest, as at spur level. In contrast to the results at spur level, the slope of the MFW-FNLAR relation was smaller for 'Van' than for 'Lapins' and 'Bing'. The relationship between

[1] Durofel 25® (COPA-TECHNOLOGY S.A., France)
[2] Atago®

Table 1. Statistical analysis of the models describing mean fruit weight (MFW) as a function of the ratio of number of fruits per leaf area (FNLAR) at spur and whole-tree level, for the cultivars 'Lapins', 'Bing' and 'Van'.

Cultivar	Y-intercept (MFW, g $fruit^{-1}$)	Slope (MFW/FNLAR, (g $fruit^{-1}$)/(fruit m^{-2} LA))	R^2
Spur level			
Lapins	10.12^a (0.21)	- 0.0060^a (0.0008)	0.25
Bing	8.30^b (0.24)	- 0.0041^a (0.0010)	0.27
Van	6.72^c (0.21)	- 0.0028^a (0.0006)	0.26
Whole-tree level			
Lapins	10.43^a (0.23)	- 0.0192^a (0.0020)	0.77
Bing	9.20^b (0.36)	- 0.0213^a (0.0042)	0.89
Van	7.72^c (0.35)	- 0.0108^b (0.0022)	0.66

Note: different letters within a single column indicate significant differences (P<0.05) between cultivars. Values between brackets are standard errors of estimates.

fruit size (equatorial diameter in mm) and MFW did not vary among cultivars:

$$\text{Size} = 15.94 + 1.18\ \text{MFW}\ (R^2 = 0.96) \qquad [4]$$

As under similar growing conditions, cultivar was the main factor affecting the relationship between MFW and FNLAR, cultivar differentiation is needed in predicting fruit weight (Proebsting, 1990). In contrast, training system did not affect this relationship. However, the results of this study refer to trees of relatively low LAI (average = 2.5) and information at higher LAI values is needed to validate the functions found here. The lack of differences between training systems at relatively low LAI is explainable, since in that situation training system has little effect on light distribution. Supplementary observations and analyses in the current experiment also showed no effects of training system or cultivar on other quality parameters (Cittadini *et al.*, 2004a; b). However, firmness was significantly correlated to MFW (Firmness = 79.5 – 1.43 • MFW; P=0.005) (Cittadini *et al.*, 2004a), titratable acidity was correlated to both MFW and FNLAR (Titratable acidity = 16.64 – 0.00993 • FNLAR – 0.644 • MFW; P=0.004) and no significant relationship (P>0.05) was found for explaining soluble solids content (Cittadini *et al.*, 2004b). The variance in fruit weight (FWV) was positively correlated to MFW:

$$FWV = MFW \cdot 0.236 - 0.716 \ (R^2 = 0.30) \quad [5]$$

The results at both spur and whole-tree level showed a negative linear relationship between MFW and FNLAR, indicating increasing source limitation as FNLAR increased, supporting results reported by Roper and Loescher (1987) and Whiting and Lang (2004). Most studies on the effect of FNLAR on fruit weight refer to isolated spurs or branches (Facteau *et al.*, 1983; Loescher *et al.*, 1985; Roper and Loescher, 1987). Facteau *et al.* (1983) observed strong effects at spur level when they were isolated by girdling, but no (or much weaker) effects on non-girdled spurs. Loescher *et al.* (1985) reported that on isolated spurs with 3 to 5 fruits per spur, the fruits were smaller, matured later, and had less colour than on adjacent non-isolated spurs. Such differences were not observed with less than 3 fruits per spur. These results suggest that when fruit set is high, at least some of the carbohydrates for fruit growth must come from other sources, because the photosynthetic capacity of spur leaves is insufficient to support potential sweet cherry growth (Roper and Loescher, 1987). In our study, results at whole-tree level were more consistent than at spur level. At spur level, the regression analysis between MFW and FNLAR only explained between 25 and 27% of the variability. As spurs were not isolated, these results strongly suggest that fruits of a spur were not only supplied by leaves on that spur, but also from less fruit-loaded spurs, non-fruiting shoots or reserves.

Whereas FNLAR appears the main determinant of fruit weight (Fig. 1), reserves could also play a role in the data variability at whole-tree level, although Whiting and Lang (2004) attributed a minor influence of crop management history on

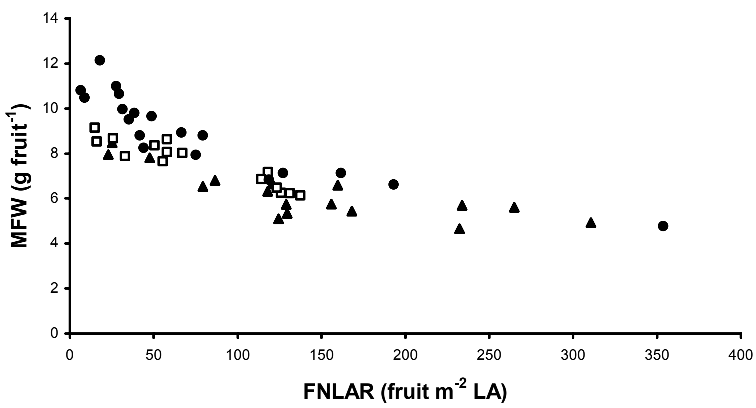

Fig. 1. Relationship between MFW and FNLAR for sweet cherry cultivars 'Lapins' (●), 'Van' (▲) and 'Bing' (□) at whole-tree level.

fruit weight variation. At anthesis, sweet cherry has very little leaf area, and vegetative buds usually open and develop simultaneously (Loescher *et al.*, 1985; Keller and Loescher, 1989; Flore *et al.*, 1996), but at bud-break, reserves stored in bark, wood and roots (Loescher *et al.*, 1985) provide the carbohydrates for growth, until assimilate supply from the leaf area of the tree is sufficient to satisfy sink demand.

According to Proebsting (1990), fruit size of different cultivars should be compared at the same FNLAR. Moreover, cultivars may differ in the sensitivity of their fruit weights to changes in FNLAR. Thus, 'Van' had the lowest MFW under low or moderate FNLAR, but at high fruit densities its MFW would be less affected by FNLAR (Table 1). In our study, comparison was based on the regression parameters for the three cultivars. The Y-intercepts can be considered to represent potential fruit weights (MFW when FNLAR approaches zero).

In the study of Proebsting (1990), fruit weight of the cultivar 'Rainier' was 2 g higher than that of 'Bing' at a similar total yield per tree. Thinning the crop, to reduce yield by half, resulted in increased fruit size for both cultivars, but MFW of 'Rainier' still exceeded that of 'Bing' by 2 g. This was analogous to the difference between 'Lapins' and 'Bing' in the present study at whole-tree level (Table 1). However, 'Van', having the lowest potential fruit weight, was less sensitive to increasing FNLAR, suggesting that at high FNLAR it had a higher capacity to mobilize reserves or transport carbohydrates from less fruit-loaded spurs or non-fruiting shoots.

Experiment 2

Mean LAI of individual trees at harvest was 3.6 (standard deviation: 0.74), resulting in an estimated PAR interception of almost 79% (Eq. [3]). While MSG and TCSAI were not significantly correlated to FNLAR (P=0.369 and P=0.092, respectively), MFW, TA and SSC decreased linearly with increasing FNLAR (P<0.05) at rates of 0.029 g, 0.027 ml NaOH and 0.065%, respectively per unit FNLAR (Fig. 2). Firmness showed the same tendency, at a rate of 0.1016 Durofel index units per unit FNLAR, but the relationship was not significant (P=0.08); neither was the relationship (P=0.40) with SSC/TA. The coefficients of determination were rather low, i.e. 0.47, 0.19 and 0.34 for MFW, TA and SSC, respectively.

In cherry production, about 75% of PAR interception at harvest has allowed maximum yields (Flore and Layne, 1990; Balkhoven-Baart and Groot, 2005). Favourable fruit quality requires, furthermore, a good light distribution throughout the canopy (Lang, 2005). Estimated PAR interception in this experiment was thus near-optimal for fruit production. Under these conditions, a linear negative relationship between FNLAR and MFW was found, in agreement with the results of earlier studies

(Facteau *et al.*, 1983; Flore, 1985; Roper and Loescher, 1987; Whiting and Lang, 2004), indicating increasing source limitation as FNLAR increases. The relationship at high LAI was consistent with the one at lower LAI (2.5) (and at an earlier stage of fruit maturity) in Experiment 1, in which MFW (g) was predicted as 9.20 – 0.0213 FNLAR.

The SSC/TA ratio has been found to be correlated to the perception of sweetness, sourness or cherry flavour by trained judges (Crisosto *et al.*, 2002). High TA negatively affected consumer acceptance in the American market if SSC was below 16% and 13% for ‘Brooks’ and ‘Bing’, respectively, while consumer acceptance was high for both cultivars with SSC exceeding 16%, irrespective of TA (Crisosto *et al.*, 2003). As in previous studies (Flore, 1985; Roper and Loescher, 1987), in this experiment SSC decreased as FNLAR increased, but it was higher than 16% even at the highest recorded value of FNLAR.

The negative relationship between firmness and FNLAR was not significant (P=0.08), but other authors have observed the same pattern (Facteau *et al.*, 1983;

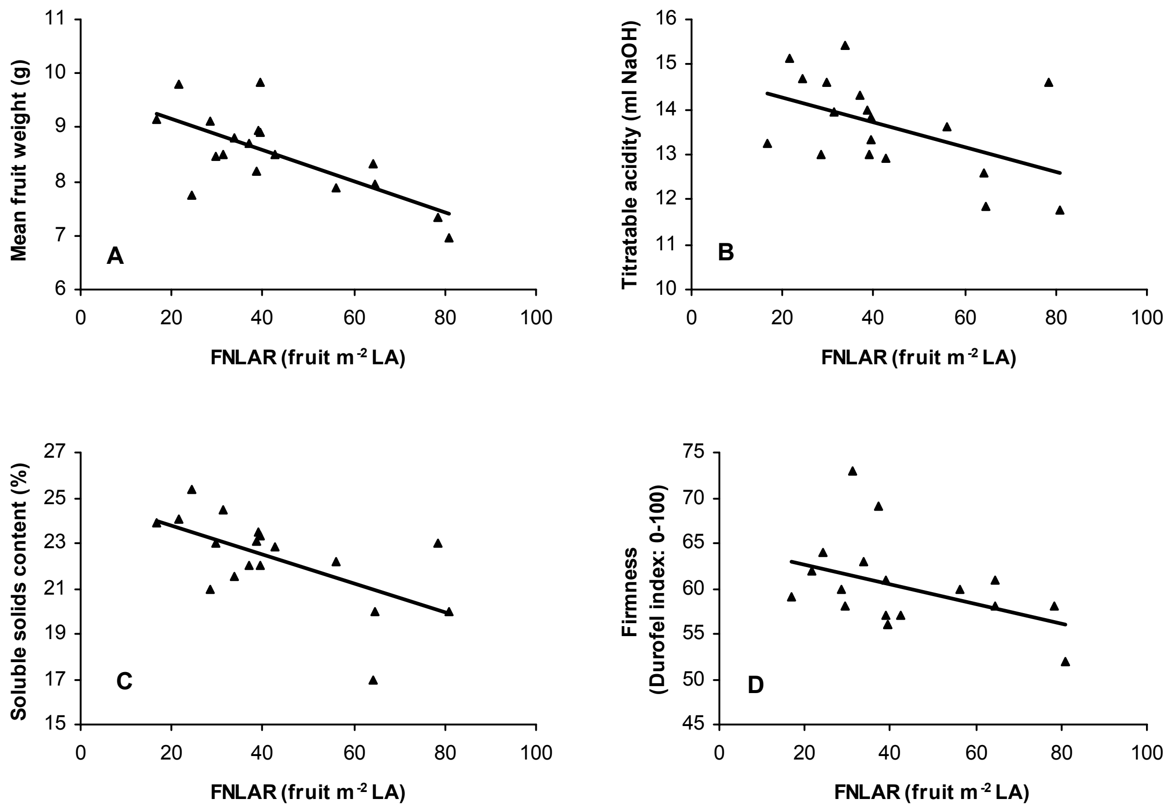

Fig. 2. Effect of fruit number to leaf area ratio (FNLAR) on (A) mean fruit weight (MFW; g fruit^{-1}), (B) titratable acidity (TA), (C) soluble solids content (SSC) and (D) firmness (F). A: y = 9.73 − 0.029x, r^2 = 0.47, P<0.001. B: y = 14.78 − 0.027x, r^2 = 0.19, P=0.044. C: y = 25.15 − 0.065x, r^2 = 0.34, P=0.008. D: y = 64.07 − 0.1016x, r^2 = 0.13, P=0.082.

Whiting and Lang, 2004). Quantification of this relationship would be even more important in other varieties, in which lack of firmness is more characteristic than in 'Bing'.

The lack of significant effects of FNLAR on vegetative growth (TCSAI and MSG) suggested that, although some competition between vegetative and reproductive growth may occur, fruits are the main sink organs. Thus, low FNLAR stimulates growth of the remaining fruits, rather than vegetative growth, as found in earlier studies (Chalmers and van den Ende, 1974; Grossman and DeJong, 1994; Marcelis and Heuvelink, 1999).

"Price-fruit quality" relationship

Fruit quality and price are closely related and differentiated by markets: farm gate prices are much lower in the domestic than in the international market. Exportable fruit can be transported from Patagonia to Europe by ship or by air. Transport costs are approximately 0.4 and 2 US\$ kg^{-1} by ship and by air, respectively. The difference of 1.6 US\$ is usually partitioned as: 0.2 US\$ to the grower, 0.2 to the packinghouse, 0.6 to the importer in Europe, whereas the remaining 0.6 US\$ is reflected in the consumer price (A.B. Pugh, INTA – EEA Chubut, *pers. comm.*).

Fruit colour is the main indicator of maturity (Mozetič *et al.*, 2004; Usenik *et al.*, 2005). To be marketable, the fruit needs an appropriate colour, according to the market and the distance to its final destination (no. 3 or 4 on the CTIFL colour chart). The stem of the fruit has to be present and in good condition, and the fruit should not show any rot, pitting, brushing, bruising, deformity and/or damage of any kind. Fruit that does not fulfil these requirements is used for industry and fetches the lowest price. Moreover, minimum threshold values are required for size, soluble solids content and firmness, set in dependence of market (industry, domestic and export) and means of transport (truck, ship and air) (Table 2). Practically all fruit sold in the domestic market is transported by cooled-truck to the Central Market of Buenos Aires (MCBA) (at 1500 to 2100 km from the production areas considered in the present study), from where it is distributed to other cities. Firmness of fruit should be >40 for the domestic market and for export to Europe at least 60 for ship transport and >50 by air. There is no restriction on soluble solids content for the domestic market, but for export a minimum of 14% is required. Minimum size (equatorial diameter) is 22 and 24 mm for the domestic and the export market, respectively. When all threshold values are met, price is mainly defined by fruit size, set in 2-mm classes (Table 3).

Fruit price is not only dependent on quality, but also on timing of marketing. Highest prices in Europe are obtained around Christmas, between December 20th and

30th (G. Laborde, CTIFL, *pers. comm.*). To sell the fruit at that specific moment, it should arrive between December 10th and 15th. Consequently, taking into account the time needed for processing and transporting, harvesting in Patagonia should be, at the latest, 5 days earlier (between December 5th and 10th) for air transport and about 30 days earlier (between November 10th and 15th) for transport by ship. In practice, however, harvesting has to be spread over a longer period to more efficiently use packing facilities and labour.

Parameters estimation for a “target-tree”

As defined earlier, “target-trees” are designed to maximize GVP at farm level. Therefore, a conceptual model to estimate GVP was defined. The model assumes 5% of the fruit for industry and 15% for the domestic market (minimum values found in practice (A.B. Pugh, INTA – EEA Chubut, *pers. comm.*)), due to various defects (lack of stem, inadequate colour, pitting, brushing, bruising, double fruits, deformities, etc.). For the remaining fruit, FNLAR determines SSC, F and MFW (actually size). These three parameters define mean fruit price (Fig. 3), taking into account weight distribution against MFW obtained with Eq. [5]. FNLAR, in combination with MFW

Table 2. Threshold values for quality parameters according to the different market and transport possibilities (A.B. Pugh, INTA – EEA Chubut, *pers. comm.*).

Quality parameter	Industry	Domestic (truck)	Export: Ship	Export: Air
Size (mm equatorial diameter)	NR[a]	>22	>24	>24
SSC[b] (%)	NR	NR	> 14	>14
Firmness (0-100 Durofel® 25)	NR	> 40	>60	>50

[a]NR: no restrictions; [b]SSC: soluble solids content.

Table 3. Farm-gate price (US\$ kg^{-1}) based on fruit size (mm), differentiated by market and transport possibilities (A.B. Pugh, INTA – EEA Chubut, *pers. comm.*).

Market	22-24	24-26	26-28	28-30	>30
Domestic	0.55	0.69	0.90	1.03	1.17
Export (transport by ship)	NM[a]	1.70	1.80	1.95	2.05
Export (transport by air)	NM	1.50	1.60	1.75	1.85

[a]NM: not marketable.

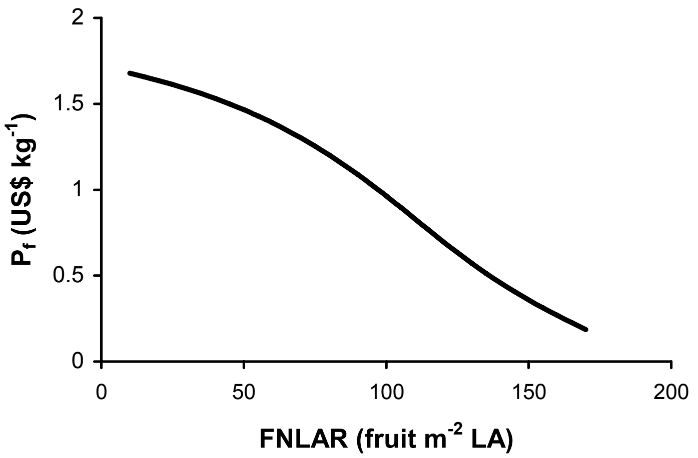

Fig. 3. Mean fruit price at farm gate (P_f) as a function of fruit number to leaf area ratio (FNLAR). FNLAR influences P_f indirectly by affecting soluble solids content, firmness and mean fruit weight. Fruit price is not a continuous function of size, but becomes continuous when size distribution is taken into account.

and LAI, also determine yield (Eq. [2]). Finally, GVP is calculated as the product of yield and fruit price (Eq. [1]) (Fig. 4).

The combination 'Bing'/'Mahaleb' on vase was used to illustrate parameters estimation (LAI and FNLAR) for a "target-tree" in Patagonian orchards. Under this training system, a LAI of 3.07 is required to attain the near-optimal situation of 75% interception of PAR at harvest (Eq. [3]).

To estimate optimum FNLAR, the relationships between fruit quality parameters and FNLAR found in Experiment 2 were used, i.e. SSC below 14% was observed with FNLAR exceeding 172 fruit m^{-2} LA (SSC = 25.15 – 0.065 FNLAR) (Fig. 2C), with MFW equal to 4.78 g (9.73 – 0.029 FNLAR) (Fig. 2A). A size of 21.6 mm (Eq. [4]) is limiting market possibilities as fresh fruit, even for the domestic market (Table 2). Similarly, when FNLAR exceeds 40 fruit m^{-2} LA, firmness limits export possibilities for cherries by ship (F lower than 60; Fig. 2D). When F is below 50, associated with more than 138 fruit m^{-2} LA and a MFW of 5.76 g (22.7 mm), cherries can only be sold in the domestic market (Table 2). Although colour is an important quality characteristic, it can be optimized through harvesting time. Titratable acidity can affect consumer acceptance, but only when SSC is below 16% (Crisosto *et al.*, 2003), which was never observed in the experiments described.

At the estimated optimum LAI of 3.07, the "fruit quality-FNLAR" relationships found in Experiment 2, the quality thresholds for different marketing possibilities defined in Table 2 and the "price-fruit quality" relationship described in Table 3 and

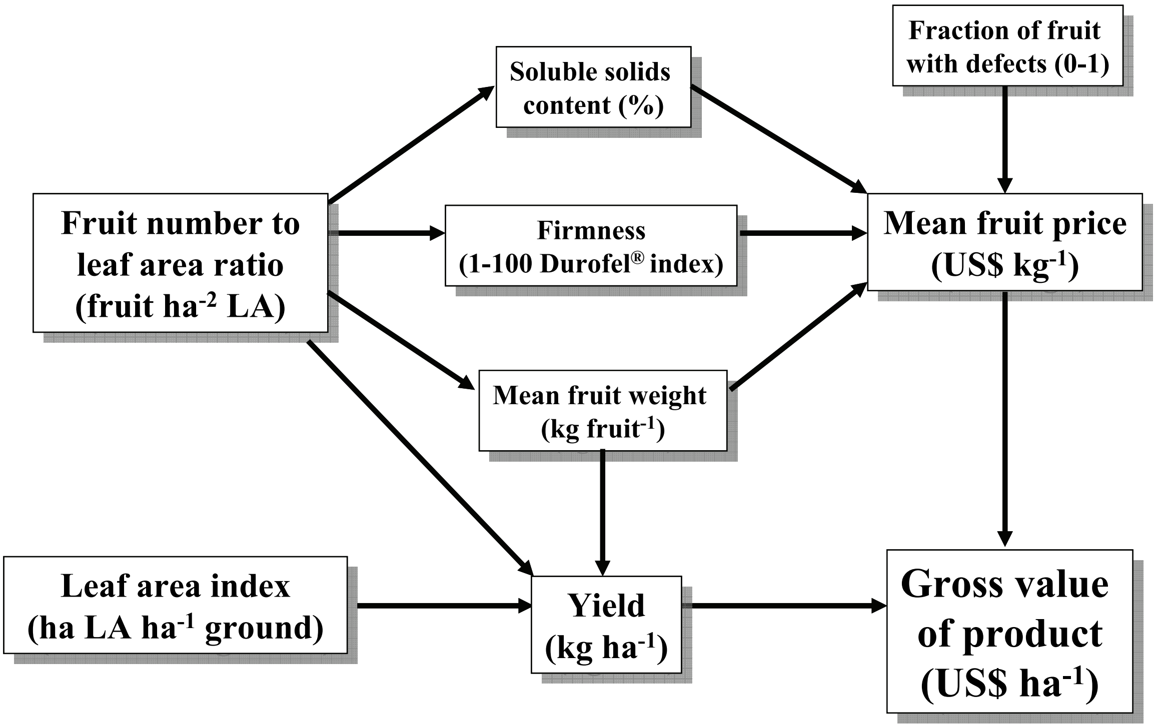

Fig. 4. Factors affecting GVP (gross value of product, US\$ ha^{-1}) at farm level. GVP = Yield • P_f (price at farm gate, US\$ kg^{-1}). Yield (kg ha^{-1}) = MFW • FNLAR • LAI; where MFW is mean fruit weight (kg fruit^{-1}); FNLAR fruit number to leaf area ratio (fruit ha^{-1} LA) and LAI leaf area index (ha ha^{-1}). Price is defined based on the information presented in Tables 2 and 3 and integrated in Fig. 3.

Fig. 3, maximum GVP was estimated at 21900 US\$ ha^{-1} (Fig. 5), with a FNLAR of 80 fruit m^{-2} LA. Yield was 18.25 Mg ha^{-1} (Fig. 6) and MFW was 7.43 g (24.7 mm), with 56.2% of the fruit in the category 24-26 mm, 27.4% in 22-24, 14.4% in 26-28, 1.6% below 22 mm and 0.4% between 28-30 mm, according to the weight distribution derived from Eq. [5] (Fig. 7). Firmness and SSC were 55.9 and 20.0%, respectively. Mean fruit price at farm gate was 1.20 US\$ kg^{-1}.

Changes in the "price-fruit quality" relationships modify optimum FNLAR. For example, if the threshold size for selling fresh fruit in the domestic market moves from 22 to 24 mm and the price for the category 26-28 mm equals those of fruits exceeding 30 mm, optimum FNLAR decreases from 80 to 70 fruit m^{-2} LA, resulting in a GVP of 19942 US\$ ha^{-1}, with 16.5 Mg ha^{-1} of fruits of 7.72 g (25.0 mm) on average.

The concept of "target-tree" resulted in a single combination of LAI (3.07) and FNLAR (80 fruit m^{-2} LA) to maximize GVP. In practice, such a precise combination will be impossible to attain, but this approach also allows determining acceptable deviations from optimal values. For example, GVP-values exceeding 90% of the maximum (19700 US$ ha^{-1}) can be attained in the range of 55 to 103 fruit m^{-2} LA, allowing considerable freedom in management practices (Fig. 5).

CONCLUSIONS

In this paper, a "target trees" concept was applied in the perennial crop sweet cherry, i.e. an approach that integrates eco-physiological information (relationship between fruit quality and FNLAR), model estimates (relationship between light interception and LAI) and expert knowledge ("price-fruit quality" relationships).

Although the example presented is limited to a single combination of cultivar and training system in a specific location, the methodology can be applied to other situations, provided reliable relevant eco-physiological information is available. The approach allows a transparent discussion on the relative merits of producing high yields of poor quality or maximizing quality at the expense of yield. The analysis suggests that the optimum is located at an intermediate situation, which has to be identified on the basis of data from local experiments and "price-fruit quality" relationships.

Once the "target-tree" has been identified, it can serve as the basis for a planning tool for management practices to promote tree vigour (e.g. winter pruning,

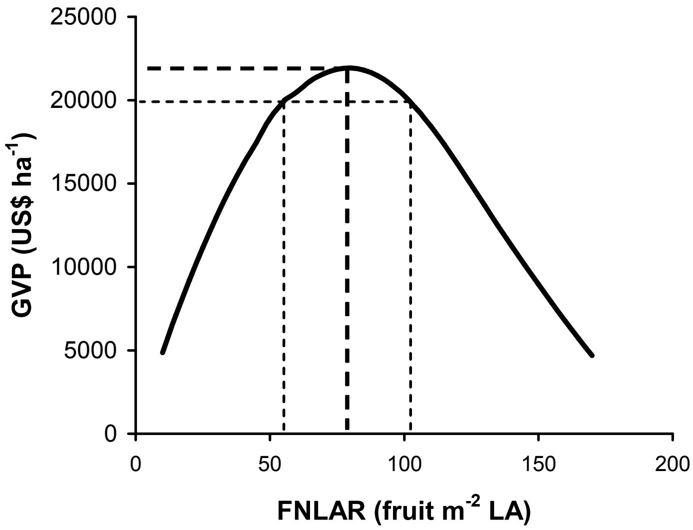

Fig. 5. Gross value of product (GVP) of Patagonian orchards at farm level as a function of fruit number to leaf area ratio (FNLAR), for 'Bing'/'Mahaleb' trees with LAI of 3.07. Maximum GVP (GVPm: 21900 US$ ha^{-1}) is observed at 80 fruit m^{-2} LA. In the range of 55 to 103 fruit m^{-2} LA, GVP exceeds 90% of GVPm (19700 US$ ha^{-1}).

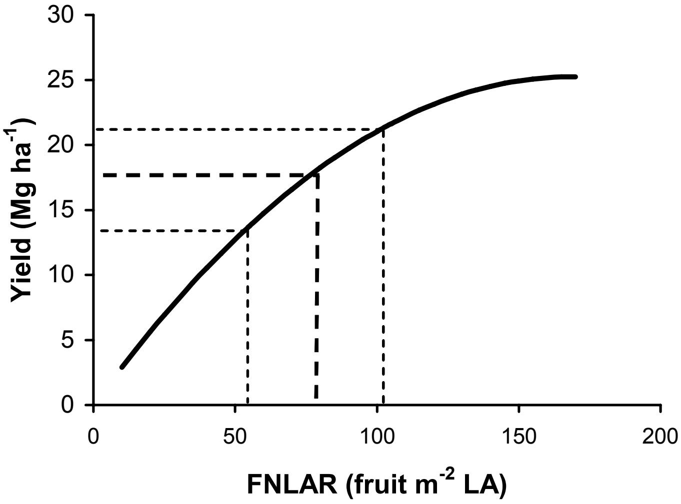

Fig. 6. Yield of Patagonian orchards as a function of fruit number to leaf area ratio (FNLAR), for 'Bing'/'Mahaleb' trees with LAI of 3.07. Maximum GVP (GVPm) is obtained at 18.25 Mg ha^{-1} (80 fruit m^{-2} LA). In the range of 55 to 103 fruit m^{-2} LA, corresponding to 13.8 and 21.4 Mg ha^{-1}, respectively, GVP exceeds 90% of GVPm.

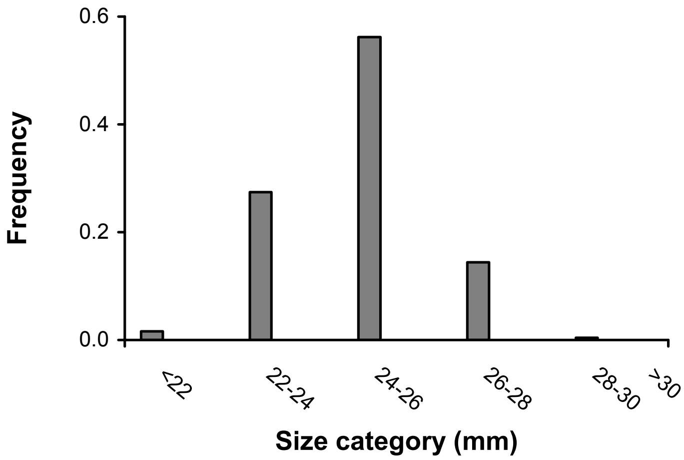

Fig. 7. Distribution of fruit size categories' in a 'Bing'/'Mahaleb' "target-tree" trained as vase in South Patagonia, with a mean size of 24.7 mm (mean fruit weight = 7.43 g).

irrigation, N-fertilization), to weaken the tree (e.g. summer pruning) or to affect fruit set and retention (e.g. hormonal treatments, boron application, beehive density and frost protection). Further research is needed to quantify and predict the effect of such practices.

5

A method for assessing frost damage risk in sweet cherry orchards of South Patagonia

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ABSTRACT

Quantification of frost damage risk is important in planning the development of new orchard areas and for decision-making on design and installation of frost control systems. The objective of this study was to develop a comprehensive method to quantify frost damage risk in different sweet cherry production areas of South Patagonia and to estimate the potential impact of frost control systems on risk reduction. Lack of historical weather data required a theoretical-empirical approach. Frost damage for any specific day of the season was assumed to occur when the minimum temperature on that day was below the specific lethal temperature for the phenological stage predicted at that moment (based on phenological models). Frost damage probability was estimated for each production location of South Patagonia as the frequency of years in which at least one damaging frost (damaging ≥ 90% of the reproductive organs) occurs, at any time during the growing season until harvest. Frost damage risk was compared among cultivars and locations. Finally, the effect of active frost control methods on frost damage risk reduction was analyzed. There was very little difference in frost damage risk among cultivars, although 'Sunburst' was the cultivar with the lowest risk. The most risky locations were Los Antiguos and Esquel, while Comodoro Rivadavia was the safest location. The frequency of years with at least one killing frost decreased dramatically when the minimum temperature was increased by 3 ˚C, using active frost control systems. The methodology presented appears useful to identify the main and secondary variables affecting frost damage risk. Thus, this type of quantitative analysis can support growers in decision-making on required investments and operational costs of the equipment for frost control, on the basis of potential impact of a particular control system on mean yields and yield stability. It may also be a guide to prioritise research issues to fill knowledge-gaps with regard to frost risk assessment.

Keywords: Lethal temperature; Frost control; Damage level; Phenology

INTRODUCTION

The production of sweet cherry in South Patagonia (Argentina) has been increasing through area expansion from 176 ha in 1997 to 578 ha at the end of 2006. Of this area, 255 ha are located in Los Antiguos (46˚ 16’ SL; 220 m above sea level, a.s.l.), 161 ha in the area of Trelew, in the Lower Valley of Chubut River (LVCHR) (43˚ 16’ SL; 30 m a.s.l.), 99 ha in Sarmiento (45˚ 35’ SL; 270 m a.s.l.), 30 ha in Esquel (42˚ 55’ SL; 570 m a.s.l.) and 33 ha in Comodoro Rivadavia (45˚ 52’ SL; 50 m a.s.l.) (Fig. 1). This increase was possible because of the favourable climate and availability of land and water, but most importantly, because harvest and marketing occurs in the “contra” season compared to the Northern Hemisphere (Cittadini *et al.*, in press[c]). However, farmers experience uncertainty and risks in cherry production. Uncertainty can be defined as imperfect knowledge of possible future results and risk as the probability that future changes on factors such as markets and climatic conditions can negatively affect the results (Meinke *et al.*, 2001). One of the possible climatic conditions causing yield and quality reduction is frost. The frequency of frosts in early spring and the average date of the last killing frost are important criteria in site selection for cherry tree planting (Longstroth and Perry, 1996). In the valleys of South Patagonia, advective freezes seldom occur (F. Manavella, INTA-EEA Santa Cruz, *pers. comm.*). In contrast, radiation spring frosts, defined as in situ cooling with clear sky and low wind speed (Thompson, 1996), are the main source of yield variability if they are not actively controlled by using heaters or sprinkler irrigation. Such equipment requires major investments, i.e. in Patagonia in 2005, about 4000 and 2000 US\$ ha^{-1} for sprinkler irrigation equipment and heaters, respectively. Substantial annual operating

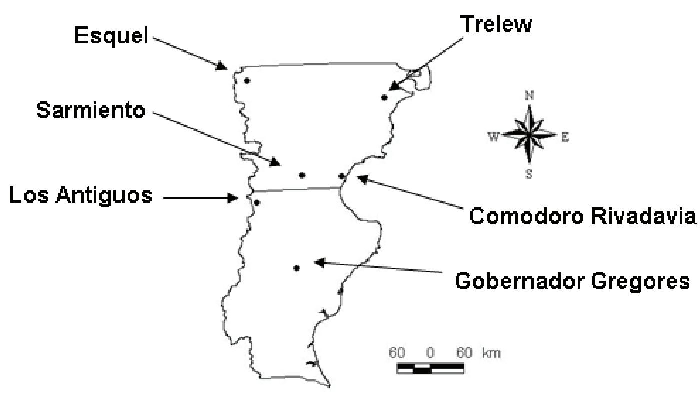

Fig. 1. Location of Trelew, Esquel, Sarmiento, Comodoro Rivadavia (Chubut Province), Los Antiguos and Gobernador Gregores (Santa Cruz Province).

expenditures, such as labour, maintenance and fuel have to be added. Rising costs of labour, oil for heating and water for sprinkling can make active frost control methods very expensive (Longstroth and Perry, 1996).

The specifications of frost control equipment (type and capacity) depend on the required increment in temperature (ΔT): the difference between the expected minimum temperature at any day of the growing season and the lethal temperature for the reproductive organs at the phenological stage at that day. In addition, the frequency of the frosts from which the crop has to be protected has to be considered. High frequency of frosts may limit the possibilities for using sprinkler irrigation in heavy soils due to the sensitivity of cherries to root asphyxia. The equipment should provide enough heat to compensate the humidity deficit and the losses through radiation and convection. During a frost with clear sky, at 0 ˚C, heat loss through radiation is about 1357 Kw m^{-2}. Convective loss depends on wind speed and ΔT, while the required compensation for humidity deficit is a function of relative humidity (RH) and wind speed (Table 1). As an example, with ΔT = 5 ˚C, wind speed 1 m s^{-1} and RH 80%, the required water flow (WF) to provide 4152 Kw m^{-2} with sprinkler irrigation systems, based on approximately 335 kJ of heat release per m^3 of water when solidifying, is 34.4 m^{-3} ha^{-1} h^{-1}. This value is equivalent to 3.44 mm h^{-1} of sprinkled water. If wind speed increases to 2 m s^{-1}, the heat requirement rises to 6950 Kw m^{-2} and consequently the sprinkler irrigation system should provide at least 5.76 mm h^{-1}.

Table 1. Heat requirements (Kw m^{-2}) for compensation of humidity deficit, radiation and convection losses, as a function of ΔT (°C), wind speed (m s^{-1}) and relative humidity (%).

Wind speed	Relative humidity	ΔT		
		3	4	5
0	90	1432	1504	1540
	80	1433	1506	1542
	70	1436	1659	1545
1	90	3014	3536	4061
	80	3111	3632	4152
	70	3207	3727	4249
2	90	4674	5715	6757
	80	4867	5908	6950
	70	5058	6100	7141

Source: adapted from Tassara (2005).

Risk perception differs among growers and there is a considerable variability in the application of frost control systems among the different zones of South Patagonia due to the lack of long term climatic data and imperfect knowledge of the complex fruit production systems. For example, only 4.4% of the orchard area of Los Antiguos is frost-protected by over-plant sprinkler irrigation and mobile heating machines, as growers strongly rely on the moderating effect of lake Buenos Aires. Similarly, frost control systems are absent in Comodoro Rivadavia, because established orchards, already in the productive phase, are located near the sea, an area apparently with low frost risk. The frost protected area in Sarmiento is 66% (heaters and over-plant sprinkler irrigation), 35% in Esquel (mobile heating machines) and 61% in LVCHR (over-plant sprinkler irrigation) (Table 2), where the unprotected area comprises orchards that have not yet reached their mature stage (Chapter 2). In different production areas of the world, frost risk has been analyzed through frost risk maps, showing the expected number of frost events for selected sites derived from long term weather data. One way of estimating local frost risk for a specific location is adding the number of events with temperatures below 0 ˚C, but this methodology does not differentiate between specific types of risk (Lindkvist *et al.*, 2000). Lindkvist and Chen (1999) used a more detailed index based on events with temperatures below 0 ˚C, subdivided according to the moment of the season of freezing temperatures as well as a division into temperature levels (how far below 0 ˚C). In addition, Pascale *et al.* (1997) developed an index for apple and peach, later adapted to sweet cherry (Damario *et al.*, 2006), taking into account average dates of occurrence of different phenological stages, the lethal temperatures for each of them and probabilities of those temperatures in specific locations. Predicting the date of occurrence of each phenological stage instead of using an average fixed day, would be a significant improvement in these types of indices. The objective of this study was to develop a comprehensive method

Table 2. Percentage of production area under frost protection and method used.

Location	Production area protected (%)	Method
LVCHR	61	Over-plant sprinkler irrigation
Comodoro Rivadavia	0	Does not correspond
Sarmiento	66	Over-plant sprinkler irrigation and heaters
Esquel	35	Mobile heating machines
Los Antiguos	4.4	Over-plant sprinkler irrigation and mobile heating machines
Gobernador Gregores	Does not correspond[a]	Does not correspond

[a] There is no production yet.

to quantify frost damage risk in various sweet cherry production areas of South Patagonia and to estimate the potential impact of frost control systems on risk reduction. Multiple frost events are possible but they were not addressed in this paper.

MATERIALS AND METHODS

Risk of frost damage was quantified by combining simulation and statistical models. Frost damage on any specific day of the season was assumed to occur when the minimum air temperature on that day was lower than the lethal temperature specified for the phenological stage predicted at that moment (based on phenological models). This is a simplification, because plant and air temperature can vary. Frost damage probability was estimated for each production location of South Patagonia as the frequency of years in which at least one killing frost occurs, at any time during the growing season until harvest. Frost damage risk was compared between cultivars (differing in phenological models) and locations at T_{90} level of damage (temperatures killing 90% of the reproductive organs). Finally, the effect of active frost control methods on frost damage risk reduction was analyzed.

Mean and minimum temperatures

In Patagonia, the number of meteorological stations is restricted and in most cases climate registration is limited to a relatively short period, usually not enough to calculate frequencies. In Trelew, in the Instituto Nacional de Tecnología Agropecuaria-Estación Experimental Agropecuaria Chubut (INTA–EEA Chubut) observations are available from 1971 to 2004 (E. Colombani, INTA-EEA Chubut, *pers. comm.*), but incomplete (only 27 years were complete). In Los Antiguos, data are available from 1999 to 2004 (INTA-EEA Santa Cruz). Similarly, 33 years of incomplete observations are available in Comodoro Rivadavia and Esquel and 28 in Gobernador Gregores, all from the Servicio Meterológico Nacional (SMN). No data were available from Sarmiento. As data are incomplete or absent, the weather data generator MarkSim (Jones and Thornton, 2000; Jones *et al.*, 2002) was used in each location for estimation of 50 years of mean and minimum daily temperatures. This software has been calibrated for Latin America and has been successfully tested in earlier studies (Mavromatis and Hansen, 2001; Jones and Thornton, 2003). Using MarkSim, it was possible to estimate frequencies based on a large number of years. The available registers were used to estimate monthly mean temperatures and monthly diurnal temperature range (difference between mean monthly maximum and mean monthly minimum) and these parameters were used as inputs for MarkSim. However, data from Esquel and Gobernador Gregores were registered at the airports, outside of the valleys, so that temperature regimes may be different. MarkSim-generated minimum temperatures and standard deviation of minimum temperatures were graphically compared with available real data to estimate accuracy of the weather generator.

Phenological models based on cumulative degree-days

Simple phenological models were developed for the cultivars ‘Bing’, ‘Burlat’, ‘Lapins’, ‘Stella’, Sunburst’ and ‘Van’, using phenological data recorded in an experimental orchard of INTA–EEA Chubut, in Trelew (LVCHR) during the seasons 1997 (Perez Bruno, 1998), 1999 (Pugh, 2001), 2000 (Pugh and Pugh, 2001) and 2001 (Pugh and Pugh, 2002). Five phenological stages were distinguished: ‘dormant’, ‘swollen bud’, ‘open cluster’, ‘white tip’, and ‘blooming and post-blooming’ (until harvest).

Air temperature for the experimental periods was recorded at the weather station of INTA–EEA Chubut. Data were transformed to cumulative degree-days (CDD) after July 15th, calculated as mean daily air temperature (T) minus a base temperature (T_0) of 4.5 ˚C (Iezzoni, 1985) ($CDD = \sum (T - T_0)$). The beginning and end of each phenological stage of each cultivar was expressed in CDD and the values of the four recorded years were averaged (Table 3). Blooming date observations from a commercial orchard in Comodoro Rivadavia (2005) with the cultivars ‘Lapins’, ‘Bing’ and ‘Sunburst’, and mean temperatures from a weather station located at the site (C. Mundet, Bahía Solano S.A., *pers. comm.*) were used for preliminary validation of the models.

Threshold temperatures for frost damage

Both, vegetative and floral buds loose their cold tolerance when they begin to swell. With advancing bud stage, the lethal temperature rises rapidly (Longstroth and Perry, 1996) and predictably (Thompson, 1996). Lethal temperatures, usually expressed as the temperatures at which 50% and 90% of the reproductive organs are killed (T_{50} and T_{90}, respectively), have been reported by various authors (De Perraudin, 1965; Proebsting and Mills, 1978; Ballard *et al.*, 1997). In this study, T_{90} values adapted from Proebsting and Mills (1978) were used for the five phenological stages distinguished (Table 4).

The phenological stages on each day (from July 15th – December 31st) over 50 years was predicted based on the phenological models previously developed, with their associated T_{90} lethal temperatures.

Empirical evidence and local reports about frost damage levels in Los Antiguos in 1996 (F. Manavella, INTA-EEA Santa Cruz, *pers. comm.*) and 2003 (Bertoli and San Martino, 2005) and in Trelew in 1999 (A.B. Pugh, INTA-EEA Chubut, *pers. comm.*) were used for preliminary validation of lethal temperatures from literature.

Frost damage risk

Frosts killing only part of the reproductive organs (e.g. T_{50}) and multiple frost events are possible, but they were not addressed in this paper. In this investigation, frost damage frequency (FDF_{90}) was calculated as the sum of the years with at least one killing frost ($\sum KFS_{90}$) over the total number of years considered (TY).

Table 3. Mean[a] cumulative degree-days (T_0 = 4.5 ºC (Iezzoni, 1985)) from July 15th to the start and end of each phenological stage for the sweet cherry cultivars 'Bing', 'Burlat', 'Lapins', 'Stella', 'Sunburst' and 'Van'.

PhS[b]	Bing		Burlat		Lapins		Stella		Sunburst		Van	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
DMT[c]		178		176		162		186		176		176
SB[d]	178	223	176	216	162	230	186	192	176	228	176	222
OC[5]	223	267	216	270	230	271	192	265	228	294	222	279
WT[f]	267	294	270	288	271	288	265	289	294	326	279	300
BPB[g]	294		288		288		289		326		300	

[a]Averages of the observations at INTA–EEA Chubut during the seasons 1997 (Pérez Bruno, 1998), 1999 (Pugh, 2001), 2000 (Pugh and Pugh, 2001) and 2001 (Pugh and Pugh, 2002). [b]PhS: Phenological stage; [c]DMT: dormant; [d]SB: swollen bud; [e]OC: open cluster; [f]WT: white tip; [g]BPB: blooming and post-blooming (until harvest).

Table 4. Temperatures killing 90% of the reproductive organs (T_{90}) of 'Bing' sweet cherry.

Phenological stage	T_{90}
Dormant	-35
Swollen bud	-17.2
Open cluster	-11.9
White tip	-7.1
Bloom and post-bloom (until harvest)	-3.6

Source: adapted from Proebsting and Mills (1978).

FDF_{90} was estimated for the cultivars ‘Bing’, ‘Burlat’, ‘Lapins’, ‘Stella’, ‘Sunburst’ and ‘Van’ in Trelew, Sarmiento, Los Antiguos, Esquel, Comodoro Rivadavia and Gobernador Gregores (Fig. 1). The effect of active frost control methods was evaluated by analyzing the reduction in FDF_{90} on ‘Bing’ when increasing the minimum temperature by 3 ˚C.

RESULTS AND DISCUSSION

Parameter validation

In Comodoro Rivadavia (2005), predicted dates for starting of blooming (10% open flowers) were 11, 4 and 2 days earlier than observed, for ‘Lapins’, ‘Bing’ and ‘Sunburst’, respectively (Table 5). Lack of weather and/or phenological data for the other locations did not allow more extensive testing of the models. The deviations may be associated with the fact that although temperature is the main driver of phonological development, other factors, such as radiation level, influence cell division (Longstroth and Perry, 1996) and therefore may affect bud development. Differentiating the base temperature for different phenological stages or using average hourly temperatures might improve model accuracy. However, lack of sufficiently detailed weather and/or phenological records for most of the region limits possibilities for improving the situation in the short term. The partial results suggest that the phenological models should be improved and tested for each cultivar in several locations.

Simulated and observed minimum temperatures were comparable in all locations analyzed. However, standard deviation of the minimum temperatures was overestimated in all locations except in Trelew (Fig. 2). This could lead to overestimation of FDF_{90}.

Table 5. Predicted (based on phenological models developed with data from Trelew) and observed dates for start of blooming (10% open flowers) in Comodoro Rivadavia during 2005, for the cultivars ‘Lapins’, ‘Bing’ and ‘Sunburst’.

Cultivar	Predicted[a]	Observed	Difference[b]
Lapins	25 September	06 October	-11
Bing	25 September	29 September	-4
Sunburst	30 September	02 October	-2

[a]Mean temperature (input data of the phenological models) was recorded at a weather station located at the site.

[b]Difference: predicted – observed (days).

No local data were available for validation of the lethal temperatures reported in the literature, but empirical evidence suggests that they are reasonably accurate. In 1999, a frost of –5 ˚C at the end of blooming killed more than 90% of the reproductive organs in Trelew (A.B. Pugh, INTA-EEA Chubut, *pers. comm.*). Similarly, a frost of –4 ˚C in 1996 killed 85% of the flowers in Los Antiguos (F. Manavella, INTA-EEA Santa Cruz, *pers. comm.*), but –1.1 ˚C in 2003, with less than 20% open flowers in varieties 'Bing' and 'Van', did not cause significant damage (Bertoli and San Martino, 2005).

Location and cultivar relevance

There was very little difference in frost damage risk among cultivars, although 'Sunburst' was the cultivar with the lowest risk (Fig. 3). According to the phenological registers (Table 3), 'Sunburst' was the safest cultivar to cultivate because the stages 'white tip' and 'bloom and post-bloom' were delayed compared with other cultivars. Differences between cultivars in frost risk levels are minor and cultivar selection alone seems to be insufficient to avoid active frost control methods in risky locations.

The most risky locations with respect to frost damage were Los Antiguos and Esquel. However, input parameters used in Los Antiguos were obtained with only 7 years of registers, so these results should be considered with caution. The presence of lake Buenos Aires (1850 km^2) indeed moderates the climate of this area and production results during the last 20 years suggests that FDF_{90} was overestimated for this location (F. Manavella, INTA-EEA Santa Cruz, *pers. comm.*). Comodoro Rivadavia was the safest location. This area is influenced by the moderating effect of the sea, considerably reducing the frequency and intensity of frosts.

Potential effects of active frost control methods on risk reduction

In most locations, the frequency of years with at least one killing frost for 'Bing' decreases dramatically when the minimum temperature was increased 3 ˚C, simulating the effect of using active frost control systems. However, under these conditions, FDF_{90} was still 0.16 in Los Antiguos and 0.06 in Gobernador Gregores (Table 6). This reduction assumes, however, perfect operation of the frost control systems, whereas in practice some operational problems may arise (e.g. energy cuts, breakdown of equipment or unnoticed frosts).

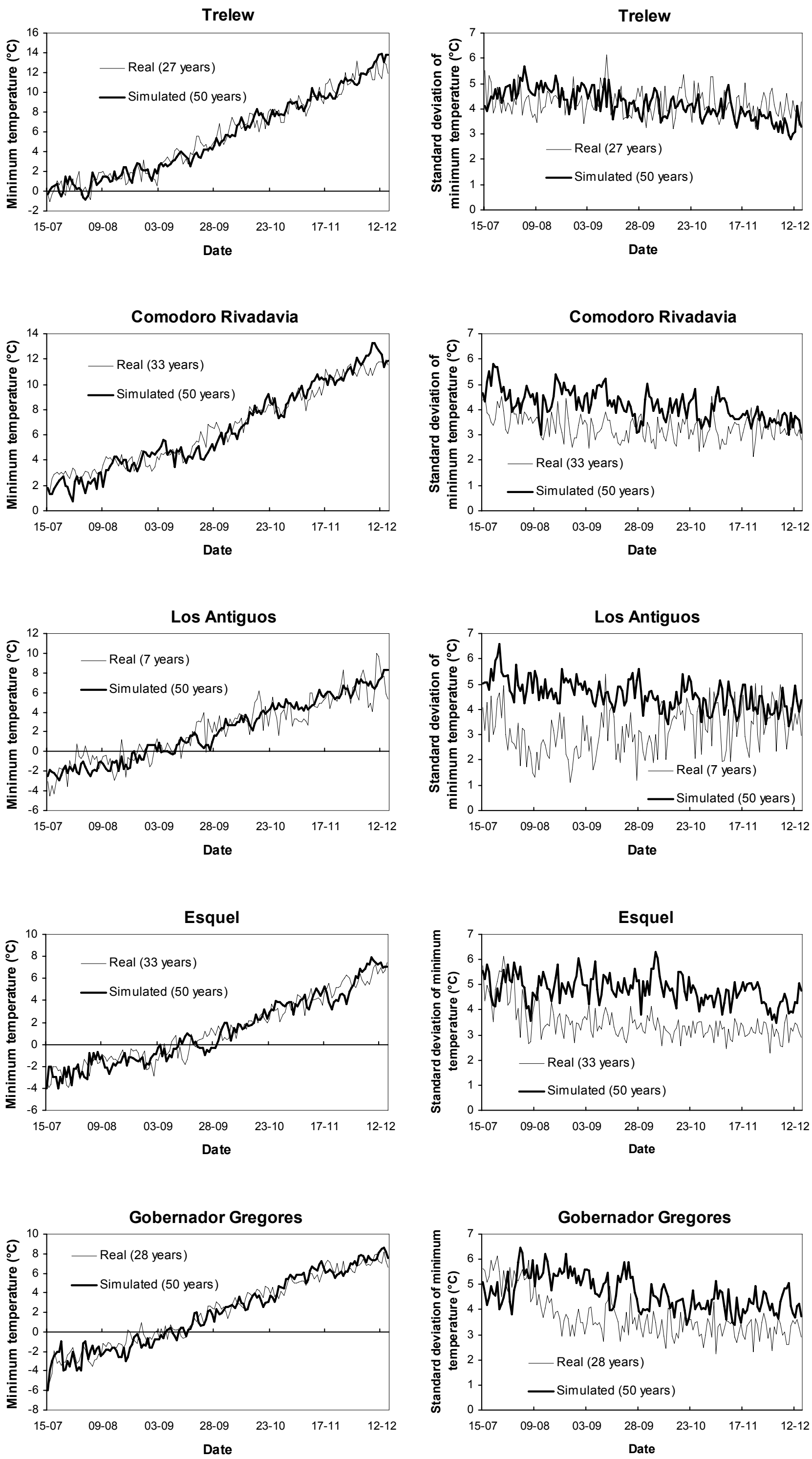

Fig. 2. MarkSim-generated and observed minimum temperature and standard deviation of minimum temperatures during the growing season for Trelew (INTA-EEA Chubut), Los Antiguos (INTA-EEA Santa Cruz), Comodoro Rivadavia, Esquel and Gobernador Gregores (SMN). No observed data were available from Sarmiento.

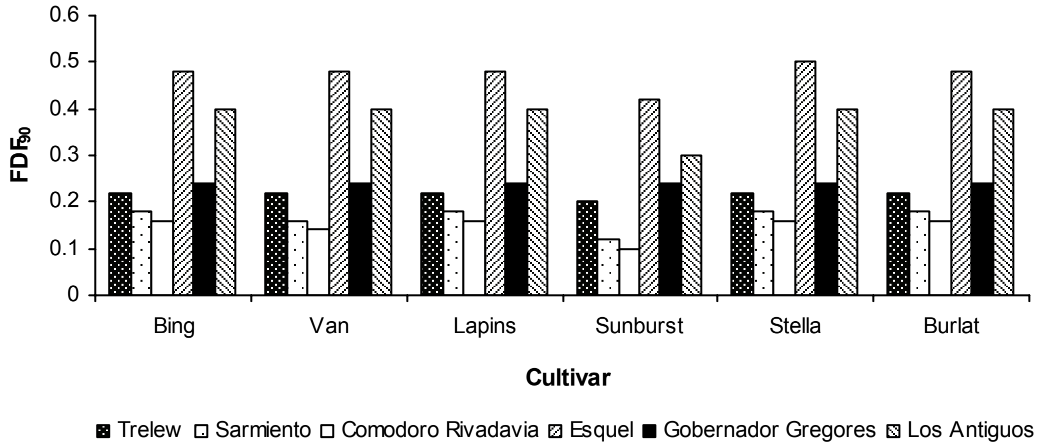

Fig. 3. Frequency of years with at least one frost killing ≥90% of the reproductive organs (FDF_{90}) for the cultivars 'Bing', 'Van', 'Lapins', 'Sunburst', 'Stella' and 'Burlat' in Trelew, Sarmiento, Comodoro Rivadavia, Esquel, Gobernador Gregores and Los Antiguos.

To analyse the suitability of equipment type for frost control, not only frost damage frequency and ΔT capability must be taken into account, but also labour demand and fuel consumption for operating the equipment, risk of its breakdown, soil drainage capacity, disease incidence in the area, etc. For example, in the most risky location, Esquel, sprinkler irrigation may be restricted to prevent spread of bacterial and fungal diseases. Therefore, sustainable development of cherry orchards in this area should be linked to efficient heating systems (capable of providing a high ΔT) or to carefully designed disease control plans to allow the use of sprinkler irrigation. Similarly, in Sarmiento, the high water table in combination with heavy soils in most of the valley limits the scope for use of sprinkler irrigation systems.

Table 6. Frequency of frost damage (T_{90}) for 'Bing' sweet cherry without frost control system and with a system increasing 3 °C the air minimum temperature in Trelew, Comodoro Rivadavia, Sarmiento, Esquel, Los Antiguos and Gobernador Gregores.

Location	No control	↑ 3 °C
Trelew	0.22	0.02
Comodoro Rivadavia	0.16	0.02
Sarmiento	0.18	0.00
Esquel	0.48	0.10
Los Antiguos	0.40	0.16
Gobernador Gregores	0.24	0.06

General remarks

Risk of loss of reproductive organs, as estimated in this study, cannot be directly translated into yield loss risk. Frosts killing only part of the reproductive organs (e.g. T_{50}) and multiple frost events are possible, but they were not addressed in this paper. When a frost occurs early in spring and kills part of the reproductive organs, some compensation may occur in the trees through reduced fruit-abortion at a later stage (Thompson, 1996). Also, the size of the remaining cherries is usually enhanced in trees bearing less fruits (Cittadini *et al.*, in press[a,b]; Whiting and Lang, 2004), partially compensating for the lower number of fruits. The magnitude of both compensating phenomena is obviously influenced by the timing of the “thinning frost” (earlier losses having greater chances for compensation), but these aspects were not considered in the present study.

CONCLUSIONS

The methodology presented has proven a useful tool to identify the main (e.g. location and frost control method) and secondary (e.g. cultivar phenology within a location) variables affecting frost damage risk. Thus, this type of quantitative analysis can support growers in decision-making related to required investments and operational costs of the equipment for frost control, on the basis of potential impact of a particular control system on mean yields and yield stability. It may also be a guide to prioritise research issues to fill knowledge gaps with regard to frost risk assessment.

However, absolute values of frost risk were estimated based on MarkSim-generated weather data, the phenological models were developed with registers from only one location, the results do not give information on actual yield losses and the duration of the frosts is not taken into account; hence these results need to be validated. The lethal temperatures also need to be validated for different cultivars under field conditions of Patagonian cherry orchards. Phenological models have to be locally tested, and eventually improved (e.g. by differentiating the base temperature for different phenological stages, by reducing the time step or by incorporating photoperiod as a driving factor).

6

FRUPAT: a tool to quantify inputs and outputs of Patagonian fruit production systems

This chapter has been published, with modifications, as:

Cittadini E.D., H. van Keulen and P.L. Peri, 2006, FRUPAT: a tool to quantify inputs and outputs of Patagonian fruit production systems. *Acta Horticulturae* 707: 223-230.

ABSTRACT

A software called FRUPAT was developed for calculating input and output coefficients (Technical Coefficients) of fruit production systems in South Patagonia. FRUPAT combined locations (Río Chubut valley; Sarmiento valley; Los Antiguos valley; Río Chico valley), edaphic environment (soil with no limitations; good quality soil but with short deepness; soil with low water holding capacity), fruit-tree crops (sweet cherry; plum; peach; apple; walnut), training systems (tatura; central leader; vase), irrigation systems (drip; furrow) and frost control systems (sprinkler irrigation; heating; passive) that provided 1080 multi-annual fruit production activities. Parameters have been identified as default values and most of those can be easily modified by the user. Relevant inputs and outputs can be estimated, such as gross value of product, expenditures, financial result, biocide use, inorganic N-application and labour. As an example of how FRUPAT can be used, some results are presented for a single physical environment (soil with no limitations in the Río Chubut valley) using sprinkler irrigation as frost control method. First, 5 crops under a single production technique (vase with furrow irrigation) are compared in terms of their monetary technical coefficients. Subsequently, results of sweet cherry under different production techniques (3 training systems with 2 irrigation systems) are presented. Finally, the time course of gross value of product, total expenditures, financial result and cumulative financial result are analyzed for a single activity (sweet cherry, trained as tatura under drip irrigation). FRUPAT may be used as a stand-alone tool for simple analysis as demonstrated here or as an intermediate step for linear programming.

Keywords: Fruit-tree crop; TC, Multi-annual; Production technique; Best technical means

INTRODUCTION

In the valleys of South Patagonia agro-ecological conditions are favourable for fruit production and different stakeholders are interested in the development of the fruit sector. However, it is not clear what systems are best for the most efficient use of the available resources to realise the various objectives of the different stakeholders. Analysing fruit production systems and their alternative management options from experimental data is generally not feasible because of their long production cycles and the extensive resources required (Meinke *et al.*, 2001). Therefore a modelling approach is more suitable.

Long-term studies may provide crucial information for decision-makers for strategic planning of sustainable land use. When performed using linear programming, such studies need large numbers of quantitative data (Technical Coefficients: TCs) for the different activities. TCs include inputs (nutrients, pesticides, labour, capital, etc.) and outputs, both desired (gross value of product) and undesired (surplus of N, biocides' emissions, risk, etc.) (De Koning *et al.*, 1995; Van Ittersum and Rabbinge, 1997). Quantification of the TCs can be based on various sources, such as experimental results, knowledge of experts and historical data; and on production ecological principles (Van Ittersum and Rabbinge, 1997; Kropff *et al.*, 2001). This paper describes the Technical Coefficient Generator (TCG) FRUPAT (Cittadini, 2005), a tool for quantification of inputs and outputs (TCs) for fruit-tree activities in South Patagonia. It may be used as a stand-alone tool for simple analysis or as an intermediate step for linear programming.

MODEL DESCRIPTION

FRUPAT consists of a first part that generates feasible fruit-tree activities and a second part that estimates the inputs and outputs (TCs) for each of them (Fig. 1).

Designing Land Use Systems

Van Ittersum and Rabbinge (1997) define land-use systems or production activities as specific crops or crop rotations grown in a particular physical environment, completely specified by their inputs and outputs. The relevant set of land use systems is defined on the basis of selected definition criteria (Hengsdijk and van Ittersum, 2003), comprising in FRUPAT location, edaphic environment, crop and production technique. Locations (4) and edaphic environments (3) are combined in land units (LUs), homogeneous

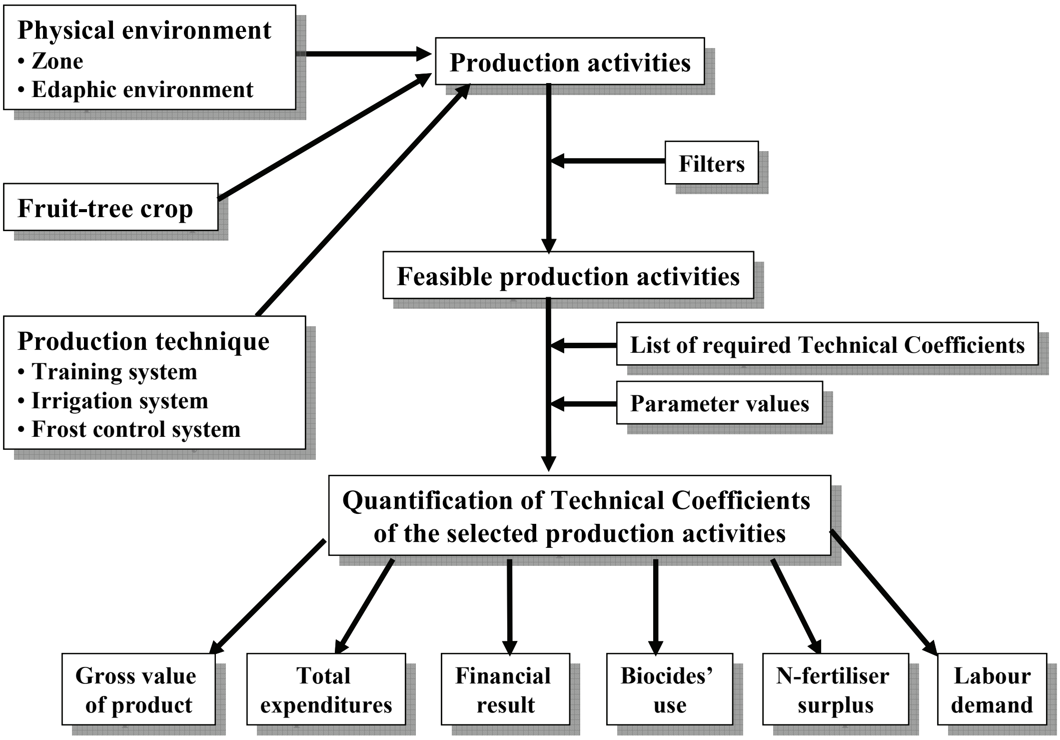

Fig. 1. General approach of FRUPAT. The combination of zone, edaphic environment, fruit-tree species, irrigation system and frost control system results in the production activities. After filtering only feasible combinations remain. Then, the user chooses the TCs that he/she wants to generate and may modify some or all the parameter values. After running the program, the TCs can be visualized for each activity in tables or graphs.

areas of land with specific characteristics and qualities. In each LU, 5 different crops can be grown, each with 18 possible production techniques (combinations of training system, irrigation system and frost control system). These combinations yield 1080 land-use systems (production activities). However, some activities can be discarded beforehand by the user as non-feasible through filtering (decision criteria based on agronomic knowledge).

Definition Criteria

Locations

FRUPAT was developed for the South Patagonian valleys of Río Chubut, Sarmiento, Los Antiguos and Río Chico (between 43° 14' and 48° 46' South latitude). The main differences among the valleys are their yield potentials due to differences in incoming radiation, air temperature and spring-frost risk and their price levels.

Edaphic environment

FRUPAT considers soils suitable for fruit-trees. Soil without physical nor chemical limitations is subdivided in “deep” (> 2 m) and “shallow” (between 1 and 2 m). Both soils have favourable physical (texture, structure, drainage capacity) and chemical (pH, sodium and salt content) properties that allow root growth without limitations, but in a shallow soil there is presence of an impermeable layer or water table near the soil surface during part of the year. Soils with low water holding capacity have no water-table influence and good drainage capacity, but are low in organic matter and nutrients and have very low cation exchange capacity.

Fruit-tree crop

Five fruit-tree crops are considered: sweet cherry, plum, peach, apple and walnut. They have different responses to suboptimal soil conditions and in phenology, which determines different frost resistance and harvest times.

Training system

As default values, walnut is planted as a central leader (without trellis) (313 trees ha^{-1}) or as a vase (156 trees ha^{-1}). The other crops can be trained as tatura (2,667 trees ha^{-1}), central leader (1,111 trees ha^{-1}) or as a vase (889 trees ha^{-1}). Different from the vase system, tatura and central leader are trellis systems (except for walnut).

Irrigation system

Irrigation is required because of the dry climate in all valleys under study (mean annual rainfall: 130 - 200 mm; potential ETP: 1240 - 1600 mm). Crops can be irrigated by drip or furrow irrigation system. Drip irrigation requires a higher investment, but is more efficient in water and N use, labour-saving and allows higher yields than furrow irrigation. Furrow irrigation allows better growth of leguminous species between the tree rows fixing N and a higher proportion of fallen leaves to be recycled.

Frost control system

Frosts are controlled using sprinkler irrigation systems or heaters or frost damage is avoided through selection of late-flowering varieties or favourable locations in the valleys. Sprinkling requires more expensive equipment, but operational costs are lower and it is effective against more severe frosts. The frequency of use depends on crop phenology and on the average number of frost events during the sensitive phenological stages. Passive frost control is usually only recommended for walnut, because of its late flowering.

Year of production

Location, crop species and training system determine the moment of maximum production and the rotation length of the crop. After maximum crop production, yield reductions due to disease problems and ageing effects can be taken into account.

Quantification of Inputs and Outputs (TC) of the Production Activities

The relevant TCs quantified for each year are: total expenditures (US$ ha^{-1}), gross value of product (US$ ha^{-1}), financial result (gross value of product minus total expenditures; US$ ha^{-1}), capital requirements (US$ ha^{-1}), break-even year to recover all preceding expenditures, permanent labour demand (persons ha^{-1}), monthly temporary labour demand (h ha^{-1}), biocide use per ha and per kg fruit (kg active ingredient (a.i.) and Toxic Units) and inorganic N-application (kg ha^{-1} and g kg^{-1} fruit). Calculation of TCs is based on scientific knowledge of the underlying physical, chemical, physiological and ecological processes, using a target-oriented approach. In the current study the target is a pre-determined yield level, from which all inputs needed for its realisation and the associated outputs are estimated. When process knowledge is incomplete or absent, calculations are based on expert knowledge, literature data or field observations. It was assumed that in all situations the growers work according to the best technical means. This concept implies that each input is applied optimally at a given production level (De Koning *et al.*, 1995). This reflects the rapid adoption of new technologies in the fruit sector in South Patagonia during the last decade.

Calculation Rules

Yield

FRUPAT allows introduction of any potential annual yield level at the mature stage for each combination of location, crop and training system. Yield is assumed to increase linearly from the first harvest to the mature yield level. Yield limiting factors include the use of suboptimal soils and furrow irrigation systems. Training system and location determine the length of the period till first harvest and that to reach stable production.

Inorganic nitrogen application

Nitrogen demand is estimated from the N exported in harvested fruits, that lost in the fraction of leaves that are not recycled and in the pruned wood. Symbiotically fixed nitrogen (inter-row pasture) can supply part (or all) of the requirements, reducing the fertiliser requirements, according to:

N_i: $(N_d - N_s)/ANR$

in which: N_i is the inorganic nitrogen application (kg ha^{-1}); N_d is the nitrogen demand of the crop (kg ha^{-1}); N_s is the symbiotically fixed nitrogen (kg ha^{-1}), assuming no losses thanks to the deep and extensive root system of trees, and ANR is the apparent nitrogen recovery (kg kg^{-1}), defined as a function of soil-type and irrigation system.

Biocide use

Biocide use is kept at the minimum requirements. Crop species dictates the required active ingredients (a.i.) and the location determines the number of applications. It is expressed as kg a.i. ha^{-1}, as g a.i. kg^{-1} fruit, as TU ha^{-1} and as TU Mg^{-1} fruit, where:

TU: a.i. • half-life / LD_{50}

in which: TU is Toxic Units; half-life is the time (d) required for degradation in soil of 50% of the a.i.; and LD_{50} is the Lethal Dose (mg kg^{-1} weight of rat), defined as the quantity that kills 50% of a population of rats.

Labour

A distinction is made between permanent and seasonal labour. Permanent labour comprises a manager and an adviser. Seasonal labour demand covers operations that can be done at any time of the year (e.g. installation of poles) and the main operations in specific seasons: January–April (e.g. summer pruning and fixing branches), June-August (e.g. planting); August (e.g. winter pruning), December (e.g. cherry harvest), etc. Labour efficiency for harvest varies with fruit size and training system (ease of picking).

Gross value of product

This variable is calculated as harvested product times price at farm gate. Three fruit quality classes are distinguished with different prices. The proportion of fruits in each class depends on training system (affecting light distribution and fruit damage due to wind or at picking) and location (different damage due to wind and transport).

Total expenditures

Expenditures are estimated for each year of the orchard's lifecycle and consist of physical investments (e.g. nursery trees, supporting structures, drip irrigation system and active frost control systems), annual inputs (e.g. biocides, fertilisers, rented beehives, electricity consumption and diesel), hired machinery and labour.

Financial result

The financial result is defined as the gross value of product minus the total expenditures. During the first years of the orchard's life cycle there is no production and therefore the financial result is negative. Once the financial result is positive, a few more years are needed to attain the first positive "cumulative" financial result (break-even year to recover the cumulative preceding expenditures).

Capital requirements

The capital requirements are calculated as the sum of the expenditures from the establishment year till the first year with a positive financial result.

Financial result/Capital requirements

This variable, expressed as a percentage, expresses the financial result of a mature orchard (12^{th} year) in relation to the capital requirements during the establishment period.

USING FRUPAT

The combination of the various definition criteria resulted in 1080 fruit-tree activities, but some of them were unfeasible and were discarded beforehand through filters (decision criteria based on agronomic knowledge). Following filtering, 432 feasible activities remained. Some of the results are presented here as an example: a single physical environment (deep soil with no limitations in the Río Chubut valley) using sprinkler irrigation as frost control method. First, 5 crops under a single production technique (vase with furrow irrigation) were compared in terms of their monetary technical coefficients. Subsequently, results of sweet cherry under different production techniques (3 training systems with 2 irrigation systems) are presented. The time course of gross value of product, total expenditures, financial result, cumulative financial result and labour demand was analyzed for a single activity (sweet cherry, trained as tatura under drip irrigation).

Comparing crops in terms of their monetary technical coefficients

Even though sweet cherry yields are low, their price is much higher than that of the other crops. Therefore, sweet cherry showed the highest gross value of product at maturity, followed by apple, peach, plum and walnut (Fig. 2). Financial result was also highest with sweet cherry, but followed by apple, walnut, peach and plum. Capital requirements were lowest for walnut because required fewer investments and had low operational expenditures. Sweet cherry demands high investments during establishment, but it showed an earlier positive financial result due to the high price of the fruit and therefore had the second lowest capital requirement.

Comparing production techniques

Production technique determines yield and the proportions of fruit quality classes, thus gross value of product and yield were not proportional. Despite having the highest investment required for establishment (mainly due to its high planting density and a more sophisticated trellis system), tatura got a high ratio of financial result at maturity/capital requirements (Table 1), similar to the combination of vase training system with drip irrigation and only slightly lower than central leader with drip irrigation. But the main difference is that the higher precocity and yield of the "tatura – drip irrigation" combination resulted in an earlier recovery of cumulative expenditures compared than for the other techniques.

ANR was lower under furrow irrigation. However, the lowest inorganic N-application per ha for this irrigation system was the consequence of an established inter-row leguminous crop that covered part of the nitrogen demand at maturity. Under the drip irrigation system, vase required slightly higher inorganic N-application per ha

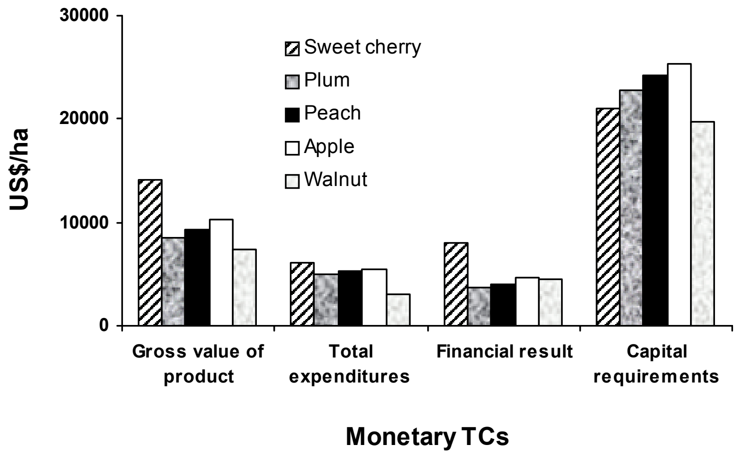

Fig. 2. Gross value of product, total expenditures and financial result of a mature orchard, and capital requirements for the 5 crops in a deep soil with no limitations in the Río Chubut valley, trained as a vase, with furrow irrigation and frost protection with sprinkler irrigation.

and per kg of fruit than central leader and tatura. Biocide use per unit of product was inversely proportional to yields, because biocide use per unit area depended only on crop and location, a single combination in the present example.

Labour demand is related to yields and fruit-picking efficiency of the training system. The highest demand was with vase training system in combination with drip irrigation, while the tatura combination resulted in the lowest labour demand.

Evolution in time of some technical coefficients

Gross value of product started on first harvest in the 3rd year, increasing until the 7th and starting to decline after the 12th (Fig. 3A). The highest total annual expenditures occurred at planting, although the sprinkler irrigation system for frost control represented a substantial expenditure during the 3rd season (Fig. 3B). Hence, the financial result became positive only in the 4th season (Fig. 3C), while cumulative financial result was positive from the 7th (Fig. 3D). Planting and installing structures were the reasons for the relatively high labour demand during the first year (Fig. 4A). From thereafter, total labour demand was basically driven by the harvesting requirements when the orchard started to produce. Harvesting was concentrated in November and mainly December, thus hired-labour demand was highest in these months (Fig. 4B). January to March were the months in which summer pruning and

Table 1. Technical Coefficients of a mature sweet cherry orchard (12th year) grown in the Río Chubut valley on a soil without limitations, frost protected through sprinkling irrigation, trained as tatura, central leader or vase, under drip or furrow irrigation.

Training system(1)	Tatura	Central leader		Vase	
Irrigation system(1)	Drip	Drip	Furrow	Drip	Furrow
Yield (Mg ha^{-1})	13.5	12.6	11.3	12.6	11.3
Gross value of product (US\$ ha^{-1})	18617	16472	14825	15637	14073
Total expenditures (US\$ ha^{-1})	5928	6089	5616	6623	6092
A. Financial result (US\$ ha^{-1})	12688	10383	9209	9013	7981
B. Capital requirements (US\$ ha^{-1})	32761	26666	24483	23283	21053
A/B * 100	38.7	38.9	37.6	38.7	37.9
Break-even year to recover cumulative preceding expenditures	7	9	9	9	9
Inorganic N-application per area (kg ha^{-1})	56	56	27	58	29
Inorganic N-application per product (g kg^{-1} fruit)	4.1	4.4	2.4	4.6	2.6
Biocide use (g a.i.(2) kg^{-1} fruit)	2.5	2.7	3.0	2.7	3.0
Biocide use (TU(3) Mg^{-1} fruit)	0.26	0.27	0.30	0.27	0.30
Total labour demand (h ha^{-1} $year^{-1}$)	2093	2170	2093	2496	2400

(1)The combination "tatura-furrow irrigation" was filtered as unfeasible; (2)active ingredient; (3)Toxic Units (see text for explanation).

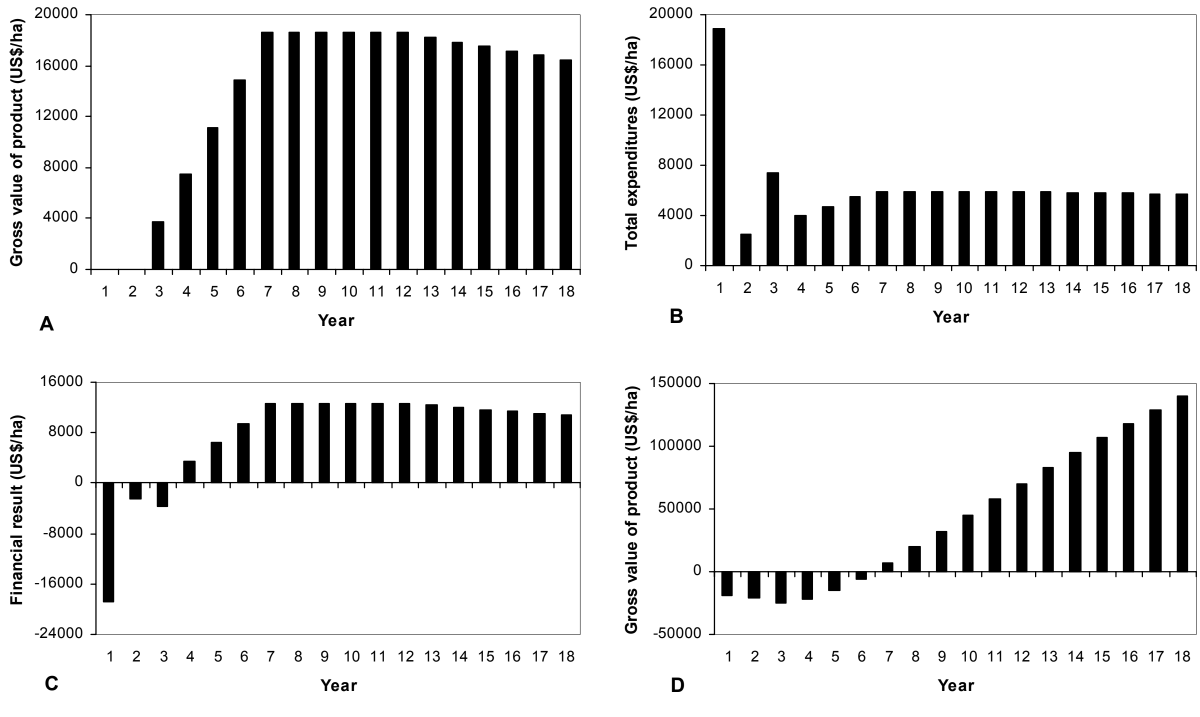

Fig. 3. Time course of gross value of product (A); total expenditures (B), financial result (C) and cumulative financial result (D) of sweet cherry in a class 2-deep soil of the Río Chubut valley, trained as tatura, with drip irrigation and frost protected with sprinkling irrigation.

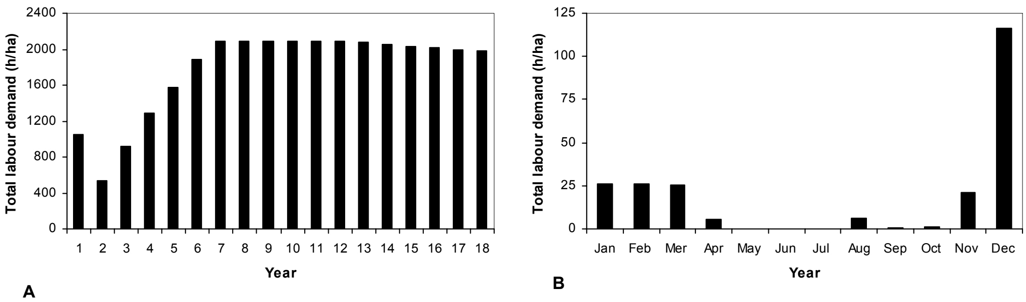

Fig. 4. Time course of total labour demand (A) and monthly hired-labour demand of a mature orchard (12th year) (B) of sweet cherry in a deep soil with no limitations in the Río Chubut valley, trained as tatura, with drip irrigation and frost protected with sprinkling irrigation.

fixing branches was performed. This strongly seasonal labour pattern could be an important limitation for regional development of the crop.

CONCLUSIONS

This study presents the first attempt to systematically quantify inputs and outputs for fruit production systems in Patagonia. However, field information was scarce, especially for yield potentials. This situation may be improved by incorporating new knowledge into FRUPAT where most parameter values can be incorporated without modifying the basic structure. The examples presented in this paper illustrate the way in which the software can be used to analyse and compare different combinations of crops, production techniques and physical environments. It also allows analyses over time for long-term explorations. The program can be used also to identify limitations for the feasibility of crops, such as capital requirements or strong seasonality of labour demand. FRUPAT can generate and quantify large numbers of theoretical land use systems based on existing knowledge before embarking on actual field experimentation. It can be used as a stand-alone tool for simple analysis, as demonstrated in this paper, or as an intermediate step in multi-objective linear programming.

7

Exploring options for farm-level strategic decision-making in fruit production systems of South Patagonia, Argentina

Submitted as:

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ABSTRACT

In South Patagonia, Argentina, sweet cherry is practically the only fruit-tree crop grown for export, resulting in a highly seasonal labour demand. Managers of deciduous perennial fruit orchards must consider both biological and economic relationships in selecting crop species and orchard design making decisions at farm level extremely complex, as especially in such perennial crops, strategic decisions ('what to plant', 'when', 'with which technology' and 'how much area of each activity') have a long-term effect. The objective of this study was to explore the consequences of different strategic decisions at farm scale in fruit production systems of South Patagonia, considering the variation in interests and aims of different stakeholders, and using a scenario approach to analyse the consequences of eventual changes in external conditions. A dynamic farm-scale optimization model called OPTIFROP was developed to generate alternative farm development plans, by allocating, in the course of the time horizon of the run, production activities to different land units, while optimising different objective functions, subject to several constraints. The model includes four objective functions at farm level: (1) maximization of the present value of cumulative financial result (PV-CFR); (2) maximization of cumulative farm labour (CUM-LABOUR); (3) minimization of cumulative farm labour and (4) minimization of the maximum inter-months deviation for labour demand (during the period of high labour demand: November to April) (LABOUR-DEV). Input and output coefficients for the land use options considered in OPTIFROP were quantified using the Technical Coefficient Generator FRUPAT. The model allowed identification of objectives that are conflicting (e.g. PV-CFR and LABOUR-DEV) and those that are so to a very limited extent (e.g. PV-CFR and CUM-LABOUR). Results of the model indicated that, although the timing and feasibility for implementing certain combinations of production technologies are affected by resource endowments and initial conditions, those factors do not influence land use selection in the long term that is driven by the objectives of the stakeholders. OPTIFROP showed that, through introduction of alternative crops, substantial reductions in labour peaks in the period November-April could be achieved with a relatively small reduction in farm income. The sensitivity of the model solution to the cherry price suggests that the fruit production sector of South Patagonia should pay more attention to the robustness of their land use plans and take preventive measures to avoid being caught unaware by a possible crisis due to changes in the context.

Keywords: Sweet cherry; Development plan; Linear programming; Trade-off; Labour demand; Seasonality

INTRODUCTION

In South Patagonia (Provinces of Chubut, Santa Cruz and Tierra del Fuego), Argentina, sweet cherry is practically the only fruit-tree crop grown for export. The crop has increased dramatically in area and production volume in the last decade thanks to favourable biophysical conditions such as suitable climate, abundant availability of land and water in various valleys, to government support through research, extension and financial assistance, and most importantly, because of the favourable economic conditions, as the crop enters the market in counter-season compared to the Northern Hemisphere (Cittadini *et al.*, in press[c]).

In addition to the regional income generated by the sector, policy makers generally positively appreciate its employment-generating capacity. However, labour demand in sweet cherry production is highly seasonal, being concentrated during harvest and post-harvest. Labour supply (both, in numbers and in skills) is already an important restriction during these periods that could well aggravate in the near future. Moreover, social problems may aggravate during the remainder of the year, especially if labourers immigrate from other regions, attracted by job opportunities, often with too high expectations. Possible beneficial effects on income and labour generation may not be sufficient to compensate for the cost of environmental degradation, especially pollution of groundwater with chemical residues (biocides and leached nutrients). Moreover, biocide use has to be harmless for beneficial insects and humans (both workers and consumers).

Managers of deciduous perennial fruit orchards must consider both biological and economic relationships in determining preferred fruit type and orchard design (Hester and Cacho, 2003), making decision-making at farm level extremely complex, as especially in such perennial crops, strategic decisions ('what to plant', 'with which technology' and 'how much area of each activity') have a long-term effect. Establishment of fruit-tree orchards requires high initial investments, and adaptations are difficult and slow, and moreover, may be constrained by financial, labour or other restrictions. Therefore, 'when to plant' also becomes relevant and a multi-annual approach is required, to take into account differences in inputs and outputs in different growth phases of the orchards (Bessembinder, 1997). Therefore, decision support tools, allowing exploration of different options (i.e. development plans at farm level), given variation in resource endowments and objectives of different stakeholders, would be helpful in informed decision-making.

Models have been shown to be suitable for such decision support, as they have the capacity to explore alternative possibilities (Mendoza *et al.*, 1986; De Wit *et al.*, 1988; Rossing *et al.*, 1997; Van Ittersum *et al.*, 1998; Hengsdijk and van Ittersum, 2002), and in a multi-period model can take into account the time dimension of alternative development plans (Spharim *et al.*, 1992).

Interactive Multiple Goal Linear Programming

Interactive Multiple Goal Linear Programming (IMGLP) is a technique especially suitable for dealing with problems in which several objectives have to be optimised simultaneously (Mendoza *et al.*, 1986). The levels of attainment of the different objectives can be expressed in their respective units, and no *a priori* weighting of their relative importance is required (Ten Berge *et al.*, 2000). Its application supports transparent discussion on feasible developments and on trade-offs between different biophysical and/or socio-economic objectives (Rossing *et al.*, 1997; Van Ittersum and Rabbinge, 1997; Van Ittersum *et al.*, 1998). The goal-oriented identification and design of feasible land use systems, i.e. in our case restricted to fruit orchards at farm level, depends on the land-related objectives of a system under study (Hengsdijk and van Ittersum, 2002). Successively, all objectives are individually optimised, without any restriction on any of the other objectives. Subsequently, an iterative cycle is started in which again each of the objectives is optimised in turn, while the other objectives are set at target-values and act as constraints, that are gradually tightened, which shows which objectives are conflicting and to what extent (Ten Berge *et al.*, 2000). Therefore, the method can support identification of feasible end-points of development within a wide range of technical and socio-economic scenarios and a variety of aims and aspirations of various stakeholders, and so explore the margins for strategies to follow. At regional level, it enables communication between policy, planning and research and can therefore serve as a tool for more efficient formulation of regional development policies (De Wit *et al.*, 1988). The aim of the approach is not to predict, but to explore the window of opportunities (Van Ittersum *et al.*, 1998; Kropff *et al.*, 2001). The method also assumes that all activities are performed according to the 'best technological means' (Van Ittersum and Rabbinge, 1997). The concept implies that, at field level, inputs and outputs are optimally allocated.

Different farmers may have different resources, skills, aims, expectations, aspirations and/or preferences, and the development objectives of farmers may differ from those of other stakeholders. When using IMGLP, several objective functions are defined for the different stakeholders and restrictions can be interactively tightened or relaxed, to mimic this variability among stakeholders' characteristics.

A scenario approach, in which the effects of external conditions (e.g. price of product, cost of labour and/or labour availability) on optimal resource allocation in the future is analysed, could be a suitable complementary method to make better decisions in the present about issues that have long-term consequences. Moreover, it may be useful to open the discussion with reluctant stakeholders, analysing 'what if' questions in a transparent way.

The objective of this study was to explore the consequences of different strategic decisions at farm scale in fruit production systems of South Patagonia, considering the variation in interests and aims of different stakeholders, and using a scenario approach to analyse the consequences of eventual changes in external conditions.

OPTIFROP: A MULTI-YEAR MODELLING APPROACH

OPTIFROP (OPTImization of FRuit Orchards in Patagonia) is a dynamic farm-scale optimisation model able to allocate, in the course of the time horizon[1] of the run, production activities to different land units, while optimising different objective functions, subject to several constraints (Fig. 1; Appendix). The model is programmed as an interactive multiple goal linear program (IMGLP) (De Wit *et al.*, 1988), and has been written in GAMS using the CPLEX solver[2] (McCarl, 2007).

The mathematical formulation of an IMGLP model is similar to that of any LP model:

Maximize or Minimize $\{w_n = \underline{c}_n{'}\underline{x}\}$

Subject to:

$A\underline{x} = \underline{b}$

$\underline{x} \geq \underline{0}$

where w_n are the objective functions: linear functions of the production activities (x) and their respective contributions (c: vector of coefficients) for the objectives. A is an $m \times n$ matrix with input–output coefficients for all production activities and $\underline{b}$ represents the $m \times 1$ right hand side (RHS) vector, i.e. the thresholds values for the restrictions. Each production activity (or land use option) is completely characterized

[1] When a multi-period analysis is used, the activities may end at different moments and for only a few of those, that moment will coincide with the time-horizon of the model. Therefore, usually terminal conditions have to be specified (McCarl and Spreen, 1997). If not, the results that relate to the final years are 'distorted' and should be ignored (Spharim *et al.*, 1992). In the present study, the second approach was used and runs for 80, 60, 50, 40 and 30 years were performed to observe differences in the steady state. Based on these preliminary results and after analysing the cycles of land use patterns, the horizon of the model was set to 50 years, but only the first 30 years were considered for further analyses of land use selection.

[2] The CPLEX solver allowed running the model approximately 20 times faster than CONOPT.

by its input and output coefficients and is identified by the combination of a number of definition criteria (in this case: crop species (c), edaphic environment (s), training system (r), irrigation system (i), frost control system (f) and moment of installation of the frost control system (m)). A multi-year approach was applied, because the fruit-tree crops considered in the study are perennial crops. Therefore, the age of the orchards (a) and the model year (t) were mathematically considered as two extra sets.

The model was designed to explore possibilities for combining production activities under different scenarios. Starting conditions, such as initial budget and current orchards can be easily set. Main outcomes of the model are the selected combinations of crop species and production techniques, the area of each combination assigned to specific land units and the timing (with an annual time step) of implementation of the orchard development plan. Thus, OPTIFROP allows construction of curves showing the trade-offs between objectives and assessment of the effects of possible changes (in the course of the model run) in the values of important external drivers (prices of specific products, labour cost and labour availability).

The model includes four objective functions at farm level: (1) maximization of the present value of cumulative financial result (PV-CFR; US\$ x 10^3); (2) maximization of cumulative farm labour (CUM-LABOUR; h x 10^3); (3) minimization of cumulative farm labour and (4) minimization of the maximum[3] inter-months deviation for labour demand (during the period of high labour demand due to thinning and/or harvest: November to April) (LABOUR-DEV; h x 10^3). Economic/financial objectives are usually assumed the main (or even the only) aim of the growers. Maximizing total labour is an objective for policy makers that wish to generate employment opportunities, but growers generally prefer to manage as few people as possible to avoid logistic problems at their farms. The model has a yearly time step, but calculation of labour demand for each month in each year allows analysing intra-year labour distribution. An evenly distributed labour demand is desirable for both, growers (to reduce necessity of hiring and firing people continuously) and policy makers (to reduce socially negative consequences).

OPTIFROP includes constraints that reflect the resource endowments of the farm (area of each edaphic environment) and its environment (labour availability per month). Initial conditions of existing farms, such as initial budget and areas of orchards of different ages already present in each edaphic environment, have to be specified by the user. Other farm-level restrictions can be included, such as biocide use (TU: Toxic Units and/or kg a.i.) and inorganic nitrogen application (kg)[4].

[3] Usually called a mini-max problem.

[4] Preliminary runs for analyzing the trade-off between PV-CFR and CUM-LABOUR, subject to upper bound values of biocides use and inorganic nitrogen application, showed that tightening the restrictions leaded to a

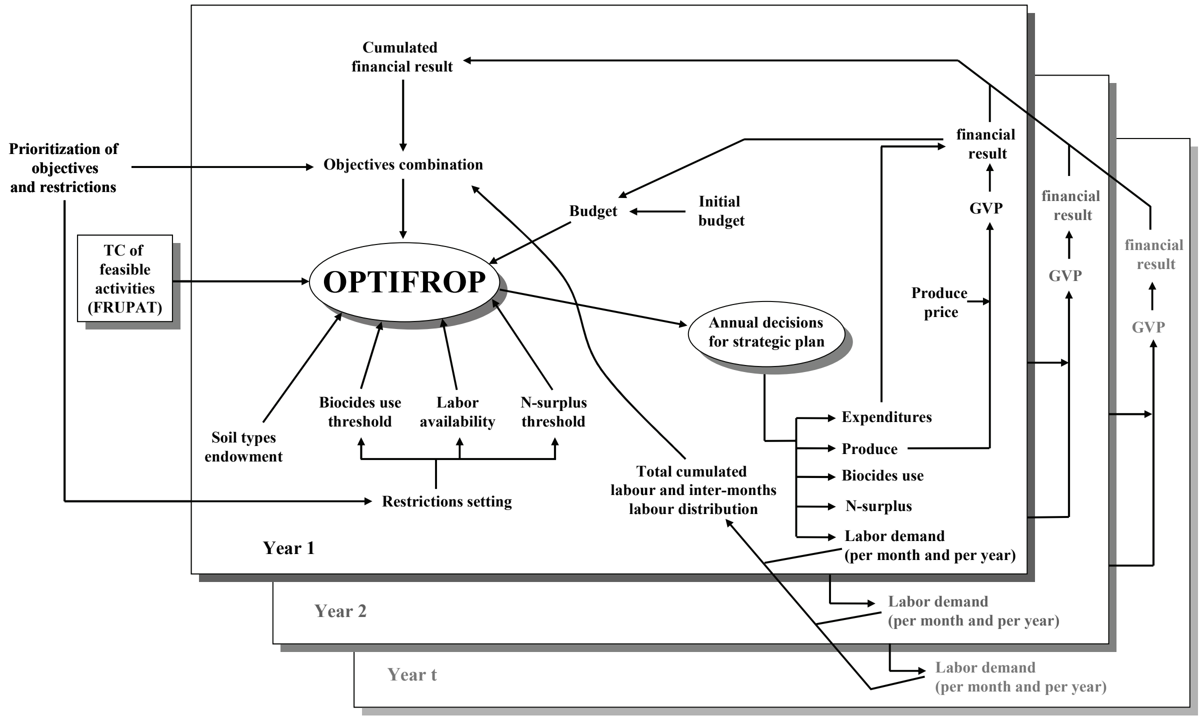

Fig. 1. Structure of OPTIFROP, showing the main components, its inputs and outputs. The time dimension is represented by the different connected planes.

Land use options

Training, pruning and other operations characterizing an orchard system are usually determined at planting and normally remain unchanged during the lifespan of the orchard (Hester and Cacho, 2003). In the context of this paper, such orchard systems are referred to as land use options or production activities, which include also the land unit in which the orchard system is established.

Input and output coefficients for the land use options considered in OPTIFROP were quantified using the Technical Coefficient Generator (TCG) FRUPAT (Cittadini, 2005; Cittadini *et al.*, 2006a), that allows combining crop-tree species (c: sweet cherry; apple; plum; peach; walnut), edaphic environment (s: soils with no limitations; shallow soils; soils with low water holding capacity), training system (r: tatura; vase; central leader), irrigation system (i: drip; furrow) and frost control system (f: sprinkler irrigation; heating; passive). The original version of FRUPAT (Cittadini, 2005;

reduction in area, but did not affect land use selection (data not shown). This is because the present study was restricted to fruit-tree crops with similar coefficients with regard to these outputs. Therefore, biocides use and inorganic nitrogen application were no further considered.

Cittadini *et al.*, 2006a) assumed that the frost control system was always installed just before the first expected crop. This was in line with the principle of ‘best technical means’ (Van Ittersum and Rabbinge, 1997). However, as mentioned before, what is best at field level, might not be best at farm level under a situation of limited resources. For instance, a financial restriction at the moment that the frost control system ‘should’ be installed, may imply a choice between installation of the frost control system and establishment of new orchards on the farm. At farm level, from an economic point of view, it may be ‘best’ to postpone installation of the frost control system (until yields of present orchards are substantial), and first plant more trees. Therefore, FRUPAT was modified by incorporating a new set ‘Moment of installation of the frost control system’ (m), giving the possibility of installing the system just before the first crop is expected or two years later (Table 1).

Some combinations do not exist (passive frost control system has no moment of installation), were considered technically unfeasible (walnut in shallow soils, tatura with furrow irrigation, furrow irrigation on shallow soils) or knowledge about their inputs and outputs was insufficient (walnut in tatura). These options were therefore filtered in FRUPAT and not taken into account in further calculations. Plum and peach were only included with the heating frost control system, because they bloom very early in the season and therefore passive control is not an option, and on most farms sprinkler irrigation is no option, as water distribution (through the irrigation network) starts later. After filtering, feasible land use options were completely characterised by

Table 1. Sets, index letter and set components used in OPTIFROP.

Set	Index	Components[a]
Soil (edaphic environment)	s	No limitations, shallow and low WHC
Crop species	c	Cherry (Ch), apple (Ap), plum (Pl), peach (Pe) and walnut (Wa)
Age of the trees (years)	a	1 to 25[b]
Training system	r	Tatura (TT), vase (VS) and central leader (CL)
Irrigation system	i	Drip (D) and furrow (F)
Frost control system (FCS)	f	Sprinkling (SK) irrigation and heaters (HT)
Moment (year) of installation of FCS	m	First expected harvest (C1) or two years later (C+2)
Year in the model	t	1 to 50

[a] Combinations of codes (between brackets) are used to indicate land use activities in the text.

[b] FRUPAT can generate a maximum of 25 years for each land use option. The specific maximum lifespan values used for generating data for OPTIFROP were defined based on crop species and training system.

their inputs and outputs at each orchard age (a) until their maximum lifespan (varying, depending on crop species and training system).

PLAUSIBILITY OF MODEL RESULTS

Effect of differences in resource endowment and initial conditions

The model was run for three hypothetical farms that represent current situations in South Patagonia (Table 2), to investigate the influence of resource endowments and initial conditions (edaphic environment, orchards present and financial resources) on the selection of production activities and to compare model results with results of current commercial farms. Preliminary runs showed that initial budget and the requirements for personal consumption only determined the time required to implement a certain development plan, but that selection of species and techniques was not affected (data not shown). Therefore, in the further analyses, farms were not differentiated with regard to these characteristics.

PV-CFR[5] and CUM-LABOUR were each maximized in two subsequent runs without imposing restrictions on the other objective functions. In both runs, labour per month, inorganic nitrogen application and biocide use[6], and labour availability were assumed to be no-limiting. However, resource endowments, initial conditions characterising each farm and a minimum requirement for personal consumption (Table 2) were imposed. Prices were assumed constant in all cases. In further runs, in which either CUM-LABOUR or LABOUR-DEV was minimized, a minimum of 50% of the potential PV-CFR was set as restriction.

Soil quality and initial land use (area and type of orchards present) affected the objective values (Table 3), but the production activities selected in the long term were determined by the objective function. Second quality soils were used only after the best edaphic environments were fully used by crops, but soil quality did not affect the final selection of crop-technique combinations. Current orchards in farms B and C were used as initial sources of income, but were latter replaced by land use activities driven by the objective functions.

[5] To calculate PV-CFR, discount rates of 3, 5 and 8% were used. The lowest value is approximately the interest on bank deposits (in dollars) in Argentina, while 8% is approximately the interest rate in Argentinean banks on loans in the same currency. Logically, the discount rate affected the values of PV-CFR, but the effect on land use selection was minor, because timing for starting to crop and to reach maturity is similar for all crops considered. In the present study, a discount rate of 3% was used for further calculations.

[6] Presently, in South Patagonia there are no thresholds for biocide use and inorganic nitrogen application. The only restriction is the rational use and book keeping demanded by voluntary regulations such as EUREP-GAP, which was taken into account in the parametrization of FRUPAT.

When the objective PV-CFR was maximized, "Ch-TT-D-SK-C1" was selected in all three farms (see Table 1 for explanation of coding). When CUM-LABOUR was maximised, "Ch-VS-D-SK-C1" was selected, while "Wa-CL-D-SK-C1" was selected when CUM-LABOUR was minimised, combined with small areas with "Wa-CL-D-SK-C+2" and "Ch-TT-D-SK-C1". Minimizing LABOUR-DEV resulted in selection of all crops except peach, with variation in frost control system and moment of installation, and with small fractions planted each year, resulting in a large dispersion of orchards' ages.

Comparison of these results with the decisions taken currently by growers in South Patagonia, suggests realistic behaviour of the model. During the last decade, sweet cherry has been practically the only fruit-tree crop planted (Cittadini *et al.*, in press[c]) and the tendency has been to select production activities with high technology (e.g. tatura training, drip irrigation and sprinkler irrigation for frost control). These activities were also selected in the model, when PV-CFR was maximised. Replacement of old (low productive) walnut and apple orchards has also been observed, specifically among growers facing limitations in land area. As in the model, usually Patagonian growers first establish orchards on the best soils and subsequently continue on those of lower quality, but production activities do not differ among soil types (within the range of soils suitable for fruit-tree-crops).

Table 2. Main characteristics and initial conditions of three hypothetical farms reflecting the current situation.

Characteristics	Farms		
	A	B	C
Total area (ha)	20	20	20
Soils without limitations (ha)	20	10	15
Soils with low WHC	0	0	5
Shallow soils	0	10	0
Present orchards (ha)	0	5	2
Crop species	–	Cherry	Walnut
Soil type used	–	No limitations	No limitations
Age (years)	–	8	20
Training system	–	Vase	Vase
Irrigation system	–	Drip	Furrow
Frost control system	–	Sprinkler irrigation	None
Initial budget (US$ x 10^3)	200	200	200
Personal consumption (US$ x 10^3)	10	10	10

Table 3. Results of runs[a] for each of the three hypothetical farms.

Objective function	Farm A			Farm B			Farm C		
	PV of cumulative financial result (US$ x 10^3)	Cumulative labour (h x 10^3)	Inter-months labour deviation (h x 10^3)	PV of cumulative financial result (US$ x 10^3)	Cumulative labour (h x 10^3)	Inter-months labour deviation (h x 10^3)	PV of cumulative financial result (US$ x 10^3)	Cumulative labour (h x 10^3)	Inter-months labour deviation (h x 10^3)
Maximization of PV-CFR	2725	1474	17.1	2999	1692	17.9	2724	1496	16.7
Maximization of CUM-LABOR	1997	1801	25.0	2126	1885	22.9	1894	1804	24.4
Minimization of CUM-LABOR[b]	1362	386	4.2	1500	504	10.5	1362	386	3.8
Minimization of LABOUR-DEV[b]	1362	792	0.5	1500	700	5.2	1362	807	0.5

[a]All runs were set for 50 years.
[b]At minimization of CUM-LABOUR and LABOUR-DEV, 50% of the potential PV-CFR was set as lower bound.

The vase training system that is observed in several production areas of the region, does not correspond with the aim of maximizing employment opportunities, but with growers' experience and history (e.g. in Los Antiguos (Cittadini *et al.*, in press[c])), with the ease of understanding of the principles behind management of this system and with the lower capital requirement of this training system. Currently, the variation in fruit-tree species is restricted, suggesting that, so far, minimization of the maximum labour deviation has not been driving the strategic decisions.

Hence, this comparison suggests that the main objective of the growers is to maximize financial/economic results, in agreement with their own statements.

SCENARIO ANALYSIS

Trade-off between objectives: farm level choices

IMGLP is a suitable method to generate trade-off curves between objectives. When constructed for the full set of objectives, it provides a complete picture of options and their respective consequences (Ten Berge *et al.*, 2000).

Trade-off analyses were performed for farm A (Table 2) to identify conflicting objectives and their interferences and to illustrate the consequences of these conflicts for the selection of different production activities. PV-CFR was maximized while LABOUR-DEV was restricted to upper bounds; CUM-LABOUR was both minimized and maximized while PV-CFR was restricted to lower bounds; and this objective was also maximized while LABOUR-DEV was restricted to upper bounds.

Maximization of PV-CFR subject to an upper bound on LABOUR-DEV

PV-CFR was 2725 x 10^3 US$ when LABOUR-DEV was not binding (more than 17.1 x 10^3 h). The only land use option selected was "Ch-TT-D-SK-C1" and all the available land was in use by the 12^{th} year of the model. LABOUR-DEV could be substantially reduced to approximately 14.4 x 10^3 h (Fig. 2) simply by combining different ages of the same production activity. In this range, PV-CFR decreased by 9.8 US$ per h of LABOUR-DEV. Further restriction of LABOUR-DEV led to allocation of small pieces of land to "Ap-TT-D-SK-C1" and "Wa-CL-D-SK-C1". The area with these land use options increased as the restriction was tightened, until 1200 h (7% of the unbounded value), where PV-CFR was 61.7% of its maximum (1682 x 10^3 US$). Within this range of LABOUR-DEV, PV-CFR decreased at a moderate rate of 65.7 US$ per h LABOUR-DEV. At still further restriction of LABOUR-DEV, also "Pl-TT-D-HT-C1" and "Pl-VS-D-HT-C1"were selected and PV-CRF drastically declined.

Land use options with peach were practically never selected, because peach has a similar labour demand pattern as plum and is economically less attractive.

Fig. 3 is a graphical representation of the model-calculated temporal labour distribution (from November to April) during the first 17 years of farm development under maximization of PV-CFR, and LABOUR-DEV constrained to 1.2 (A) and 17.1 (B) h x 10^3. A more even labour distribution throughout the years also resulted in much lower monthly labour demands (Figure 3A). In year 17, in December, the most demanding month in both cases, labour demand was 3.5 and 18 x 10^3 h in situation A and B, respectively. This type of analysis supports a transparent discussion on the consequences of possible future labour shortages for the feasibility/desirability of alternative farm-level development plans, i.e. replacing the current cherry monocultures, even though they are optimal under the current conditions.

Maximization of CUM-LABOUR subject to a lower bound on PV-CFR

When maximizing CUM-LABOUR, a lower bound on PV-CFR was not affecting the solution up to 2000 x 10^3 US$ (Fig. 4). Below that threshold value, 5.5 ha of "Ch-TT-D-SK-C1" was planted in the first year of the model, and from the 6^{th} year onwards small areas of this same land use type, but trained as vase, were planted each year, until all available land of the farm was occupied at the 9^{th} year. For this 20 ha farm,

Fig. 2. Trade-off between PV-CFR (objective function that is maximized; 10^3 US$) and upper bound on LABOUR-DEV (10^3 h) during the period November-April.

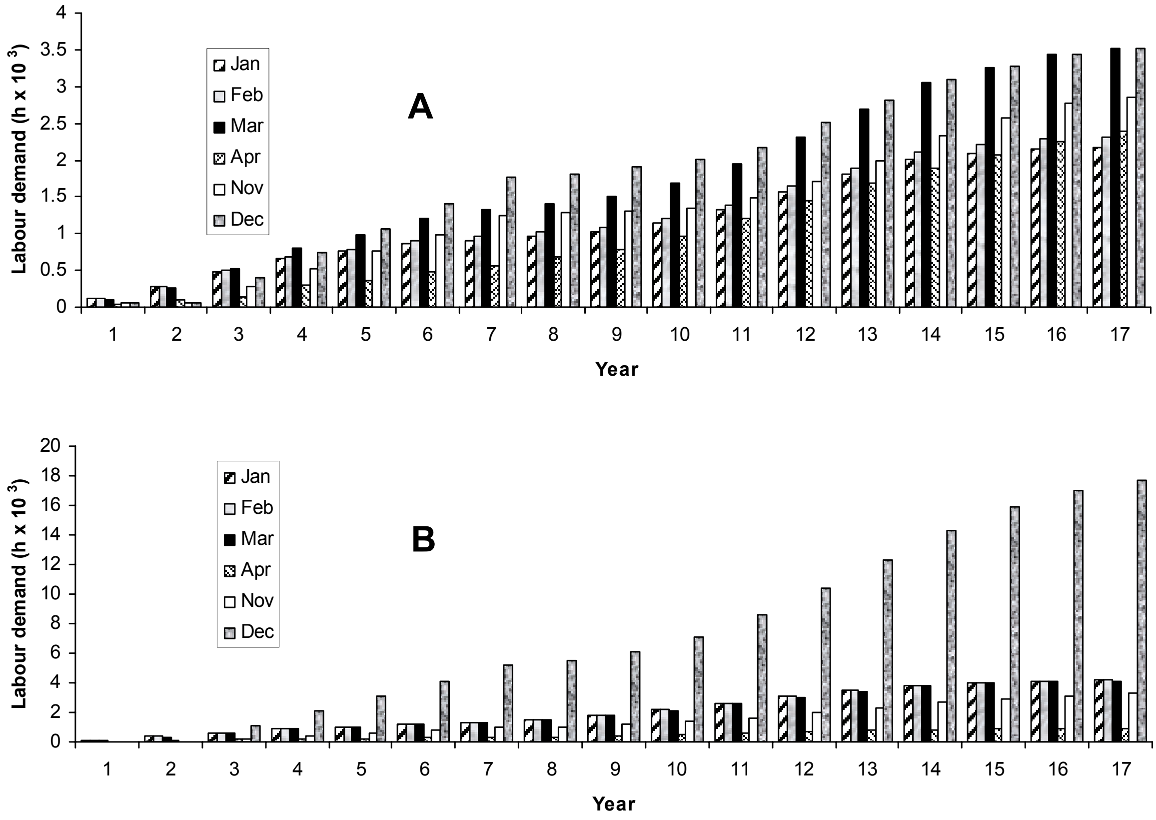

Fig. 3. Monthly labour demand (from November to April) during the first 17 years of the farm-level development plan when PV-CFR is maximized, subject to an upper bound on LABOUR-DEV of 1.2 (A) and 17.1 (B) h x 10^3.

this resulted in a labour demand of 1801 x 10^3 h for the 50 years period (i.e. an average of 1801 h ha^{-1} $year^{-1}$).

Further increasing the acceptable lower bound on PV-CFR led to a decrease in the objective value of CUM-LABOUR, associated with a gradual increase in tatura-trained sweet cherry at the cost of vase-trained sweet cherry, without other changes in the production activity. When minimum PV-CFR was set to a lower bound of 2725 x 10^3 US$ (above this threshold the model becomes unfeasible), CUM-LABOUR was 1474 x 10^3 h and "Ch-TT-D-SK-C1" was the only production activity selected.

Thus CUM-LABOUR and PV-CFR are hardly conflicting, and high values of both objectives can be attained simultaneously. The only difference in choice of production activities is the selected training system.

Minimization of CUM-LABOUR subject to a lower bound on PV-CFR

Obviously, minimization of CUM-LABOUR, which can be a growers' objective as a way of reducing management and logistic problems, and maximization of PV-CFR are conflicting objectives. Minimizing CUM-LABOUR with no lower bound on PV-CFR still led to some activities because some income is needed for personal consumption (set to 10,000 US\$ year^{-1}; Table 2), resulting in a PV-CFR of 119 x 10^3 US\$, while CUM-LABOUR was 34.9 x 10^3 h (Fig. 4). In that situation, only 1.6 ha was planted of "Wa-CL-D-SK-C1".

Increasing the lower bound on PV-CFR led to a remarkably increase in labour needs, and gradual expansion of this land use type, however, using heating as frost control method. To achieve at least 1000 x 10^3 US\$, small areas of "Ch-TT-D-SK-C1" were planted. As the restriction was further increased, the relative importance of latter activity also increased, until it became the only production activity when minimum PV-CFR was set at a lower bound of 2725 x 10^3 US\$ (as said before, above this value the model becomes unfeasible), with CUM-LABOUR equal to 1474 x 10^3 h. Other crops were not selected in any of the runs.

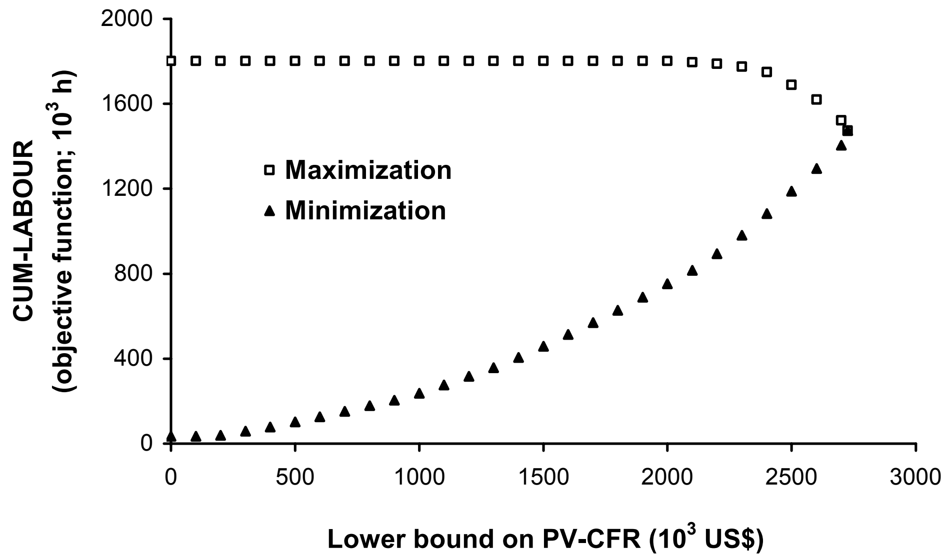

Fig. 4. Trade-off between CUM-LABOUR (objective function that is maximized and minimized; 10^3 h) and lower bound on PV-CFR (10^3 US\$)[7].

[7] Although the plots in this figure suggest a smooth relation, the curves have a piecewise linear pattern, as in the other trade-off curves.

Maximization of CUM-LABOUR subject to a lower bound on LABOUR-DEV

For policy makers, activities generating job opportunities are attractive. However, an uneven intra-annual distribution of the demand might create undesirable social effects. Therefore, in the next step of the analysis CUM-LABOUR is maximized, while restricting inter-months variability (LABOUR-DEV).

Maximization of CUM-LABOUR with no restriction on LABOUR-DEV (above 25 x 10^3 h) resulted in 1801 x 10^3 h, using all available land planted to "Ch-VS-D-SK-C1", as presented in a previous section. Tightening LABOUR-DEV reduces CUM-LABOUR, but until 20.8 x 10^3 h to a limited extent (on average, 5.3 h of CUM-LABOUR per h of LABOUR-DEV) (Fig. 5). The main modifications in the farm-level development plan were the introduction of small areas of "Ch-TT-D-SK-C1" and "Ch-VS-F-SK-C1". Below the 20 x 10^3 h point, also "Ap-TT-D-SK-C1" was selected. At about 18.4 x 10^3 h labour deviation, "Ap-VS-F-SK-C+2" was included. Some "Pl-TT-D-HT-C1" and "Pl-VS-F-HT-C+2" was included below 4000 h, of which the area increased as the restriction was tightened. At lower LABOUR-DEV, several walnut technologies were selected, with a large variation in age of the different activities.

In general, the shape of the trade-off curve and the selected production activities at different points are comparable to the PV-CFR vs. LABOUR-DEV analysis, supporting the conclusion of limited conflict between PV-CFR and CUM-LABOUR.

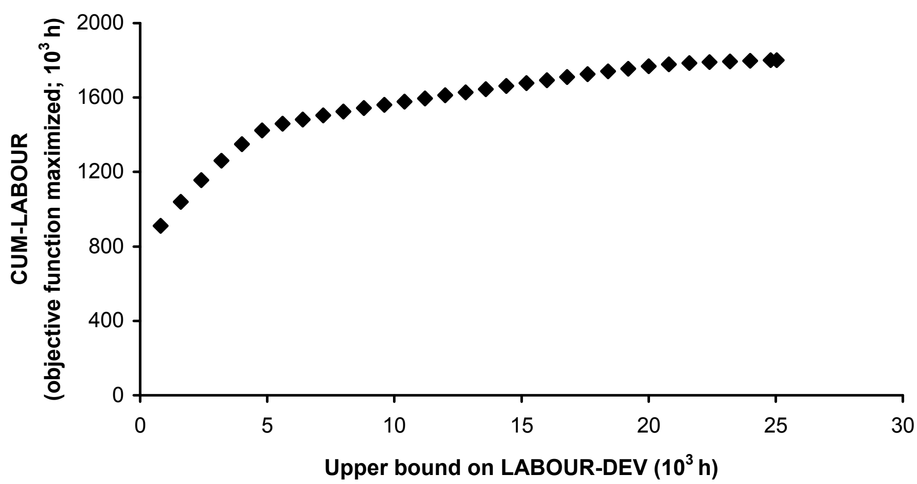

Fig. 5. Trade-off between CUM-LABOUR (objective function that is maximized; 10^3 h) and upper bound on LABOUR-DEV (10^3 h) during the November-April period.

Effect of the context: external drivers influencing optimal farm-level development plan

Growers' decisions influence costs and profit per hectare and are made in the context of uncertain future prices of inputs and outputs (Hester and Cacho, 2003). In addition to choices that different stakeholders can make with regard to objectives and acceptable levels for restrictions, external drivers, such as trends in prices of the (presently) most profitable product, cost of labour and labour availability, may affect the optimal combination of production activities at farm level.

In South Patagonia, labour cost increased, in real terms, by 37% from 2005 to 2007 (Pugh, INTA-EEA Chubut, *pers. comm.*). Concurrently, growers constantly complained about difficulties to hire workers during the peak season, a problem that seems to increase each year. During the same period, average cherry prices received by growers dropped approximately 27%. Although these developments may have been associated with specific situations, it shows the relevance of analysing the consequences of a changing context. Therefore, the effect of external drivers was analyzed by formulating eight scenarios (Table 4).

In all scenarios, PV-CFR was maximized in runs of 80 years[8], using the basic data of farm A, assuming that the external drivers remain constant or change at 2% per year during the run.

Table 4. Scenarios based on reduction in prices of sweet cherry (the only crop selected when PV-CFR was maximized without imposing target values on other objectives), increases in labour costs and reduced labour availability (= is stable; ↓ is decreasing; and ↑ is increasing).

Scenario	External driver		
	Cherry price	Labour cost	Labour availability
1	=	=	=
2	=	=	↓
3	=	↑	=
4	=	↑	↓
5	↓	=	=
6	↓	=	↓
7	↓	↑	=
8	↓	↑	↓

Note: changes were set to 2% per year for the three drivers.

[8] The horizon of the model was extended from 50 to 80 years to allow unequivocal identification of the effect of changes in the values of the external drivers on land use selection.

Scenario 1 is the base situation, with constant prices, cost of labour and labour availability. In this situation PV-CFR was 3461 x 10^3 US$, while CUM-LABOUR and LABOUR-DEV were 2595 and 17.1 x 10^3 h, respectively. As in the 50-year run, in this scenario only “Ch-TT-D-SK-C1” was selected (Table 5). If labour availability decreases (scenario 2), PV-CFR, CUM-LABOUR and LABOUR-DEV all decrease. The reduction in labour availability led to incorporation of more than 2 ha of “Ap-TT-D-SK-C1” in year 10, complementing 13.6 ha of “Ch-TT-D-SK-C1” that were gradually incorporated since the first year. All available land was used from the 13th year onwards.

In scenario 3, increasing labour costs resulted in a PV-CFR of 2074 x 10^3 US$, while CUM-LABOUR was 1670. LABOUR-DEV was practically unaffected (17.0 x 10^3 h). The increasing cost of labour led to a partial replacement of “Ch-TT-D-SK-C1” by “Wa-CL-D-SK-C1” from year 42 onwards.

In scenario 4, combining increasing labour costs and decreasing labour availability, PV-CFR was 1901 x 10^3 US$, and initially only “Ch-TT-D-SK-C1” was selected to a total area of 8.3 ha in year 7. The following year, 2 ha of “Wa-CL-D-SK-C+2” was introduced and in year 9, another 2.3 ha, but with installation of the frost control system just before the first expected harvest. This trend of replacing cherry by walnut combinations continued, but in year 50 (at 37% of the original labour availability and labour cost 2.64 times higher), still 34% of the area was planted to “Ch-TT-D-SK-C1”, suggesting some robustness in the current main land use in Patagonian fruit-producing farms, in terms of labour cost and availability.

In scenario 5, at present labour cost and availability, but decreasing prices of cherries, PV-CFR was 1970 x 10^3 US$, while CUM-LABOUR and LABOUR-DEV were 2054 x 10^3 and 8.5 x 10^3 h, respectively. In the first year, 5.5 ha of “Ch-TT-D-SK-C1” was planted and in year 5, 0.15 ha of “Ap-TT-D-SK-C1” was introduced. From that moment onwards, the area of apple increased each year, until occupying all available land. The cherry orchard was uprooted when it was 18 years old (at that moment the cherry price was 71% of the original). In the 55th year, 5.5 ha of “Wa-CL-D-SK-C1” was introduced, replacing a fraction of the apple technology that reached its maximum lifespan.

The complete replacement of cherries under the decreasing price scenario, represents a warning sign with respect to the sensitivity of the present orchard systems in South Patagonia to cherry price. If the current rate of decline in cherry prices at farm-level would continue for some years, the systems could become economically unfeasible. Therefore, attaining high yields and exportable quality is important, but reducing packaging, transaction and transport costs, allowing to offer a better farm-gate price, is fundamental.

A similar development was observed in scenario 6, in which, in addition to the cherry price, also labour availability declined. The only difference was that the introduction of “Wa-CL-D-SK-C1”, replacing “Ap-TT-D-SK-C1” started in year 37 with 0.24 ha.

In scenario 7, combining decreasing cherry prices and increasing labour costs, PV-CFR was 1295 x 10^3 US$, while CUM-LABOUR and LABOUR-DEV were 752 x 10^3 and 4.9 x 10^3 h, respectively. In the first year, 5.4 ha of “Ch-TT-D-SK-C1” was planted and in year 5, 0.15 ha of “Wa-CL-D-SK-C+2” was introduced, followed in the subsequent year, with another 1.9 ha. In year 7, 1.6 ha of “Wa-CL-D-SK-C1” was selected and from then onwards, the area with the two walnut technologies increased each year, covering all available land in the 10^{th} year. As in scenario 5, the cherry technology was uprooted when that orchard was 18 years old. Identical results were observed in scenario 8, indicating that labour demand was not limiting the value of the objective function in scenario 7.

DISCUSSION

The objective of this study was to explore options for farm-level strategic decision-making in farms in South Patagonia, specialized in fruit production. The multi-objective linear programming model OPTIFROP appeared a suitable tool for such analyses, allowing quantification of the trade-offs between various objectives and

Table 5. PV-CFR (objective maximized), CUM-LABOUR, LABOUR-DEV and main changes in farm-level development plans in eight scenarios (see Table 4).

Scenario	PV-CFR (10^3 US$)	CUM-LABOUR (10^3 h)	LABOUR-DEV (10^3 h)	Main changes in the farm development plan
1	3461	2595	17.1	“Ch-TT-D-SK-C1” is always selected
2	2942	2254	12.7	“Ch-TT-D-SK-C1” → “Ap-TT-D-SK-C1”
3	2074	1670	17.0	“Ch-TT-D-SK-C1” → “Wl-CL-D-SK-C1”
4	1901	1395	11.9	“Ch-TT-D-SK-C1” → “Wl-CL-D-SK-C1”
5	1970	2054	8.5	“Ch-TT-D-SK-C1” → “Ap-TT-D-SK-C1” → “Wl-CL-D-SK-C1”
6	1939	1882	8.4	“Ch-TT-D-SK-C1” → “Ap-TT-D-SK-C1” → “Wl-CL-D-SK-C1”
7	1295	752	4.9	“Ch-TT-D-SK-C1” → “Wl-CL-D-SK-C1”
8	1295	752	4.9	“Ch-TT-D-SK-C1” → “Wl-CL-D-SK-C1”

exploration of the effects of external factors on land allocation to different technologies. Thus, using the model in a participatory and interactive fashion can be a valuable support in transparent discussions with stakeholders about the robustness of their current systems and about the consequences of current decisions in an uncertain future.

The model allowed identification of objectives that are conflicting and those that are so to a very limited extent. Results of the model indicated that, although the timing and feasibility for implementing certain combinations of production technologies are affected by resource endowments and initial conditions, those factors do not influence land use selection in the long term that is driven by the objectives of the stakeholders. However, land use options in the model were restricted to 5 fruit-tree crops with relatively similar requirements in terms of investments, soils and labour. Incorporation of other crop species, perennial and/or annual, might allow more complete attainment of different objectives. Such 'complementary' crops would have to be attractive to growers and therefore they should be selected in close consultation with stakeholders. Technically, OPTIFROP allows the incorporation of other activities with minor effort.

In analysing the results, it has to be considered that OPTIFROP is a farm-scale model and therefore assumes equal external conditions for the different crop products (with the exception of product price evolution that can be specifically set for each crop). This might not be true, because packing facilities, marketing channels, expertise and minimum regional scale required, may differentially affect different crops. Thus, the method of analysis presented here only allows overall assessment of possible conflicts between different objectives. It is therefore not suitable (and was not intended) for formulation of strategic guidelines for development, but for support in strategic thinking, as the results represent the window of opportunities for orchard design, identifying maximum attainable and minimum acceptable values of different objectives of stakeholders.

In the analyses, the passive frost control system was never selected, not even for late blooming species, such as apple or walnut, although in specific situations, installation of the frost control system was delayed to allow other expenditures. That suggests that installation of a frost control system is practically always good practice[9], although the method and the optimum moment of installation may vary, depending on the specific situation.

[9] This seems to by supported by some figures: in South Patagonia, the sprinkler irrigation system requires an investment of approximately 4000 US\$ ha^{-1}. The average price of sweet cherries at farm gate is about 1.2 US\$ kg^{-1} and a yield of at least 10 Mg ha^{-1} is relatively common when frosts are controlled. In Trelew (Chubut Province) Cittadini et al. (2006b) estimated the frequency of years with at least one killing frost (killing > 90% of the reproductive organs) at 0.22, while this value decreased to 0.02 when the minimum temperature was increased 3 ˚C using active frost control methods.

It is generally accepted in South Patagonia that a more even distribution of labour demand would be desirable to avoid logistic and social problems. However, growers are hardly willing to lose significant income in efforts to realize that goal. OPTIFROP showed that, through introduction of alternative crops, substantial reductions in labour peaks in the period November-April could be achieved with a relatively small reduction in farm income.

Maximization of job opportunities (CUM-LABOUR) is an objective commonly expressed by policy makers and financial assistant from the provincial government for orchard establishment indirectly stimulated employment opportunities. Moreover, the close correlation between total labour demand and the financial result, that indeed is an explicit goal for growers and policy makers, implies that with the present orchard systems, labour demand is close to its maximum.

The synergistic effects of growers with clear economic/financial objectives, government support through research, extension and financial support, and the relatively high cherry prices as a result of marketing in the 'counter' season, have been important drivers for the rapid expansion of the cherry area with relatively advanced technological systems. OPTIFROP results agreed with this situation. However, the sensitivity of the model solution to the cherry price suggests that the fruit production sector of South Patagonia should pay more attention to the robustness of their land use plans and take preventive measures to avoid being caught by being unaware of a possible crisis due to changes in the context.

8

General discussion

GENERAL DISCUSSION

The main objective of this study was to assess constraints and opportunities for fruit production systems in South Patagonia (Chubut and Santa Cruz Provinces), Argentina. The study focused on sweet cherry, because of its current importance in the region and the lack of information on many important production aspects, such as yield and quality potential, and frost damage risk. To expand the scope of the study, and examine possibilities for alleviating constraints facing cherry production systems, such as strong seasonality of labour demand and limited labour supply (both in numbers and in skills), other fruit-tree crops were also analyzed. Moreover, under the present mono-cropping system, facilities, machinery, and knowledge on logistics and marketing channels, are under-utilized.

Attention was paid to the description and quantification of the trade-off between yield and fruit quality in cherry orchards, examining options for improved management to reduce yield and quality variability, exploring potentials of other fruit production systems for complementing cherry, and analyzing the trade-offs between potentially conflicting objectives at farm level before taking long-term decisions. The main emphasis in the study was on the development of tools in support of transparent discussions on effects of strategic (frost damage risk assessment; FRUPAT; OPTIFROP) and tactical ("target-tree" model) decisions. These tools constitute a significant contribution to the fruit industry in South Patagonia, a sector still in its infancy with respect to regional development, to support growers, extensionists and researchers in developing structured thinking for analyzing and processing available (fragmented) information.

However, insufficient or low quality data were a constraint throughout the study, and therefore the results are not a guide for fruit production, but rather a first attempt at integrating highly fragmented disciplinary knowledge into a consistent framework for future research on fruit production systems in South Patagonia. A real change in the sector towards more sustainable land use systems will require formulation, implementation and enforcement of science-based policy measures at regional level, which was outside the scope of this study.

Land use models have encouraged much scientific collaboration and understanding, but their use by policy makers and farmers remains a challenge (Van Paassen, 2004; Van Paassen *et al.*, 2007; Van Keulen, 2007). Models should be suitable for use in a participatory fashion by growers, researchers, extensionists, planners and policy makers, with flexibility for changing parameters, incorporating new activities, analyzing different scenarios and setting different objectives. The models developed in the current study meet these flexibility requirements, but stakeholder involvement in their development has been limited. In the course of the study, attempts were made to take into account different stakeholders' perspectives, aims and visions, by permanent consultations and discussions with growers, extensionists, researchers and policy makers, but no formal participatory procedure was implemented. In future "research for development" projects, this has to be a core issue, because to engage in joint learning, the models and the users need a common frame of reference and common interests (Van Paassen, 2004) and therefore intended users have to be formally involved during the model development process. Such a procedure has to start with a clear identification of the relevant stakeholders to assure offering acceptable alternatives. With the exception of the area of Los Antiguos, where growers have some 30 years of experience, in the remainder of South Patagonia, fruit (i.e. sweet cherry) development has been mostly limited to small and medium investors, that started their activities as a source of supplementary income. However, this activity appeared so far not attractive for traditional farmers. To involve also these stakeholders, other crops may have to be considered, and/or alternative technologies or whole systems, may have to be designed and evaluated.

With some time-overlap with the finalization of this thesis, an EU-funded project, designated EULACIAS (EUropean Latin American Co-Innovation of Agro-ecosystemS), has started at the beginning of 2007. The primary aim of that project is to identify opportunities and trade-offs for income generation and sustainable use of natural resources in Latin America, by linking quantitative systems approaches to participatory learning processes with participation of researchers, farmers, extensionists and local policy makers. One of the case studies in the project is "Sustainable development of fruit production systems in South Patagonia". As such, this project is intended as a follow-up of the work described in this thesis, and offers opportunities for implementation of the concepts and models developed during this study.

Results of the current study contribute to advancement of fruit sciences through incorporation of concepts otherwise seldom mentioned in fruit research, such as the "target-tree" approach, the frost damage risk estimation method and the multi-year optimization model.

Crop growth models for apple (Lakso *et al.*, 2001) and peach (Grossman and DeJong, 1994) have been developed. In sweet cherry, blooming intensity and fruit set is highly variable and although chemical (Lenahan and Whiting, 2006; Whiting *et al.*, 2006) and mechanical (Podestá Bajuk *et al.*, 2006) thinning has been applied experimentally, fruit- (or blossom-) thinning is seldom practiced commercially. Therefore, predicting fruit sink strength (an essential component in modelling carbohydrate partitioning) is extremely difficult and an alternative empirical approach has been developed. The “target-tree” concept was derived from the crop ideotype concept in plant breeding (Donald, 1968), and has been described as ‘the use of physiological approaches in crop breeding’ (Sedgley, 1991), aiming at tailoring of plants for increased production. In particular, the target tree resembles the ‘market ideotype’ defined by Donald (op. cit.), as ‘the ideotype that is characterized by desirable characteristics at the end-point, i.c. the quality characteristics of the desired product such as bread-making quality of the grain’. To our knowledge, this approach has thus far not been applied to perennial crops.

In different production areas of the world, frost risk has been analyzed through construction of frost risk maps, derived from long-term weather data, showing the expected number of frost events for selected sites. One way of estimating location-specific frost risk is adding the number of events with temperatures below 0 °C, but such estimates do not differentiate between specific types of risk (Lindkvist *et al.*, 2000). Lindkvist and Chen (1999) used a more detailed index, based on events with temperatures below 0 °C, specified according to the moment of the season, and according to severity of the frost (degrees below 0 °C). Pascale *et al.* (1997) developed an index for apple and peach, later extended to sweet cherry (Damario *et al.*, 2006), taking into account average dates of occurrence of specific phenological stages, associated ‘lethal’ temperatures, and probabilities of those temperatures in specific locations. In this thesis, a significant methodological improvement in calculating this type of indices was achieved by defining a frost damage event as any specific day in the season with minimum air temperature below the lethal temperature specified for the phenological stage predicted at that moment (based on phenological models). Frost damage probability is then estimated as the relative frequency of years in which at least 1 killing frost occurs, at any time during the growing season until harvest.

Technical coefficient generators (TCG) have been widely used in different studies using (Interactive) Multiple Goal Linear Programming (IMGLP) techniques, i.e. exploratory land use analyses (Seligman, 1992; De Koning, *et al.*, 1995; Bouman *et al.*, 1998; Bouman *et al.*, 1999; Hengsdijk *et al.*, 1999; Hengsdijk and van Keulen, 2002; Ponsioen *et al.*, 2003), but as far as we know, FRUPAT is the only TCG specifically developed for quantification of fruit-tree production systems. Similarly, IMGLP models have been widely used (Mendoza *et al.*, 1986; De Wit *et al.*, 1988; Rossing *et al.*, 1997; Van Ittersum *et al.*, 1998; Hengsdijk and van Ittersum, 2002) and multi-annual optimization models have been developed for perennial crops such as alfalfa (Knapp, 1987) and for crop rotations (Dogliotti, 2003). Specifically in the fruit-tree sector, many models have been developed to optimize different aspects. Hester and Cacho (2003) developed a dynamic model for fruit thinning optimization in apple orchards; Blanco *et al.* (2005) used a mixed integer linear programming model to optimize the operation of a packaging facility for apple and pear in northern Patagonia, Argentina; Oppenheim (2003) presented a multi-annual linear programming model to maximize economic result for apple and pear orchards through optimizing tree replacement and cash flow dynamics; with the same goal, Kearney (1994) used a similar model to optimize cultivar combination and replacement strategy in pip-fruit orchards.

OPTIFROP is innovative in that it is a dynamic farm-model applied to orchard systems that allows interactive optimisation of economic, environmental and social objectives, while considering several fruit-tree crops, different farm resource endowments (finances and area of different soil types) and different crop management technologies, such as training, irrigation and frost control system, and enabling inclusion of time-variable restrictions (labour availability) and parameters (fruit price and labour cost) over the planning horizon of the model. The model allowed to quantify the trade-off between conflicting objectives (e.g. maximization of present value of cumulated financial result vs. maximum inter-months labour deviation) and between those that only do so to a very limited extent (e.g. maximization of cumulated labour vs. present value of cumulated financial result). An important model outcome was that by incorporating complementary crops, substantial reductions in inter-months labour deviation (considering the period November-April) could be achieved with a relatively low reduction in farm income. OPTIFROP results also putted in evidence some weakness of the current fruit production systems in South Patagonia associated to their sensitivity to cherry price.

A final remark about this thesis concerns the potential regional impact at scientific and institutional level. As the fruit sector is relatively new in South Patagonia, at the beginning of the study scientific knowledge in the field was scarce. Therefore, this thesis represents a significant contribution to development of this part of Argentina, as a starting point for fruit and farming systems research in the region. Moreover, the research was integrated into a regional project of the *Instituto Nacional de Tecnología Agropecuaria*, thus working as a catalyst for consolidation of research and extension groups of the region.

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Summary

Sweet cherries from the end of the world: options and constraints for fruit production systems in South Patagonia, Argentina

North Patagonia (Neuquén and Río Negro Provinces), and in particular the upper valley of Río Negro, is a traditional region of fruit production. Here most of the Argentinean apples and pears are produced. However, in South Patagonia (Chubut, Santa Cruz and Tierra del Fuego Provinces), development of this agricultural sector has been rather limited and concerns almost exclusively the production of sweet cherry, with an area increase from 176 ha in 1997 to 578 ha at the end of 2006. These new orchards are all designed as intensive systems (modern training systems with high planting density, drip irrigation systems and sprinkler irrigation as frost control method) and planted with cultivars that potentially produce high quality fruit, suitable for export markets. Growers from the Lower Valley of Chubut River, Los Antiguos, Sarmiento and Comodoro Rivadavia have been exporting sweet cherries to Europe for some time. Concurrently, provincial organisations and INTA (*Instituto Nacional de Tecnología Agropecuaria*) were convinced of the possibilities to expand sweet cherry production and have been supporting the development of this crop through applied research and extension. Diversification towards other fruit-tree crops has not really developed, neither does policy promote it. Different fruit crops need packing facilities and labour at different times of the season, and they have similar commercial canals and logistic knowledge requirements. Hence, even though sweet cherry seems currently the most profitable crop in the region, other fruit crops may be interesting to increase the use efficiency of the available resources, to complement income and to spread risk.

The general objective of this study was to assess constraints and opportunities for fruit production systems in Chubut and Santa Cruz Provinces (South Patagonia, Argentina). Nevertheless, emphasis was on sweet cherry, because this is currently the most important fruit-tree crop, while at the same time many important aspects, such as yield and quality potential of - and frost damage risk to - this crop are poorly understood.

In the context of cherry production for export, it is important to define fruit quality and how this can be affected. Although quality has different meanings for different stakeholders (producers, distributors, consumers, etc.) consumer acceptance seems to be the most important factor to be considered. Several parameters can be used to estimate indirectly consumer acceptance, but independent of consumer liking, firmness is a key aspect for marketing cherries overseas. Colour is related to many

other parameters, such as soluble solids content, titratable acidity and firmness, and is therefore the main tool to determine harvest date. To optimize economic result, research should include the effect of agricultural practices not only on yield, but also on quality variables, especially fruit size, which is the main determinant of fruit price.

To estimate the optimal combination of yield and fruit quality, a "target-tree" approach to maximize gross value of product (GVP; US$ ha^{-1}) at farm gate was developed and applied to sweet cherry orchards, integrating eco-physiological information, model estimates and expert knowledge. Minimum fruit quality thresholds define the suitable market for the fruit (export, domestic or industry), with their associated price ranges. In addition, on both domestic and export markets, price depends mainly on fruit size. The Fruit Number to Leaf Area Ratio (FNLAR; fruit m^{-2} LA) determines fruit quality (and indirectly fruit price), but in combination with Mean Fruit Weight (MFW) and Leaf Area Index (LAI), also yield. GVP is calculated as the product of yield and fruit price. The combination 'Bing'/'Mahaleb' trained as vase was used to illustrate parameter estimation (LAI and FNLAR) for a "target-tree" in Patagonian orchards, using experimental results. Under these conditions, a LAI of 3.07 is required to intercept 75% of Photosynthetic Active Radiation (PAR) at harvest. With these parameters, and considering "price-fruit quality" relationships based on expert knowledge, maximum GVP was obtained with 80 fruit m^{-2} LA and a yield of 18.25 Mg ha^{-1}. Although this example was limited to a single combination of cultivar and training system in a specific location, the methodology can be applied to other situations, provided reliable relevant eco-physiological information is available.

Quantification of frost damage risk is important in planning the development of new orchards and to decide on design and installation of frost control systems. Therefore, a comprehensive method to quantify frost damage risk in different sweet cherry production areas of South Patagonia was developed and the potential impact of frost control systems on risk reduction was estimated. Frost damage for any specific day of the season was assumed to occur when the minimum temperature on that day was below the specific lethal temperature for the phenological stage predicted at that moment (based on phenological models). Frost damage probability was estimated for each production location of South Patagonia as the frequency of years in which at least one damaging frost (damaging ≥ 90% of the reproductive organs) occurs, at any time during the growing season until harvest. Frost damage risk was compared among cultivars and locations. Finally, the effect of active frost control methods on frost damage risk reduction was analyzed. There was very little difference in frost damage risk among cultivars, although 'Sunburst' was the cultivar with the lowest risk. The most risky locations were Los Antiguos and Esquel, while Comodoro Rivadavia was the safest location. The frequency of years with at least one killing frost decreased

drastically when the minimum temperature was increased by 3 ˚C, using active frost control systems. The methodology presented appears useful to identify the main and secondary variables affecting frost damage risk. Thus, this type of quantitative analysis based on potential impact of a particular control system on mean yields and yield stability can support growers in decision-making on required investments and operational costs of the equipment for frost control.

Due to the long lifespan of orchard systems, an explorative modelling study was performed. OPTIFROP (OPTImum FRuit Orchards in Patagonia) is a dynamic farm model, developed as an Interactive Multiple Goal Linear Program (IMGLP), capable of allocating, throughout the time horizon of the run, production activities to different land units, while optimizing different (conflicting) objective functions, subject to several constraints. Exploratory studies are highly demanding in terms of quantitative information (technical coefficients for every single activity: TC) and therefore automation of the calculations is needed. For deriving land use options and quantifying the TCs required for OPTIFROP, software called FRUPAT was developed. FRUPAT allows combining crop-tree species (sweet cherry; apple; plum; peach; walnut), edaphic environment (soils with no limitations; shallow; with poor water holding capacity), training system (tatura; vase; central leader), irrigation system (drip; furrow), frost control system (sprinkler irrigation; heating; passive) and moment of installation of the frost control system (just before the first crop is expected or two years later). Some combinations did not exist, were considered technically unfeasible or knowledge about their input and outputs was too weak and were therefore filtered in FRUPAT and not taken into account for further calculations. After filtering, feasible land use options were completely characterised by their inputs and outputs at each orchard age until their maximum lifespan.

The aim of OPTIFROP was to support strategic decision-making, such as ‘when to plant’, ‘what to plant’, ‘with which technology’, and ‘how many hectares of each activity’. Thus, the model allowed identification of the options for development plans for Patagonian farms (‘window of opportunities’). The model allowed to quantify the trade-off between conflicting objectives (e.g. maximization of present value of cumulated financial result vs. inter-months labour deviation) and between those that only do conflict to a very limited extent (e.g. maximization of cumulated labour vs. present value of cumulated financial result). The model results showed that by diversification, hence, considering other crops than sweet cherry only, substantial reductions in inter-months labour deviation (considering the period November-April) could be achieved with a relatively low reduction in farm income. OPTIFROP outcomes also putted in evidence that the current fruit production systems in South Patagonia are sensitive to cherry price.

The different methods developed in this thesis contribute significantly to the fruit industry in South Patagonia by supporting growers, extensionists and researchers in developing structured thinking for analyzing and processing available (fragmented) information. Results of the current study contribute to advancement of fruit sciences through incorporation of concepts otherwise seldom mentioned in fruit research, such as the “target-tree” approach, the frost damage risk estimation method and the multi-year optimization model.

Finally, this thesis has a potential regional impact at scientific and institutional level. As the fruit sector is relatively new in South Patagonia, at the beginning of the study scientific knowledge in the field was scarce. Therefore, this thesis represents a significant contribution to development of this part of Argentina and is a starting point for fruit and farming systems research in the region. Moreover, the research was integrated into a regional project of INTA, thus working as a catalyst for consolidation of research and extension groups of the region.

Samenvatting

Kersen van de andere kant van de wereld: mogelijkheden voor en beperkingen van fruitproductiesystemen in Zuid Patagonia, Argentinië

Noord Patagonia (de provincies Neuquén en Rio Negro), en in het bijzonder het stroomopwaartse gedeelte van de vallei waardoor de Rio Negro stroomt, is traditioneel gezien de regio waar fruit wordt geproduceerd. Hier komen de meeste appels en peren vandaan die in Argentinië worden geproduceerd. De ontwikkeling van deze landbouwsector is in Zuid Patagonia (de provincies Chubut, Santa Cruz en Tierra del Fuego) achtergebleven en beperkt zich hoofdzakelijk tot de productie van kersen. Het areaal onder kersen is van 1997 tot het einde van 2006 wel gegroeid van 176 ha tot 578 ha. Deze nieuwe boomgaarden zijn allemaal ontworpen als intensieve systemen, gekenmerkt door hoge plantdichtheden, moderne snoeimethoden, druppelirrigatiesystemen en sproeiinstallaties ter voorkoming van nachtvorstschade. De gebruikte cultivars zijn potentieel hoog producerend met kersen van goede kwaliteit, geschikt voor de exportmarkt. Fruittelers uit de Lower Valley van de Chubut River, Los Antiguos, Sarmiento en Comodoro Rivadavia exporteren al enige tijd kersen naar Europa. Bovendien waren provinciale organisaties en INTA (Instituto Nacional de Tecnologica Agropecuaria, het nationale onderzoeksinstituut) overtuigd van de mogelijkheden voor uitbreiding van de kersenproductie en hebben de ontwikkeling van deze teelt gestimuleerd door toegepast onderzoek en voorlichting. Diversifiëren van de fruitteelt door teelt van andere vruchten dan alleen kersen is niet echt op gang gekomen en wordt ook niet gepromoot door de overheid. Wanneer verschillende fruitsoorten in één bedrijf zouden worden verbouwd, zouden bestaande verpakkingsfaciliteiten en aanwezige arbeid gedurende langere tijd gebruikt kunnen worden, terwijl dezelfde logistieke kennis en kanalen voor vermarkten gebruikt zouden kunnen worden. Hoewel kersenteelt op dit moment het meest winstgevend lijkt in deze regio, kan de teelt van andere soorten fruit interessant zijn om de efficiëntie van gebruik van faciliteiten en arbeid te verhogen. Bovendien kan teelt van verschillende soorten fruit het risico verminderen en het inkomen van fruittelers complementeren.

De algemene doelstelling van deze studie was het verkennen van beperkingen en mogelijkheden voor fruitproductiesystemen in de provincies Chubut and Santa Cruz (Zuid Patagonia, Argentinië). Toch lag het accent op kersenteelt, omdat deze teelt op dit moment het belangrijkst is en er tegelijkertijd nog weinig bekend is over veel

aspecten van de teelt, zoals het potentieel aan opbrengst en kwaliteit, en het risico van vorstschade.

De definitie van kwaliteit en de vraag hoe deze door de teelt kan worden beïnvloed zijn van belang in verband met de export van kersen. Hoewel kwaliteit voor verschillende belanghebbenden (telers, distributeurs en consumenten) een verschillende betekenis kan hebben, lijkt acceptatie door consumenten de belangrijkste factor waarmee rekening dient te worden gehouden. Voor het schatten van acceptatie door consumenten kunnen verschillende kenmerken worden gebruikt, maar afgezien van de voorkeur van consumenten, is stevigheid van de vrucht het belangrijkste kenmerk bij het op de markt brengen van kersen in het buitenland. De kleur is aan veel andere kenmerken gerelateerd, zoals aan de inhoud aan oplosbare vaste delen, titreerbaar zuur en stevigheid, en is daarmee het belangrijkste kenmerk om het moment van oogsten te bepalen. Om het economische resultaat te optimaliseren, zou onderzoek zich niet alleen op het effect van teelmaatregelen op de opbrengst moeten richten, maar ook op kwaliteitskenmerken, in het bijzonder op de grootte van de vrucht omdat die de prijs bepaalt.

Voor het schatten van de optimale combinatie van opbrengst en kwaliteit is een benadering gevolgd waarin een boom wordt ontworpen die leidt tot de maximale bruto waarde van het product (Gross Value of Product; US\$ ha^{-1}) aan de poort van het bedrijf. Bij de ontwikkeling van dit 'prototype' van een boom in de kersenteelt, zijn eco-fysiologische informatie, modelberekeningen en expert kennis geïntegreerd. Drempelwaarden voor kwaliteitskenmerken van de vruchten bepalen de geschiktheid voor de verschillende markten (export, thuismarkt, industriële verwerking) en de daarbij behorende prijzen. Op de thuismarkt en de exportmarkt is de prijs hoofdzakelijk afhankelijk van de grootte van de vrucht. Het aantal vruchten per eenheid bladoppervlak (Fruit Number to Leaf Area Ratio; FNLAR in fruit m^{-2} LA) bepaalt de kwaliteit van de vruchten (en indirect dus de prijs), en, in combinatie met het gemiddelde vruchtgewicht (Mean Fruit Weight, MFW) en de bladoppervlakte index (Leaf Area Index; LAI), ook de opbrengst. De bruto waarde van het product wordt berekend als het product van opbrengst en prijs. De combinatie van kersen van de variëteit Bing op een Mahaleb-onderstam en gesnoeid in een vaasvorm is gebruikt als illustratie. In dit voorbeeld wordt uitgelegd hoe de geschatte kenmerken (LAI en FNLAR) kunnen worden gebruikt voor de karakterisering van het 'prototype' van een boom voor boomgaarden in Zuid Patagonië. Daarbij is gebruik gemaakt van experimentele resultaten. Onder deze omstandigheden, is een LAI van 3.07 vereist om 75% van de fotosynthetisch actieve straling (Photosynthetically Active Radiation, PAR) op het moment van oogst te onderscheppen. Met deze kenmerken, en rekening houdend met de relatie tussen kwaliteit en prijs zoals die door experts is vastgesteld, kon worden berekend dat de maximale bruto waarde van het product wordt bereikt bij 80 vruchten m^{-2} LA met een opbrengst van 18.25 Mg ha^{-1}. Hoewel dit voorbeeld beperkt is tot een enkele combinatie van cultivar en snoeisysteem op een specifieke locatie, kan de methodologie ook worden toegepast in andere situaties, mits de relevante eco-fysiologische informatie beschikbaar is.

In de planning van de ontwikkeling van nieuwe boomgaarden is het kwantificeren van het risico voor vorstschade belangrijk. Dit om te kunnen beslissen of een systeem ter voorkoming van nachtvorstschade moet worden geïnstalleerd, en zo ja welk systeem. Voor het vaststellen van dat risico werd een methode ontwikkeld die het mogelijk maakt het risico van vorstschade in verschillende kersenteeltgebieden in Zuid Patagonië te kwantificeren en het potentiële effect te berekenen van toepassing van een specifiek systeem ter voorkoming van vorstschade. Vorstschade op een bepaalde dag in het seizoen werd verondersteld voor te komen, wanneer de minimumtemperatuur op die dag lager is dan de schadedrempel, gedefinieerd als functie van het fenologische stadium waarin de fruitbomen op die dag verkeren. Het fenologische stadium van de fruitbomen werd voorspeld met behulp van fenologische modellen. De kans op vorstschade is geschat voor alle productiegebieden in Zuid Patagonië en is uitgedrukt als de frequentie van jaren waarin tenminste één vorstschade veroorzakende gebeurtenis voorkomt gedurende enig tijdstip van de groei tot aan de oogst (schade werd verondersteld als $\geq$ 90% van de generatieve organen zijn aangetast). Het risico voor vorstschade is vastgesteld voor verschillende cultivars en locaties. Ten slotte is het effect geanalyseerd van de installatie van systemen ter voorkoming van vorstschade op het risico voor vorstschade. Er was weinig verschil in risico voor vorstschade tussen cultivars, hoewel 'Sunburst' de cultivar was met het laagste risico. De meest riskante locaties waren Los Antiguos en Esquil, terwijl Comodoro Rivadavia de veiligste locatie was. De frequentie van jaren met tenminste één schadelijke vorst verminderde dramatisch als de drempelwaarde voor de minimumtemperatuur door het gebruik van systemen ter voorkoming van vorstschade met 3 ^{0}C werd verhoogd. De gepresenteerde methode blijkt nuttig om de meest belangrijke en de secondaire factoren, die het risico voor vorstschade bepalen, te identificeren. Dus, dit type van kwantitatieve analyse, waarmee de potentiële effecten kunnen worden berekend van installatie van systemen ter voorkoming van vorstschade op gemiddelde opbrengsten en stabiliteit van opbrengsten, kan telers helpen te beslissen welke investeringen noodzakelijk zijn en welke operationele kosten daarmee gemoeid zijn.

Boomgaarden hebben een lange levenscyclus waardoor experimenteel werk moeilijk is. Daarom is een verkennende studie met een model uitgevoerd. OPTIFROP (OPTImum Fruit Orchards in Patagonia) is een dynamisch bedrijfsmodel, een zogenaamd interactief lineair programmeringsmodel voor meervoudige doelen. Dit model is geschikt voor het berekenen van de optimale allocatie van productieactiviteiten aan landeenheden binnen het bedrijf, over een tijdsbestek van meerdere productiecycli van boomgaarden, waarbij meerdere, vaak conflicterende doelstellingen worden geoptimaliseerd, rekening houdend met de aanwezige beperkingen. Dit soort verkennende studies vragen veel kwantitatieve informatie (Technische Coëfficiënten, TC's, voor elke productieactiviteit) en daarom is automatisering van de berekeningen gewenst. Daarvoor is het computerprogramma FRUPAT ontwikkeld, dat TC's kan berekenen voor productieactiviteiten, die als opties voor landgebruik kunnen worden opgenomen in het optimaliseringsmodel. In FRUPAT kunnen verschillende fruitsoorten (kersen, appel, pruim, perzik en walnoten) worden gecombineerd met verschillende bodems (bodems zonder beperkingen, ondiepe bodems en bodems met een laag waterhoudend vermogen), verschillende snoeisystemen ('tatura', 'vaas', 'central leader'), verschillende irrigatiesystemen (druppelirrigatie of via voren), verschillende systemen ter voorkoming van vorstschade (sproeiers, verwarming, passief) en verschillende momenten van installeren van dit systeem (net voor de boomgaard voor de eerste keer vrucht draagt of twee jaar later). Bij het genereren van de technische coëfficiënten zijn sommige combinaties uitgesloten, omdat zij technisch onmogelijk zijn of omdat er te weinig kennis beschikbaar was om de relaties tussen input en output te kunnen kwantificeren. Inputs en outputs van de waarschijnlijke combinaties voor elk type boomgaard voor elk jaar over de gehele, maximale levenscyclus van de boomgaard kunnen zo worden gegenereerd.

Het doel van het model OPTIFROP is om ondersteuning te bieden bij het nemen van strategische beslissingen, zoals bij vragen als 'wanneer planten', 'wat planten', 'met welke teelttechnieken', en 'hoeveel hectare van iedere activiteit'. Het model genereert dus verschillende ontwerpen voor fruitbedrijven in Patagonië, die samen de zogenaamde 'window of opportunities' vormen. Met het model kan de uitruil worden gekwantificeerd tussen conflicterende doelen (maximalisatie van de huidige waarde van het cumulatieve financiële resultaat versus minimalisatie van verschillen in arbeidsvraag tussen de maanden) en tussen gedeeltelijk conflicterende doelen (maximalisering van cumulatieve arbeid versus maximalisatie van huidige waarde van het cumulatieve financiële resultaat). De modelresultaten tonen aan dat bij diversificatie, dus bij introductie van meer fruitsoorten dan alleen kersen, de verschillen in arbeidsvraag tussen de maanden substantieel kleiner kunnen worden, in het bijzonder in de periode november tot april. Dit gaat ten koste van een geringe vermindering in bedrijfsinkomen. Resultaten van het model OPTIFROP tonen ook aan dat de huidige fruitteelt in Zuid Patagonië gevoelig is voor de prijs van kersen.

De verschillende instrumenten die in dit proefschrift worden beschreven vormen nuttige bijdragen voor de ontwikkeling van de fruitteelt en -industrie in Zuid Patagonië, doordat ze telers, voorlichters en onderzoekers helpen bij de ontwikkeling van gestructureerd denken bij de analyse en bewerking van beschikbare (vaak fragmentarische) informatie. Resultaten van deze studie dragen bij aan de vooruitgang in de tuinbouwwetenschappen doordat het ontwikkelde instrumentarium (de benadering via het 'prototype' van een boom, de methode om risico voor vorstschade te schatten en het optimaliseringsmodel over meerdere jaren) nu in het fruitonderzoek kan worden gebruikt.

Ten slotte, dit proefschrift heeft in potentie een regionale invloed op wetenschappelijk en institutioneel gebied. Omdat de fruitsector aan het begin van deze studie relatief nieuw was in Zuid Patagonië, was er weinig kennis op dit gebied. De kennis en inzichten neergelegd in dit proefschrift, dragen daarom substantieel bij aan de ontwikkeling van dit deel van Argentinië en vormen het startpunt voor fruit- en bedrijfssystemenonderzoek in de regio. Bovendien was dit onderzoek geïntegreerd in een regionaal project van INTA en heeft daardoor gewerkt als katalysator voor het onderzoek en de voorlichting in de regio.

Resumen

Cerezas desde el fin del mundo: opciones y restricciones para los sistemas de producción de frutas en Patagonia Sur, Argentina

La Patagonia Norte (Provincias de Neuquén y Río Negro), y en particular el Alto Valle de Río Negro, es la región donde tradicionalmente se producen frutas. Aquí se producen la mayoría de las manzanas y peras argentinas. Sin embargo, en Patagonia Sur (Provincias de Chubut, Santa Cruz y Tierra del Fuego), el desarrollo de este sector agrícola ha estado bastante limitado y concerniente casi exclusivamente a la producción de cerezas, con un incremento en área de 176 ha en 1997 a 578 ha a finales de 2006. Estos nuevos montes han sido diseñados como sistemas intensivos (sistemas modernos de conducción con alta densidad de plantación, sistemas de riego por goteo, y riego por aspersión como método de control de heladas) y plantados con cultivares que potencialmente producen fruta de alta calidad, apropiada para mercados de exportación. Desde hace algún tiempo, productores del Valle Inferior del Río Chubut, Los Antiguos, Sarmiento y Comodoro Rivadavia han estado exportando cerezas a Europa. Al mismo tiempo, organizaciones provinciales y el INTA (*Instituto Nacional de Tecnología Agropecuaria*) han estado convencidos sobre las posibilidades de expansión de la producción de cerezas y han estado apoyando el desarrollo de este cultivo mediante investigación aplicada y extensión. La diversificación hacia otros cultivos frutícolas arbóreos realmente no ha empezado a desarrollarse, ni tampoco ha habido una política de promoción en ese sentido. Diferentes cultivos frutícolas requieren mano de obra e instalaciones de empaque en diferentes momentos de la temporada, y tienen similares canales comerciales y requerimientos de conocimiento sobre logística. Por lo tanto, a pesar de que el cerezo parece ser hoy en día el cultivo más rentable en la región, otros cultivos frutícolas podrían ser interesantes para incrementar la eficiencia de uso de los recursos disponibles, como así también para complementar el ingreso y para disminuir el riesgo.

El objetivo general de este estudio fue evaluar las restricciones y oportunidades para los sistemas de producción de frutas en las Provincias de Chubut y Santa Cruz (Patagonia Sur, Argentina). No obstante, el énfasis fue puesto en el cerezo, debido a que hoy en día es el cultivo frutícola arbóreo más importante, mientras que al mismo tiempo hay una insuficiente comprensión sobre muchos aspectos importantes, tales como el potencial de rendimiento y de calidad, y el riesgo de daño por heladas.

En el contexto de la producción de cerezas para exportación, es importante definir la calidad de la fruta y cómo ésta puede ser afectada. A pesar de que la calidad tiene diferentes significados para diferentes interesados (productores, distribuidores,

consumidores, etc.) la aceptabilidad por parte del consumidor parece ser el factor más importante a ser considerado. Se pueden usar varios parámetros para estimar la aceptabilidad en forma indirecta, pero independientemente del gusto del consumidor, la firmeza es un aspecto clave para comercializar cerezas en mercados transoceánicos. El color se relaciona a muchos otros parámetros, tales como el contenido de sólidos solubles, la acidez titulable y la firmeza, y por ende es la principal herramienta para determinar el momento de cosecha. Para optimizar el resultado económico, la investigación debe incluir el efecto de las prácticas agrícolas no sólo sobre el rendimiento, sino también sobre las variables de la calidad, especialmente el tamaño de la fruta, el cual es el principal determinante del precio.

Para estimar la combinación optima de rendimiento y calidad de fruta, se desarrolló un enfoque de "árbol objetivo" para maximización del valor bruto de la producción (VBP; US\$ ha^{-1}) a nivel predial, y se aplicó a montes de cerezo, integrando información eco-fisiológica, estimaciones de modelos y conocimiento de expertos. Umbrales mínimos de calidad de fruta definen el mercado apropiado para la fruta (exportación, doméstico o industria), con sus asociados rangos de precios. Además, tanto en mercados domésticos como de exportación, el precio depende principalmente del tamaño de la fruta. La Relación Número de Frutos por Área Foliar (RNFAF; frutos m^{-2} AF) determina la calidad de la fruta (e indirectamente el precio), pero en combinación con el Peso Medio del Fruto (PMF) y el Índice de Área Foliar (IAF), también el rendimiento. El VBP es calculado como el producto del rendimiento y el precio de la fruta. Usando resultados experimentales, se utilizó la combinación 'Bing'/'Mahaleb' conducida en vaso para ilustrar la estimación de parámetros (IAF y RNFAF) para un "árbol objetivo" en montes Patagónicos. Bajo estas condiciones, se requiere un IAF de 3.07 para interceptar 75 % de la Radiación Fotosintética Activa (RFA) a cosecha. Con estos parámetros, y considerando relaciones "precio-calidad de fruta" basadas en conocimiento de expertos, el máximo VBP fue obtenido con 80 frutos m^{-2} AF y un rendimiento de 18.25 Mg ha^{-1}. A pesar de que este ejemplo se limitó a una sola combinación de cultivar y sistema de conducción en una localización específica, la metodología puede ser aplicada a otras situaciones, en la medida que se disponga de información ecofisiológica relevante y confiable.

La cuantificación de riesgo de daño por heladas es importante en la planificación de la implantación de nuevos montes y para decidir sobre el diseño e instalación de sistemas de control de heladas. Por lo tanto, se desarrolló un método exhaustivo para cuantificar el riesgo de daño por heladas en diferentes zonas de producción de cerezos de Patagonia Sur y se estimó el impacto potencial de los sistemas de control de heladas sobre la disminución del riesgo. Se asumió que, para cualquier día específico, el daño por heladas ocurre cuando la temperatura mínima en ese día es menor a la temperatura letal específica para el estado fenológico predicho en ese momento (basado en modelos fenológicos). La probabilidad de daño por heladas fue estimada para cada zona de producción de Patagonia Sur como la frecuencia de años en los cuales ocurría al menos una helada dañina (dañando ≥ 90 % de los órganos reproductivos), en cualquier momento de la estación de crecimiento, hasta cosecha. Se comparó el riesgo de daño por heladas entre cultivares y entre zonas. Finalmente, se analizó el efecto de los métodos activos de control de heladas sobre la reducción del riesgo de daño por heladas. Hubo muy pequeñas diferencias en riesgo de daño por heladas entre cultivares, aunque 'Sunburst' fue el cultivar con el menor riesgo. Las zonas más riesgosas fueron Los Antiguos y Esquel, mientras que Comodoro Rivadavia fue la zona más segura. La frecuencia de años con al menos una helada letal decreció dramáticamente cuando la temperatura mínima fue incrementada en 3 ˚C, usando sistemas activos de control de heladas. La metodología presentada parece ser útil para identificar las variables principales y las secundarias que afectan el riesgo de daño por heladas. Así, este tipo de análisis cuantitativo basado en el impacto potencial de un sistema particular de control sobre los rendimientos medios y sobre su estabilidad, puede ayudar a los productores en la toma de decisiones sobre las inversiones requeridas y los costos operativos de los equipos para control de heladas.

Debido a la larga vida útil de los sistemas de montes frutales, se llevó a cabo un estudio exploratorio de modelación. OPTIFROP (*OPTImum FRuit Orchards in Patagonia*: Montes frutales óptimos en Patagonia) es un modelo predial dinámico, desarrollado como Programa Lineal Interactivo con Múltiples Objetivos (PLIMO), capaz de asignar, a lo largo del horizonte temporal de la corrida del programa, actividades productivas a diferentes unidades de tierra, sujetas a varias restricciones, mientras se optimizan diferentes (en conflicto) funciones objetivo. Los estudios exploratorios son muy demandantes en términos de información cuantitativa (coeficientes técnicos para cada una de las actividades: CT) y por lo tanto es necesaria la automatización de los cálculos. Para derivar opciones de uso de tierras y cuantificar los CTs requeridos para OPTIFROP, se desarrolló un programa llamado FRUPAT. Dicho programa permite combinar especies frutales (cerezo; manzano; ciruelo; duraznero; nogal), ambiente edáfico (suelos sin limitantes; somero; con poca capacidad de retención de agua), sistema de conducción (tatura; vaso; eje central), sistema de riego (goteo; surcos), sistema de control de heladas (riego por aspersión; calefacción; pasivo) y momento de instalación del sistema de control de heladas (justo antes de la primera cosecha esperada o dos años más tarde). Algunas combinaciones no existían, fueron consideradas técnicamente inviables o el conocimiento acerca de sus insumos y productos era muy pobre, por lo que fueron filtradas en FRUPAT y dejadas de lado para cálculos adicionales. Tras el filtrado, las opciones viables de uso de tierra fueron completamente caracterizadas a través de sus insumos y productos para cada año de edad del monte y hasta su máxima vida útil.

El propósito de OPTIFROP es apoyar la toma de decisiones, tales como 'cuándo plantar', 'qué plantar', 'con qué tecnología', y 'cuántas hectáreas de cada actividad'. Así, el modelo permitió identificar las opciones de planes de desarrollo en chacras Patagónicas ('ventana de oportunidades'). El modelo permitió cuantificar la relación costo-beneficio entre objetivos contrapuestos (Ej. maximización del valor presente del resultado financiero acumulado vs. desvío entre meses de necesidad de mano de obra) y entre aquellos que sólo se contraponen hasta cierto punto (Ej. maximización de la mando de obra acumulada vs. valor presente del resultado financiero acumulado). Los resultados del modelo mostraron que mediante la diversificación, es decir, considerando otros cultivos además de cerezo, se podrían lograr substanciales reducciones en el desvío entre meses de necesidad de mano de obra (considerando el período noviembre-abril), con una reducción relativamente baja en el ingreso a nivel predial. Los resultados de OPTIFROP también pusieron en evidencia que los sistemas de producción actuales en Patagonia Sur son sensibles a los precios de la cereza.

Los diferentes métodos elaborados en esta tesis son una contribución significativa al sector frutícola de Patagonia Sur, ayudando a productores, extensionistas e investigadores, a desarrollar un pensamiento estructurado para el análisis y procesamiento de la información disponible (fragmentada). Los resultados del presente estudio contribuyen al avance de la ciencia en fruticultura mediante la incorporación de conceptos poco mencionados en investigación frutícola, tales como el enfoque de "árbol objetivo", la estimación de riesgo de daño por heladas y el modelo de optimización plurianual.

Finalmente, esta tesis tiene un potencial impacto regional a nivel científico e institucional. Debido a que el sector frutícola es relativamente nuevo en Patagonia Sur, al comienzo de este estudio el conocimiento científico sobre el tema era escaso. Por lo tanto, esta tesis representa una contribución significativa para el desarrollo de esta parte de Argentina y es un punto de partida para la investigación en fruticultura y en sistemas de producción en esta región. Además, la investigación estuvo integrada dentro de un proyecto regional de INTA, por lo que actuó como un catalizador para la consolidación de grupos de investigación y extensión de la región.

APPENDIX: OPTIFROP formulation

The model formulation of OPTIFROP is presented here. The model is linear and can be solved using linear programming (LP). The variables for optimization in OPTIFROP are the Present Value of the Cumulated Financial Result (PV-CFR), the Cumulated Labour (CUM-LABOUR) and the inter-months Labour Deviation (LABOUR-DEV).

The sets that define the different activities are crop-tree species (c), age of the orchard (a), edaphic environment (s), training system (r), irrigation system (i), frost control system (f) and moment of installation of the frost control system (m). In the formulation, multiple summations over different indices are indicated by a single *sigma* (e.g. $\sum_{c,a,s}$), equivalent to a series of *sigmas*, separately for each index ($\sum_{c} \sum_{a} \sum_{s}$). Also for presentation purposes, the sign ∀ is used meaning "*for all*".

Decision variables are prefixed by the letter X and all letters are in italic; auxiliary variables are presented with all letters in italic; data and parameters are written with regular letters; and objective functions are fully in capital letters.

This section presents the equations used for formulating the constraints, the auxiliary variables, the balances and the objective functions.

CONSTRAINTS

Available land

The total area occupied at any year (t) by the sum of all the activities in each edaphic environment has to be lower or equal than the available area of each edaphic environment, which is a parameter that has to be defined by the model user:

$$\sum_{c,a,r,i,f,m} X_{c,a,s,r,i,f,m,t} \leq \mathrm{Total\_land}_{s} \qquad \forall\ s,t$$

in which $a \leq MLS_{c,r}$

$X_{c,a,s,r,i,f,m,t}$: Area (ha) of all activities (combination of c, a, s, r, i, f, m) at any model-year (t)
$Total\_land_s$: Area (ha) of each edaphic environment (s).
$MLS_{c,r}$: Maximum lifespan (years), depending on crop species (c) and training system (r).

Initial orchards

In the first year of the model run (t=1) the total area with orchards will include those already present plus those planted in that initial year:

$$X_{c,a,s,r,i,f,m,t} = \mathrm{Initial\_orchards}_{c,a,s,r,i,,f,m} \qquad \forall\ c,a,s,r,i,f,m$$

in which a>1 and t=1

Initial_orchards$_{c,a,s,r,i,,f,m}$: *Area (ha) with orchards already present (a>1) at the first year (t=1)*[1].

Inorganic nitrogen application

The inorganic nitrogen applied at the farm has to be lower or equal than certain threshold to be set by the model user:

$$\sum_{c,a,s,r,i,f,m} \text{Inorg\_N}_{c,a,s,r,i,f,m} \bullet X_{c,a,s,r,i,f,m,t} \leq \text{Upper\_bound\_Inorg\_N} \qquad \forall\ t$$

in which $a \leq MLS_{c,r}$

Inorg_N$_{c,a,s,r,i,f,m}$: Inorganic nitrogen that has to by applied for the activity "c, a, s, r, i, f, m" (kg ha^{-1}).
Upper_bound_Inorg_N: Upper limit set by the model user for inorganic nitrogen application at farm level (kg).

Biocides use

The biocides use of the farm has to be lower or equal than a certain threshold to be set by the model user:

$$\sum_{c,a,s,r,i,f,m} \text{Biocides\_use}_{c,a,s,r,i,f,m} \bullet X_{c,a,s,r,i,f,m,t} \leq \text{Upper\_bound\_biocides\_use} \qquad \forall\ t$$

in which $a \leq MLS_{c,r}$

Biocides_use$_{c,a,s,r,i,f,m}$: Biocides use of the activity "c, a, s, r, i, f, m" (kg a.i. ha^{-1} or Toxic Units ha^{-1}).
Upper_bound_biocides_use: Upper limit set by the model user for biocides use at farm level (kg a.i. or Toxic Units).

Labour availability

In every month, the total labour demand of the farm has to be lower or equal to the monthly available labour:

$$Farm\_labour\_Month_t \leq \text{Avialable\_labour\_Month}_t \bullet \text{Lab\_avail\_CF}_t \qquad \forall\ t$$

Farm_labour_Month$_t$: Monthly labour demand (h) of the farm.
Avialable_labour_Month$_t$: Monthly available labour (h) for the farm during each year of the model run.
Lab_avail_CF$_t$: Annual (t) correction factor for labour availability at farm level.

AUXILIARY VARIABLES

Monthly labour demand of the farm

The labour demand of the farm in each specific month is the sum of the monthly labour

[1] At the first year (t=1), the model get track of orchards of a>1 with this equation, and when t>1, with the equation "Perennial crops balance" (see later). New orchards (a=1) are not restricted by these two equations and can therefore be planted at any time.

demand of all activities:

$$\sum_{c,a,s,r,i,f,m} \text{Labour\_Month}_{c,a,s,r,i,f,m} \bullet X_{c,a,s,r,i,f,m,t} \qquad \forall\ t$$

in which $a \leq MLS_{c,r}$

$Labour\_Month_{c,a,s,r,i,f,m}$: Labour requirement per month for the activity "c, a, s, r, i, f, m".

Inter-months labour deviation

Calculation of seasonal (for the period November-April) inter-months variability of labour demand, required creating two deviational variables which represent the positive and negative deviations from the monthly average of labour demand for the season each year:

$$Farm\_labour\_Month_t - PosLabour_{t,m} + NegLabour_{t,m} = Average\_monthly\_labour\_season_t \qquad \forall\ t$$

$PosLabour_{t,m}$: Positive deviations (h) from the monthly average of labour demand for the season (November-April) each year.
$NegLabour_{t,m}$: Negative deviations (h) from the monthly average of labour demand for the season (November-April) each year.
Average_monthly_labour_season: Monthly average of labour demand (h) for the season (November-April) each year.

Next, two other auxiliary variables were created, representing the highest and lowest inter-months deviations of labour demand:

$$PosLabour_{t,m} \leq LabMax\_pos \qquad \forall\ t,m$$

$$NegLabour_{t,m} \leq LabMax\_neg \qquad \forall\ t,m$$

LabMax_pos: Highest inter-months deviations of labour demand (h).
LabMax_neg: Lowest inter-months deviations of labour demand (h).

Budget

In year 1, the available budget is equal to the initial budget. When t>1, the yearly available budget is dynamic and can be formulated in a "balance equation", i.e. the budget at the beginning of year t is equal to the budget at the beginning of year t-1 plus the financial result of the farm[2] at the end of the year t-1 minus the personal consumption in year t-1:

$$Budget_t = \text{Initial\_budget}_t \qquad t=1$$

$$Budget_t = Budget_{t-1} + Farm\_finance_{t-1} - \text{Pers\_consump}_{t-1} \qquad \forall\ t>1$$

$Budget_t$: Avaialble budget (US$) at the beginning of each year (t)
Initial_budget: Available budget (US$) at the beginning of year 1.
$Pers\_consump_t$: Annual amount (US$) required for the grower and his/her family for living and personal consumption in the previous year (t-1).
$Farm\_finance_t$: Annual financial result of the farm (US$) at the end of the previous year (t-1).

[2] The annual financial result of the farm ($Farm\_finance_t$) is a free variable, being possible to have negative values too.

Annual financial result of the farm

The farm financial result each year is calculated as the annual Gross Value of Product of the farm minus all the annual farm expenditures:

$$Farm\_finance_t = Farm\_GVP_t - Farm\_expend_t \qquad \forall\, t$$

$Farm\_GVP_t$: Annual gross value of product (produce x price) at farm level (US\$).
$Farm\_expend_t$: Total annual expenditures (US\$) at farm level.

Farm Gross Value of Product (GVP)

The annual Gross Value of Product of the farm is formulated as:

$$Farm\_GVP_t = \sum_{c,a,s,r,i,f,m} \mathrm{GVP}_{c,a,s,r,i,f,m} \bullet \mathrm{Pf\_CF}_{t,c} \bullet X_{c,a,s,r,i,f,m,t} \qquad \forall\, t$$

in which $a \leq MLS_{c,r}$

$GVP_{c,a,s,r,i,f,m}$: Gross value of product of the activity "c, a, s, r, i, f, m" (US\$ ha^{-1}).
$Pf\_CF_{t,c}$: Annual (t) fruit price correction factor for each crop species (c)

Farm expenditures

Expenditures at farm level include all required investments, labour, annual inputs and costs due to eventual eradication of orchards:

$$Farm\_expend_t = \sum_{c,a,s,r,i,f,m} (\mathrm{Cost{-}labour}_{c,a,s,r,i,m,f} + \mathrm{Labour\_cost}_{c,a,s,r,i,m,f} \bullet \mathrm{Lab\_cost\_CF}_t) \bullet X_{casrifmt} +$$
$$Farm\_Erad\_cost_t \qquad \forall\, t$$

in which $a \leq MLS_{c,r}$

$Cost{-}labour_{c,a,s,r,i,m,f}$: All annual expenditures (US\$ ha^{-1}) for the activity "c, a, s, r, i, f, m", except labour.
$Labour\_cost_{c,a,s,r,i,m,f}$: Labour expenditures (US\$ ha^{-1}) for the activity "c, a, s, r, i, f, m".
$Lab\_cost\_CF_t$: Annual (t) labour cost correction factor.
$Farm\_Erad\_cost_t$: Annual expenditures (US\$) for orchards eradication (due to activities reaching the maximum lifespan (MLS) or because their continuation is not optimal).

Farm eradication cost

Orchards can be eradicated because they reach their maximum lifespan or because their continuation is non-optimal.

$$Activity\_Erad\_cost_{c,a,s,r,i,f,m,t} = (X_{c,a-1,s,r,I,f,m,t-1} - X_{c,a,s,r,i,f,m,t}) \bullet \mathrm{Erad\_ha} \qquad \forall\, c,a,s,r,i,f,m,t>1$$

in which $a \leq MLS_{c,r}$

$Activity\_Erad\_cost_{c,a,s,r,i,f,m,t}$: Annual expenditures (US\$) for eradicating the activity "c, a, s, r, i, f, m"
Erad_ha: Cost (US\$ ha^{-1}) for eradicating one ha of orchard.

$$Farm\_Erad\_cost_t = \sum_{c,a,s,r,i,f,m} Activity\_Erad\_cost_{c,a,s,r,i,f,m} + \sum_{c,a',s,r,i,f,m} X_{c,a',s,r,i,f,m,t} \bullet \text{Erad\_ha} \qquad \forall\ t>1$$

in which $a \leq MLS_{c,r}$ *and* $a' = MLS_{c,r}$

BALANCES

Perennial crops balance

With ageing, any activity can only remain with the same area or decrease (due to eradication), but not to increase, because new plantings would be a=1 and therefore will be considered as a different activity:

$$X_{c,a,s,r,i,f,m,t} \leq X_{c,a-1,s,r,i,f,m,t-1} \qquad \forall\ c,a,s,r,i,f,m,t>1$$

in which $MLS_{c,r} > a > 1$

Budget balance

In each year, the total farm expenditures have to be lower or equal than the available budget at that year:

$$Farm\_expend_t \leq Budget_t \qquad \forall\ t$$

OBJECTIVE FUNCTIONS

Maximisation of the present value of the cumulative financial result

The present value of the cumulated financial result (PV-CFR) of the farm, which is one of the objective functions that the model user may chose, was calculated considering a given discount rate (i) as:

$$\text{PV-CFR} = \sum_t Farm\_finance_t / [(1 + i)^t]$$

Maximisation and minimisation of total cumulated labour

Farm cumulated labour, that can be a maximization or minimization objective function, was calculated as:

$$\text{CUM-LABOUR} = \sum_{c,a,s,r,i,f,m} \text{Labour}_{c,a,s,r,i,f,m} \bullet X_{c,a,s,r,i,f,m,t}$$

in which $a \leq MLS_{c,r}$

CUM-LABOUR: Total cumulated labour at farm level over the complete planning horizon (h).
$Labour_{c,a,s,r,i,f,m}$*: Annual labour demand (h* ha^{-1}*) for the activity "c, a, s, r, i, f, m".*

Minimisation of the maximum monthly (November-April) labour level

The positive and negative highest deviations (mini-max problem) of inter-month labour requirement, which can be set as a minimization objective function in OPTIFROP, can be calculated as:

LABOUR-DEV = LabMax_pos + LabMax_neg

LABOUR-DEV: positive and negative highest deviations of inter-month labour demand (h).

CURRICULUM VITAE

Eduardo Daniel Cittadini was born in Trelew, Argentina, on October 22nd 1970, being the youngest of eleven siblings. He grew up in the same city, following primary and secondary school at *Colegio Padre Juan Muzio*. In 1989, he moved to Balcarce to study agronomy at the Faculty of Agricultural Sciences, National University of Mar del Plata, graduating as Agronomist Engineer in 1994.

Immediately afterwards, he started to work in Río Gallegos, in the most southern city of the continental part of Argentina, as private advisor with *Borrelli, Perez & Asoc.*, a consultancy firm devoted to large sheep ranches of Santa Cruz, Tierra del Fuego and Chubut Provinces, evaluating agro-ecological conditions of natural grasslands to assess stocking rates and define management plans. At the same time, he was appointed as advisor of a group of sheep ranchers in the framework of *Cambio Rural* program (INTA-SAGPyA).

At the end of 1995, he started to work in the *Agencia de Extension Rural* (AER) of Gobernador Gregores, on a contract with GTZ doing experimentation and extension on vegetable production. One year later, he continued the same task, but with a working fellowship of INTA. During his stay in Gobernador Gregores, he was also lecturer in an Agricultural High School. In 1999, he participated in the three months International Course on Vegetable Production, at the International Agricultural Centre (Wageningen, The Netherlands), which was supported by a NUFFIC fellowship. Back in Argentina, he was in charge of the AER Gobernador Gregores until he moved to Wageningen to start his Master of Science in 2000, again financially supported by a NUFFIC fellowship. He graduated "*cum laude*" in January 2002 in Crop Science, with specialization in Production Ecology.

After his graduation, he was contracted by INTA in the *Estación Experimental Agropecuaria* (EEA) Chubut, working as researcher on cherry ecophysiology and fruit-tree production systems, in the group *Fruticultura*. In October of the same year, he started his PhD program in Wageningen at the Chair group Plant Production Systems, this time with financial support through a sandwich fellowship of Wageningen University. During 2003 he was head of the group *Fruticultura*, a position that he has conducted again from August 2005 to the present. Before, in October 2004, he was appointed as INTA staff.

Eduardo Cittadini has been supervisor or co-supervisor of undergraduate and master students from Wageningen University and from *Universidad Nacional de la Patagonia San Juan Bosco*, and has participated in the writing of project proposals at regional, national and international level. He has also been reviewer of research proposals and scientific articles for proceedings of the Argentinean Congresses of Horticulture and for the journal *Horticultura Argentina*.

Since early 2007, he leads the Argentinean team of the EU-funded project EULACIAS (EUropean – Latin American Co-Innovation of Agro-ecosystemS) and coordinates the work-package “Farm scale determinants of livelihoods: natural resources use”.

He is married to Gabriela Romano since 1997, with whom he has, so far, two children: Adriano and Micaela.

LIST OF PUBLICATIONS

Scientific articles published

Cittadini, E.D., Peri, P.L., 2006. Estimation of leaf area in sweet cherry using a non-destructive method. *RIA* (INTA) 35(1): 143-150.

Cittadini, E.D., Romano, G.S., 2004. Efecto de la población de plantas y del peso medio del "diente semilla" sobre el rendimiento, el calibre, la tasa de conversión, la uniformidad de los bulbos y el nivel de pérdida de plantas en ajo Violeta Santacruceño. *Horticultura Argentina* 23(54): 12-19.

Cittadini, E.D., van Keulen, H., Peri, P.L., 2006. FRUPAT: a tool to quantify inputs and outputs of Patagonian fruit production systems. *Acta Horticulturae* 707: 223-230.

Cittadini, E.D., de Ridder, N., Peri, P.L., van Keulen, H., 2006. A method for assessing frost damage risk in sweet cherry orchards of South Patagonia. *Agricultural and Forest Meteorology* 141: 235-243.

Cittadini, E.D., van Keulen, H., Peri, P.L., de Ridder, N., 2006. Designing a "target-tree" for maximizing gross value of product in Patagonian sweet cherry orchards. *International Journal of Fruit Science* 6(3): 3-22.

Peri, P.L., **Cittadini, E.D.**, Romano, G.S., 1997. Efecto de cortinas cortaviento sobre la producción de ajo violeta en la Provincia de Santa Cruz, Argentina. *Revista Espacios (UNPA)* 10: 6-10.

Romano, G.S., **Cittadini, E.D.**, Pugh, B., Schouten, R., 2006. Sweet cherry quality in the horticultural production chain. *Stewart Postharvest Review* 6:2.
(http://www.stewartpostharvest.com/Vol2_2006/December_2006/Romano.pdf).

Scientific articles in press

Cittadini, E.D., Peri, P.L., de Ridder, N., van Keulen, H. Relationship between mean fruit weight and the ratio of fruit number to leaf area, at spur and whole-tree level, for three sweet cherry varieties. *Acta Horticulturae.*

Cittadini, E.D., Rodríguez, M.J., van Keulen, H., de Ridder, N., Peri, P.L. Fruit dry weight and quality of 'Bing' sweet cherries grown without source limitations. *Acta Horticulturae.*

Cittadini, E.D., Vallés, M.B., Rodríguez, M.J., van Keulen, H., de Ridder, N., Peri, P.L. Effect of fruit number to leaf area ratio on fruit quality and vegetative growth of 'Bing' sweet cherry trees at optimal LAI. *Acta Horticulturae.*

Cittadini, E.D., Sanz, C.E., Szlápelis, S.E., Manavella, F.A., San Martino, L., Muñoz, M., Pugh, A.B., Cárcamo, M.Á., Mundet, C.A., Peri, P.L., de Ridder, N., Kikuchi, N., Ñancucheo, J.A., van Keulen, H. Sweet cherry production in South Patagonia, Argentina. *Acta Horticulturae.*

Book

Cittadini, E.D., San Martino, L. (Eds.), 2006. El cultivo de cerezos en Patagonia Sur: Tecnología de manejo, empaque y comercialización. Ediciones INTA, Buenos Aires, Argentina, 200 pp.

Book chapters

Cittadini, E.D., 2006. La situación actual del sector productor de cerezas en la Patagonia Sur. In: Cittadini, E.D., San Martino, L. (Eds.). El cultivo de cerezos en Patagonia Sur: Tecnología de manejo, empaque y comercialización. Ediciones INTA, Buenos Aires, Argentina, pp. 15-20.

Cittadini, E.D., 2006. Ecofisiología y potencial productivo del cerezo. In: Cittadini, E.D., San Martino, L. (Eds.). El cultivo de cerezos en Patagonia Sur: Tecnología de manejo, empaque y comercialización. Ediciones INTA, Buenos Aires, Argentina, pp. 21-30.

Pugh, B., **Cittadini, E.D.**, 2006. Implantación y conducción de montes de cerezo. In: Cittadini E.D.; L. San Martino (Eds.). El cultivo de cerezos en Patagonia Sur: Tecnología de manejo, empaque y comercialización. Ediciones INTA, Buenos Aires, Argentina, pp. 59-72.

Software development

Cittadini, E.D., 2005. FRUPAT: a Technical Coefficient Generator (TCG) for fruit production systems of South Patagonia. CD-rom, ISBN: 987-521-160-5. EEA Chubut (INTA), Argentina – PPS (WUR), The Netherlands.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities).

Review of Literature (5.6 credits)

- Eco-physiology of sweet cherry.
- Alternatives for developing the fruit sector in South Patagonia (Argentina), with emphasis on sweet cherry production.
- Quantitative analysis of agricultural systems and linear programming optimization.

Writing of Project Proposal (7 credits)

- Development of a participatory decision support system for the fruit sector in South Patagonia (Argentina), with emphasis on sweet cherry production.

Laboratory Training and Working Visits (6 credits)

- Sweet cherry production systems. Pruning and training systems; INIA, Badajoz, Spain (2003).
- Fruit production systems. Integrated pest management; INTA-EEA Alto Valle, General Roca, Argentina (2004).
- Writing of regional project (INTA): Intensive and sustainable development of fruit production systems in South Patagonia; INTA-AER Los Antiguos, Los Antiguos, Argentina (2004).
- Writing of national project (INTA): Influence of biotic and management factors on quality, yield and sustainability of organic and environmentally friendly fruit production systems; INTA Central, Buenos Aires, Argentina (2006).
- Writing of international project (FP6 program of EU): EUropean-Latin American Co-Innovation of Agro-ecosystemS (EULACIAS); INTA-EEA Chubut, Trelew, Argentina (2006).

Post-Graduate Courses (5.6 credits)

- Course: Eco-physiology of sweet cherry and orchard management; organizer, translator and participant; INTA-EEA Chubut, Argentina - Washington State University, USA (2006).
- International workshops of EULACIAS: (a) Definition of the approach for each module (work package) and common research methodologies along case studies; Universidad de Chapingo, Mexico (2006). (b) Writing of PhD and Post-Doc preliminary proposals; Universidad de la República, Uruguay (2007). (c) Discussion of preliminary research results; Universidad de Chapingo, Mexico (2007). Participant.

Deficiency, Refresh, Brush-up and General Courses (4.2 credits)

- MSc course: GIS basics-data processing (Mark: 8); WUR (2002).

Competence Strengthening / Skills Courses (1.4 credits)

- Time planning and project management; PE&RC (2003).

Discussion Groups / Local Seminars and other Scientific Meetings (7 credits)

- Discussion group: Sustainable land-use and resource management (2002-2003).
- Symposium: “Environmental system analysis: environmental research at the edge of science and society”; Ede, the Netherlands (2003).
- Technical Comity of the Agricultural Research Station Chubut (monthly), Trelew, Argentina (2003, 2005 and 2006).
- Argentinean Congress of Horticulture; Merlo, Argentina; poster presentation (2004).
- First National Conference on blueberry and other berries (Buenos Aires University), Buenos Aires, Argentina; lecturer (2006).
- Course: International marketing of fruits; Trelew, Argentina; organizer and participant (2007).
- Scientific publishing; participant (2007).
- Meeting of the chair group plant production systems (2007).

PE&RC Annual Meetings, Seminars and the PE&RC Weekend (1.2 credits)

- The PE&RC introduction weekend (2002).
- PE&RC annual meeting: Ethic and science (2002).

International Symposia, Workshops and Conferences (3.9 credits)

- VII International Symposium on Modelling in Fruit Research an Orchard Management (Copenhagen, Denmark); poster presentation (2004).
- V International Cherry Symposium (Bursa, Turkey); oral and poster presentations (2005).
- XII Latin American Congress of Horticulture (General Roca, Argentina); oral and poster presentations.

Courses in which the Candidate has Worked as a Teacher

- Modelling sweet cherry production systems; 12 days.
- Yield-fruit quality relations in sweet cherry; 17 days.
- Floral biology of sweet cherry; 4 days.
- Farm-modelling for optimization of fruit production systems in South Patagonia; 7 days.
- Variability among actors with regard their perception and attitudes towards technology in the sweet cherry sector of South Patagonia; 7 days.