FRUPAT: A Tool to Quantify Inputs and Outputs of Patagonian Fruit Production Systems

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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 (good quality soil with water-table depth exceeding 2 m; good quality soil with water-table depth between 1 and 2 m; low water holding capacity soil without water-table influence), 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, N-fertiliser surplus and labour. As an example of how FRUPAT can be used, some results are presented for a single physical environment (good quality soil with water-table depth exceeding 2 m, 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.

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, 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.

METHODOLOGY

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 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).

The Definition Criteria

1. 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.
2. Edaphic Environment. FRUPAT considers soils of classes 4F and 2 (AAFRD, 2000) (suitable for fruit-trees). Class 2 is subdivided in “deep” (> 2 m) and “shallow” (between 1 and 2 m). A deep class 2 soil has favourable physical (texture, structure, drainage capacity) and chemical (pH, sodium and salt content) properties that allow root growth without limitations, while a shallow class 2 soil has similar characteristics, but there is presence of an impermeable layer or water table near the soil surface during part of the year. Class 4F soils have no water-table influence and good drainage capacity, but are low in organic matter and nutrients and have very low cation exchange capacity and water holding capacity.
3. 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.
4. 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).
5. 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 senesced leaves to be recycled.
6. 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 only recommended for walnut, because of its late flowering.

7. 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 N-fertiliser surplus (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

1. 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.

2. Nitrogen Fertiliser Surplus. N-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:

$$N_{fa}: (N_d - N_s)/ANR$$

in which: N_{fa} is the nitrogen fertiliser requirement (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}) and ANR is the apparent nitrogen recovery (kg kg^{-1}), defined as a function of soil-type and irrigation system.

N-fertiliser surplus (N_{fs} in kg ha^{-1}; lost through leaching or volatilisation) is defined as the fraction of N-fertiliser not taken up by the crop:

$$N_{fs}: N_{fa} * (1 - ANR)$$

3. 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:

$$TU: a.i. * half\text{-}life / LD_{50}$$

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.

4. 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. 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).

5. 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).

6. Total Expenditures. Expenditures are estimated for each year of the orchard's life cycle 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.

7. 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).

8. 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.

9. 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.

RESULTS AND DISCUSSION

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 (class 2-deep soil of 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, walnut, plum and peach (Fig. 2). Financial result followed the same order, because total expenditures were similar for all crops. Capital requirements were slightly lower for sweet cherry than for the other crops because although sweet cherry demands high investments during establishment, it showed an earlier positive financial result. Frost protection using sprinkler irrigation was not required for walnuts production, because of its late flowering. This would allow the use of a passive strategy, thus restricting capital requirements.

Comparing Production Techniques

Production technique determines yield and the proportions of fruit quality classes, thus gross value of product and yield were not proportional. For all monetary technical coefficients, tatura was the best option despite its high total expenditures (Table 1). Thus, capital requirements for establishment were highest for tatura, mainly due to its high planting density, but the ratio of financial result at maturity/capital requirements was again higher, with the combination of vase training system with furrow irrigation attaining a similar ratio. However, 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 N-surplus per ha for this system was the consequence of an inter-row leguminous crop established that completely covered the nitrogen demand at maturity. Under the drip irrigation system, tatura showed a higher N-surplus per ha than central leader and vase. However, the opposite was observed for the surplus per unit of product, due to the higher yield under the tatura training system. 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.

Evolution in Time of Some Technical Coefficients

Gross value of product followed a sigmoid yield curve, starting 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 already from the 5th (Fig. 3D). Planting and installing structures were the reasons for the relatively high labour demand during the first year (Fig. 4A). 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). This strongly seasonal labour pattern could be an important limitation for crop profitability.

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.

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Tables

Table 1. Technical Coefficients of a mature sweet cherry orchard (12th year) grown in the Río Chubut valley on a class 2-deep soil, frost protected through sprinkler 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})	16.2	14.4	13.0	14.4	13.0
Gross value of product (US$ ha^{-1})	26116	22097	19887	21650	19485
Total expenditures (US$ ha^{-1})	4133	4046	3691	4252	3867
A. Financial result (US$ ha^{-1})	21983	18051	16196	17398	15617
B. Capital requirements (US$ ha^{-1})	20070	18019	15895	16499	14351
A/B * 100	109.5	100.2	101.9	105.4	108.8
Break-even year to recover cumulative preceding expenditures	5	7	7	7	7
N-fertiliser surplus per area (kg ha^{-1})	6.5	6.2	0	6.2	0
N-fertiliser surplus per product (g kg^{-1} fruit)	0.40	0.41	0	0.41	0
Biocide use (g a.i[2]. kg^{-1} fruit)	2.1	2.36	2.62	2.36	2.62
Biocide use (TU[3] Mg^{-1} fruit)	0.21	0.24	0.27	0.24	0.27
Total labour demand (h ha^{-1} year^{-1})	1920	2016	1939	2227	2112

[1]The combination “tatura – furrow irrigation” was filtered as unfeasible; [2]active ingredient; [3]Toxic Units (see text for explanation).

Figures

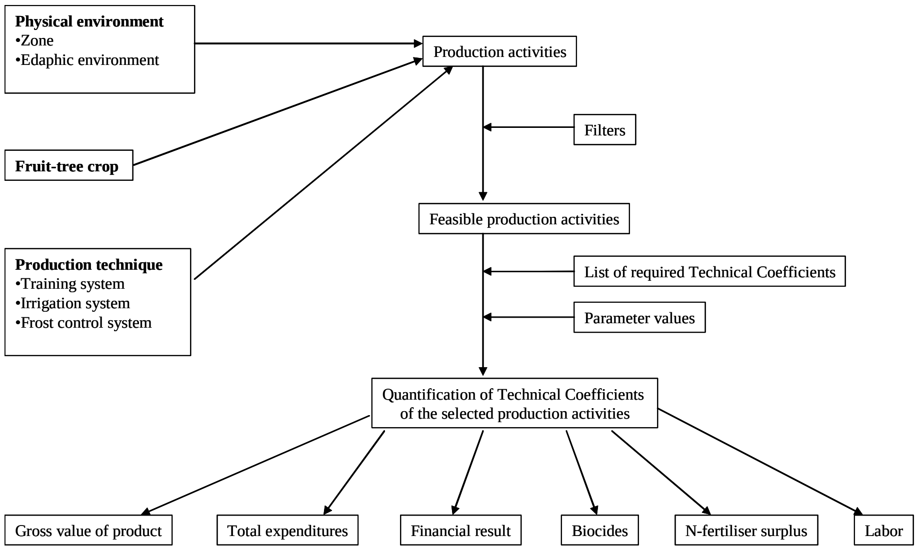

Fig. 1. General approach of FRUPAT. The combination of zone, edaphic environment, fruit-tree species, irrigation system and frost control system results in the production activities. After filtering only feasible combinations remain. Then, the user chooses the TCs that he/she wants to generate and may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

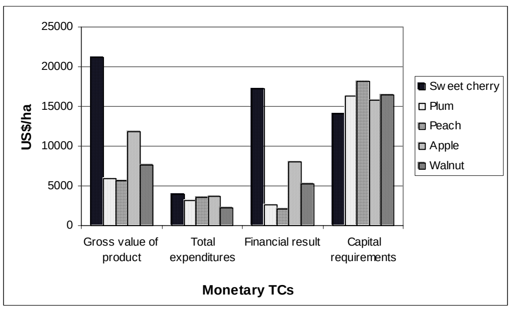

Fig. 2. Gross value of product, total expenditures and financial result of a mature orchard, and capital requirements for the 5 crops in a class 2-deep soil in the Río Chubut valley, trained as a vase, with furrow irrigation and frost protection with sprinkler irrigation.

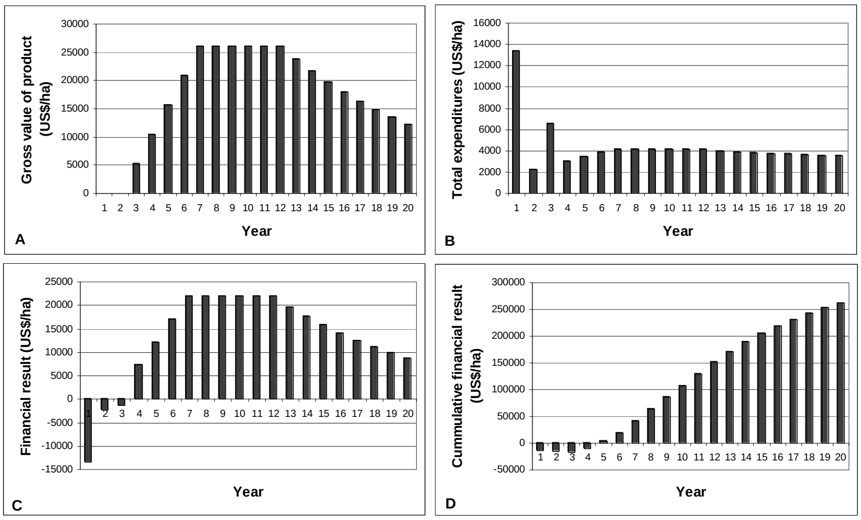

Fig. 3. Time course of gross value of product (A); total expenditures (B), financial result (C) and cumulative financial result (D) of sweet cherry in a class 2-deep soil of the Río Chubut valley, trained as tatura, with drip irrigation and frost protected with sprinkling irrigation.

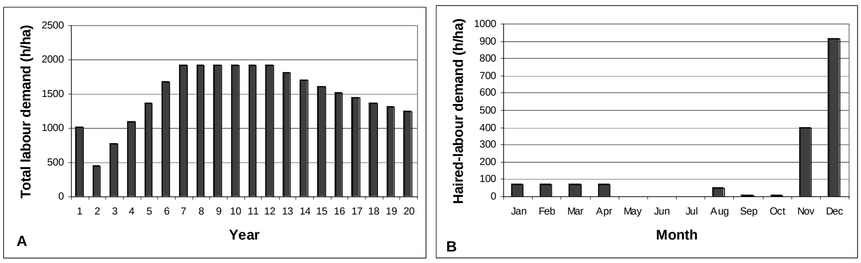

Fig. 4. Time course of total labour demand (A) and monthly haired-labour demand of a mature orchard (12th year) (B) of sweet cherry in a class 2-deep soil of the Río Chubut valley, trained as tatura, with drip irrigation and frost protected with sprinkling irrigation.