



# Optimising fruit production choices

Mathematical modelling techniques show that choosing the right cultivar mix for deciduous fruit production units can drastically improve profitability.

\_\_\_\_\_ by Mathys Steenkamp and Wim Gevers

**T**he competitiveness of South African deciduous fruit exports has come under severe pressure in recent years. It has been a persistent struggle to find ways of keeping input costs as low as possible in the face of a price mechanism that is driven by global demand and supply – where prices move independently from local input cost structures and increases. South African fruit

producers have experienced substantial rises in major input costs like labour, energy and product development, but prices on the global market have stayed much more constant, especially in rand terms. Several cultivars have even experienced downward trends over certain periods.

Finding ways of cutting input costs and improving efficiencies is an on-going challenge.

A further possibility of improving competitiveness lies in finding a better cultivar mix for a particular production unit. There are different market prices and input cost structures for different cultivars, and by achieving an improved production mix, the profitability of the production unit can be enhanced. The solution to the problem is however not as simple as merely calculating the most profitable

### FRUIT-BEARING CAPACITY OF TREES BY AGE

1 to 2 years	: 0% fruit-bearing
2 to 3 years	: 25% fruit-bearing
3 to 4 years	: 40% fruit-bearing
4 to 5 years	: 80% fruit-bearing
5 years and older	: 100% fruit-bearing

cultivar and only planting that cultivar. Several constraints have to be borne in mind, and this makes the problem more intricate. One of the strongest considerations is diversification. Fruit producers know from experience that they need to diversify to hedge themselves against sudden fluctuations in the price of even the most profitable cultivars. In addition, a diversified mix of cultivars can, owing to different ripening times, improve the utilisation of farm labour.

This study done at the University of Stellenbosch Business School (USB) investigated the possibility of building a model based on operations research techniques to support the decision of putting a 20-year cultivar mix strategy in place for a particular production unit. The unit can be a farm or a group of farms operating as a strategic entity. Analytical models are ideal for finding an optimal mix of inputs, for example to maximise the profit based on a number of alternative options, but where these options on their own and collectively are subject to a set of pre-defined constraints.

The objective of the study was to develop a tool capable of assisting strategic decision-making which will optimise the allocation of scarce resources. As such, the envisaged model should provide a structured way of bringing important assumptions into the decision-making process, for example:

- Market price variation over years and between cultivars;
- Changes in consumer preferences;
- The production losses caused by re-establishing orchards (trees only achieve full production after five years); and
- Technological advances.

#### Study approach

This particular study addressed the problem by way of two stages of linear programming modelling.

The first-stage model was needed to determine the optimal cultivar mix that the production unit should set as an objective. Since it is not feasible for a farm to change immediately to a substantially different combination of cultivars, a subsequent decision was required, namely the plan to implement the proposed change in an optimal way over time. Therefore, the second-stage model was built. This model made use of intertemporal linear programming – a technique that sequentially takes the optimised output of one year as input into the next, until it reaches an optimised output at the end of the period.

A 20-year period was chosen after thorough discussions with fruit producers and consultants supporting fruit producers. It is very important to take into account that it takes a number of years for fruit trees to become fully productive. Replacing orchards with new cultivars therefore has to be carefully phased in over time to ensure the year-on-year viability of the farm. See the box **top left** for details about the fruit-bearing capacity of trees by age.

#### Modelling the production unit

The model was built around a typical production unit with 13 different cultivar options, namely seven apple cultivars, two pear cultivars, one category for other apples, one category for other pears, plums, and lastly nectarines.

##### Stage 1

The first step was to formulate the profit function that needs to be maximised. The total profit is a summation of the profit contributions of each of the cultivar choices. The complete profit function would thus be: Profit contributed by cultivar<sub>1</sub> + Profit contributed by cultivar<sub>2</sub> + ..... + Profit contributed by cultivar<sub>13</sub>.

The profit contribution of each of the cultivars is given by:

Sales income for cultivar<sub>1</sub> (rand)  
minus fixed cost based on production area (ha) of cultivar<sub>1</sub> (rand)  
minus variable cost based on production area (ha) of cultivar<sub>1</sub> (rand)  
minus variable cost based on tonnage produced of cultivar<sub>1</sub> (rand)

Several relevant constraints were identified and built into the stage 1 model. They were as follows:

- The total area for all cultivars (dependent on the production unit).

- A maximum of 70% of the total area can be assigned to apples as a group.
- The area for any individual apple cultivar is restricted to 20% of the total area for apples (i.e. there must be at least five apple cultivars in the total mix).
- At least 30% of the total area must be assigned to the remaining fruit – the three pear cultivar options, nectarines and plums. However, the area for any individual cultivar may not exceed 30% of the total area assigned to this category.
- The harvesting season has been modelled on a daily basis to constrain it for the available labour. This constraint need not be used in cases where sufficient temporary harvesting labour is available.

### Replacing orchards with new cultivars has to be carefully phased in to ensure year-on-year viability

The percentages above were chosen for this particular model following discussions with producers and consultants, and were used for developing and testing the model. But the idea is that when the model is subsequently applied in practice, these can be changed to accommodate other diversification or risk considerations for a particular production unit.

##### Stage 2

The second phase made use of an intertemporal linear programming method. The goal that had to be programmed was to reach the optimal financial position for the production unit after a 20-year period.

In this part, the goal function that had to be optimised was as follows:

Capital position end of year 1 for production unit =  
Opening capital position in year 1  
plus optimal profit based on the goal function for year 1  
minus owner's remuneration for the year  
minus cost of removal of trees  
minus cost of planting new trees  
minus interest on outstanding debt (new debt can be taken out to fund shortfalls)  
minus tax at the standard rate  
plus interest received on positive cash balance (excess cash first repays debt) »



In this stage-2 model, a few new constraints were defined. For each one of these, the specific values could be adjusted by the user of the model to investigate different scenarios. The constraints were:

- The maximum allowable number of old trees removed in a given year.
- The maximum number of new trees planted in a given year.
- The maximum allowable amount of debt at any point in time.

### Findings obtained by running the model

In the development and testing of the model, data from more than 30 production units were obtained from auditors working in this field, with the cooperation of the farms. These data were processed as input data for the model.

The model shows that there are rather dramatic changes needed in the cultivar mix if the present

## PROPOSED CHANGES TO ACHIEVE OPTIMAL CULTIVAR MIX

Major reductions (more than 50%)	Granny Smith apples, other pears	
Moderate reductions (up to 50%)	Golden Delicious, the Starking and Topred category, Packham pears, plums.	
Moderate increases	Royal Gala apples	: 22%
Large increases	Other apples	: 98%
	Braeburn apples	: 121%
	Pink Ladies	: 192%
	Pears – Forelle	: 222%
	Nectarines	: 705%
	Fuji apples:	: 901%

average mix of the farms studied is used as a basis. The results show the recommended changes to the mix of cultivars to achieve an optimal blend (see box **above**).

However, a very important finding is that, on average, across the farms modelled, the optimal cultivar mix represented a near 90% increase in the objective function of the model, i.e. the profit of the production unit.

and the relevance of historic data.

It is therefore advisable carefully to develop one's assumptions based on sound business and economic principles and to allow room for different possible scenarios. The model should also be run year on year, and changes to the model and the assumptions should be incorporated as trends change and new cultivars are developed or gain popularity in the market. ■

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### The utility of the model in practice

It is important to recognise that models like these are essentially *decision support models* – and not *decision models*. They do not provide a mechanistic way of formulating a long-term strategic decision that can be implemented blindly. Running the model is based on a number of assumptions about the specific production unit, and about trends in the market. The data are essentially based on historic patterns and projections based on past experience. The validity of the output is directly related to the quality of the assumptions made



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This research was conducted by Mathys Steenkamp as his MBA study project at the University of Stellenbosch Business School, supervised by Prof Wim Gevers. The research report, '*n Besluitnemingsteunstelsel vir die optimum sagtevrugte kultivar keuse vir produksie-eenhede* (A decision support system for the optimal deciduous fruit cultivar mix for production units) was presented in December 2007. This research was also presented by the authors at the IFORS Conference in Johannesburg in July 2008, with the title: *A decision support model for the choice of cultivars of deciduous fruit on a Western Cape farm.*