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OPTIMIZING THE LONG-TERM PRODUCTION OF CITRUS FARMS

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Abstract. **In this paper it is shown how linear programming and simulation can be used to assist managers of citrus farms in making the difficult decisions of how to plant and replant orchards. The models are also designed in such a way that they can help to bridge the communication gap which often exists between the modeler and the user who, more often than not, are unfamiliar with each other's jargon.**

Linear programming is used to establish the optimum allocation of land to the different varieties/cultivars. Since the different types of trees have different life cycles, improper planting and replanting schedules can lead to wide swings in production and, hence, capacity problems and widely varying profits over time. The simulation models are Excel-based and interactive, and allow rapid assessment of the long-term effects of any replanting scheme. Examples of the application of the models are presented to show how the profitability of estates can be substantially increased and stabilized.

Tambankulu Estate

Tambankulu Estate, where the model was first developed, is in north-eastern Swaziland, close to the Mozambique border. At the time of this study in 1991, three types of citrus were grown there, Valencia oranges, and two grapefruit varieties, Marsh and Texas Star Ruby. On average about 55% is of export quality, the rest is used locally, mainly for juice. The trees on which these fruits are grown have different useful lifetimes and their yields follow approximately Gompertz curves over time with virtually no fruit for the first two to three years, thereafter increasing to about 50 t/ha for Star Ruby, 63 t/ha for Marsh and 75 t/ha for Valencia. After 15 to 25 years, depending on the variety, both the yields and the quality decline rapidly resulting in less fruit for export, which is the most profitable. Finally, the total area available for planting is limited, making any planting of new trees subject to removal of (older) existing trees.

This combination of long, but variable, yield and quality lifetimes and long lead times to useful production levels, makes it difficult to:

a) balance production with packhouse and staff capacity,
b) adjust production to changing tastes and demand,
c) calculate the best replacement schedule for ageing trees, and
d) find the optimum mix of varieties to plant.

In the past planting and replanting had been done "by feeling" without the benefit of computerised quantitative techniques. This resulted in a mix of varieties and areas planted with each variety which, if the replanting scheme used at the time of the study had been continued, would have led to unacceptably wide swings in production as shown in Fig. 1 below. The continuing decline in total yield in fact gave rise to this study.

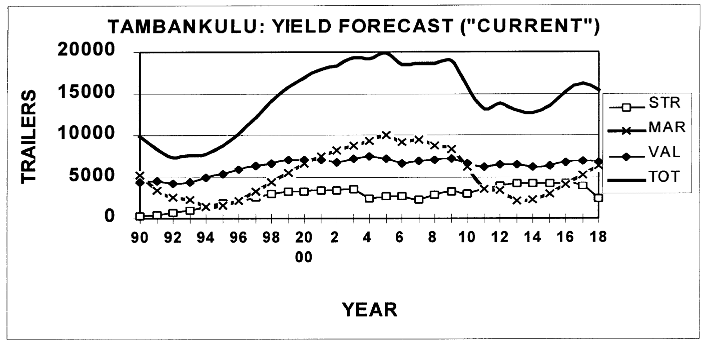

Figure 1. Note the wide swings in production.

Figure 2 below shows the layout of the orchards when the study was started. The varieties and dates of planting are indicated. The total areas allocated to each variety at the time as well as the optimum allocation as determined by linear programming are also shown. A change to the latter alone, without any change in replanting strategy, would have meant a 30% to 50% higher income. (See Appendix 1 for the LP Model).

A still greater improvement is obtained by solving the problem posed by Fig. 3 below which represents the life cycles of the three citrus varieties, from planting up to the time they should be replaced because of drop in yield and quality.

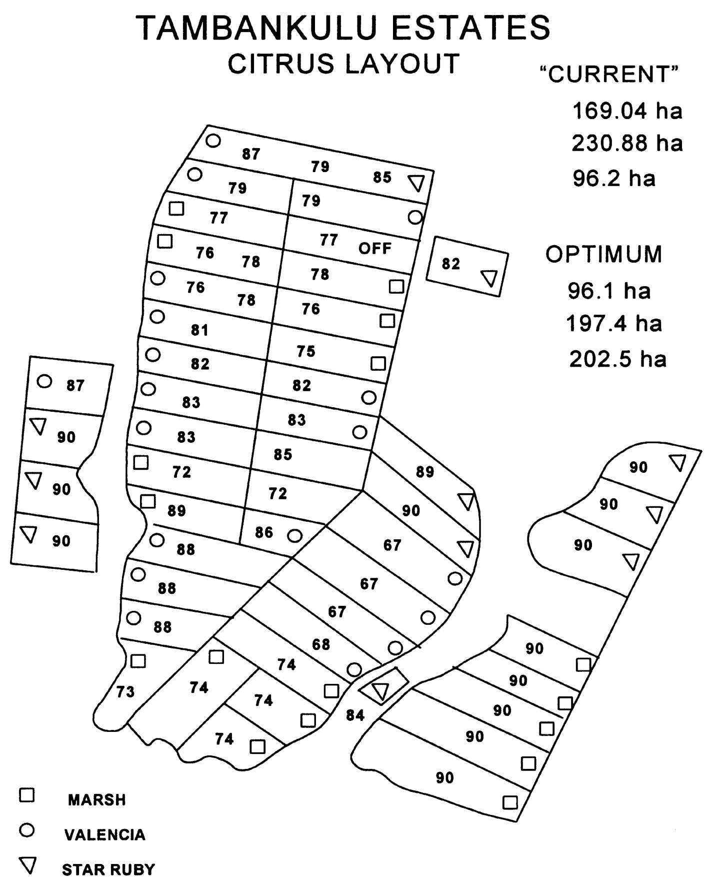

Figure 2. Layout of orchards at start of study.

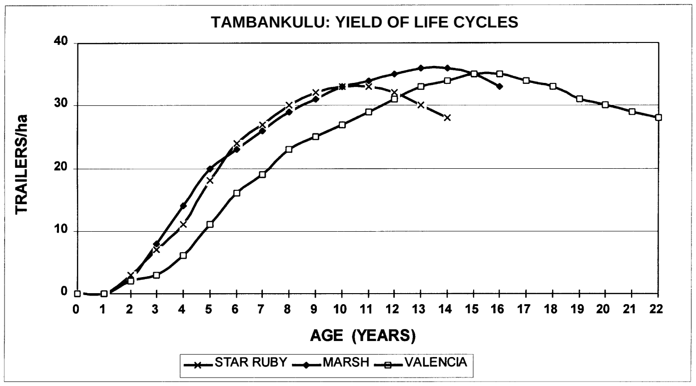

Figure 3. Life cycles of the three citrus varieties til replacement.

The life times are 14 years for Star Ruby, 16 years for Marsh and 22 years for Valencia. These varying lifetimes, together with the rather haphazardly planted area of Fig. 2, directly caused the wide fluctuations in Fig. 1. Occasionally the peaks will coincide, and give a high total yield, only to drift apart and give very low total yield at other times. Theoretically, the only way to avoid this is to plant and replant in such a way that each variety's total annual yield is constant and equal to the average annual yield over its lifetime. This would require the following:

Let the total area planted with variety i be A_i, and let the lifetime of this variety be n_i. Then break each area up into n_i orchards of equal size and plant them so that trees in each successive orchard are a year younger than those of the previous one. The result of this scheme, together with the optimum land allocation as found by linear programming, would give the total yields of Fig. 4 below.

Not only have the fluctuations disappeared, but a constant slack of about 1500 trailers of fruit per annum (equivalent to about 2200 tons) has been created in the packhouse instead of a capacity problem due to peaks. This means that more land (if available) could be planted increasing total production even more. The difficulty, of course, in practice is how to get from the "current" mix of varieties, land allocation, and replanting strategy, to arrive at the ideal situation of Fig. 4, or at least something close to it. The number of variables involved are legion. Already there are 51 orchards, each of which could be changed and re-changed in any number of ways during the 25 year horizon (replanting with the same or a different variety). Simulation was chosen as the best method to handle this complexity and a spreadsheet-based model was built for the purpose. The model requires the following inputs:

1. The tree yield life cycles for all the varieties

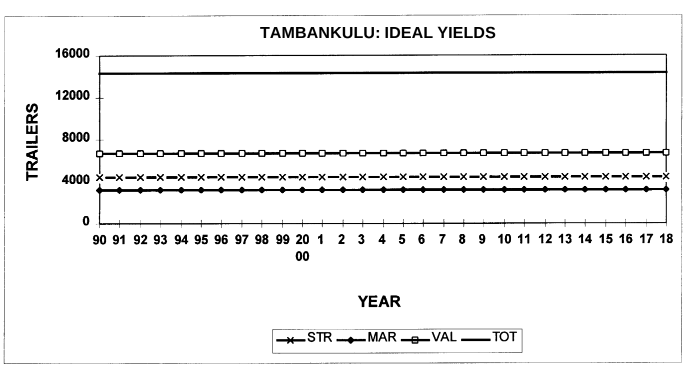

Figure 4. Tambankulu total ideal yields.

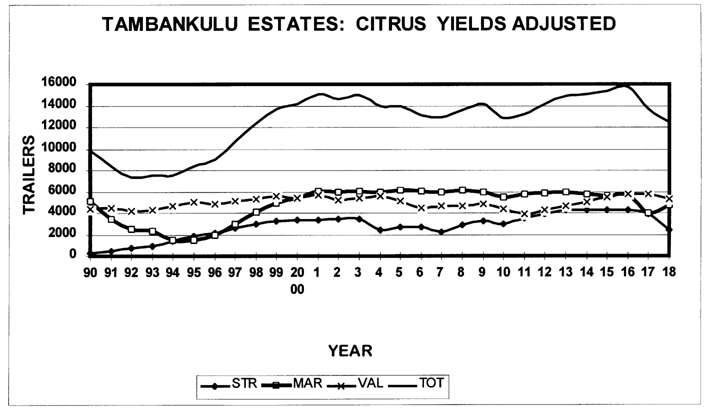

Figure 5. Tambankulu citrus yield adjustments.

2. The number, sizes, and year of first planting of all the orchards or plots and
3. The "normal" age at which to replant any orchard.

The model then calculates the total yield for each variety and the grand total for each year over a chosen horizon, say 25 years, automatically updating the ages of the trees every year and replanting any orchard that has reached the end of its life cycle. The results are represented as a series of graphs. If monetary data are available, graphs of annual income over the horizon can also be generated. The user can then interact with the model and experiment with changing orchards, areas, varieties, replanting dates and, if new data suggest it, life cycles at will. In this way it becomes relatively easy to assess the long term effects of any changes one wishes to examine. Figs. A and B in Appendix 2 illustrate some parts of the spreadsheets.

Results for Tambankulu

Figures 5 and 6 below show the improvement in the planting patterns and income that were obtained after some interactive replanting changes in the Tambankulu model.

Note in Fig. 5 that the peak has dropped to about 15,000 trailers from about 18,000, freeing packhouse capacity. Also note the general increase in yield and the smoothing of the total yield. This of course also implies better/more efficient and more stable use of labour and equipment. The income figures, calculated from the data generated for Fig. 6 and shown in Table 1 below, are even more impressive:

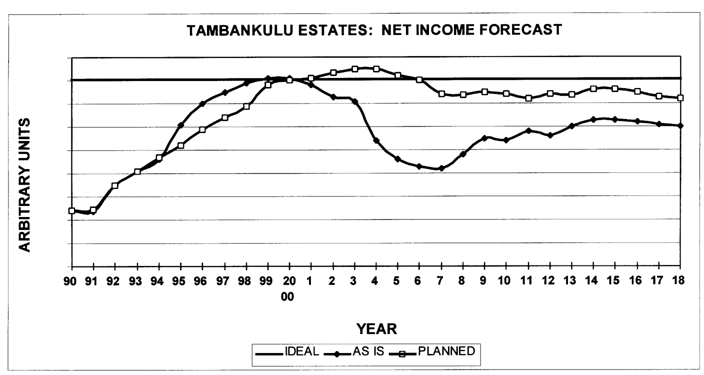

Figure 6. Tambankulu net income forecast.

Table 1. Average annual net income over the next 20 years (Present values).

"Current" case	RX Million
Theoretical Optimum	X + 60.7%
After some replanting	
As of 1990	X + 20.8%
As of 1998 (after the runup)	X + 50.6%

Other Applications

In addition to the Tambankulu Estate case reported on here, the model has been implemented at another much larger estate in South Africa, Letaba Estates. That model includes 10 varieties of citrus and 6 cultivars of mangos, ranging in lifetimes from about 15 years to 40 years, in hundreds of orchards/plots consolidated into 385 plots in the model (based on same age, variety and proximity to one another). As with Tambankulu, the users have reported the model to be of great benefit, firstly, by making their planning problem much simpler and, secondly, by allowing them to significantly increase the profit potential of the estate. In the case of Letaba, which consists of two large (approximately 1200 ha) farms, the model was also used to start the planting of the one farm (a new one) in such a way as to alleviate, somewhat, a serious drop in yields in the other (an old established farm) because almost all of the trees are nearing the end of their economic life simultaneously as they were planted over a very short period about 40 years ago, without any replanting since then except to replace trees which had died.

Conclusion

Long range planning in the citrus industry is difficult and complex because of the long life times of the trees, the long lead times before trees are fully in production and the widely differing life cycles of different varieties. This causes wide swings in production and income far into the future if one "does not get it right", and adjustments at that time are too late and very costly. The computer model presented here is a useful tool in that it helps the user to rapidly assess the future effects of any planned changes in existing farms, as well as helping in the planning stages of new ones to "get it right from the start".

This also applies to other types of fruit, vineyards and possibly forestry as well.

Appendix 1

Example of a linear programming model to optimize land allocation

Program: Linear Programming
Problem Title: Tambankulu

*****Input Data*****

Max. Z = 7391X1 + 7391X2 + 10365X3 + 26378X4
Subject to
C1 1X1 + 1X2 + 1X3 + 1X4 <= 496
C2 22.557X1 <= 3600
C3 22.557X2 + 17.778X4 <= 3600
C4 24.315X3 <= 4800

*****Program Output*****

Final Optimal Solution at Simplex Tableau:3

Variable	Value	Reduced Cost
X1	96.105	0.000
X2	0.000	24089.643
X3	197.409	0.000
X4	202.486	0.000
Constraint	**Slack/Surplus**	**Shadow Price**
C1	0.000	7391.000
C2	1432.161	0.000
C3	0.000	1067.945
C4	0.000	122.311

Objective Coefficient Ranges

Variables	Lower Limit	Current Upper Values	Limit	Allowable Increase	Allowable Decrease
X1	0.000	7391.000	10365.000	2974.000	7391.000
X2	No limit	7391.000	31480.643	24089.643	No limit
X3	7391.000	10365.000	No limit	No limit	2974.000
X4	7391.000	26378.000	No limit	No limit	18987.000

Right Hand Side Ranges

Constraints	Lower Limit	Current Upper Values	Limit	Allowable Increase	Allowable Decrease
C1	399.895	496.000	559.491	63.491	96.105
C2	2167.839	3600.000	No limit	No limit	1432.161
C3	2471.197	3600.000	5308.649	1708.649	1128.803
C4	3256.222	4800.000	7136.791	2336.791	1543.778

*****End of Output*****

Appendix 2

Examples of the Computer Screen for the Simulation Program

Figure A

TAMBANKULU ESTATES: LONG RANGE CITRUS PLANNING MODEL

Yields in Trailers/ha at age —>								
Age	0	1	2	3	4	5	6	7
Star Ruby	0	0	3	7	11	18	24	27
Marsh	0	0	3	8	16	20	23	26
Valencia	0	0	2	3	6	11	16	19

					<—	1990	—>	<—
Orchard	Type	Life (Years)	Area (ha)	Year Pltd	Age	Orchd Trlrs	Slble Trlrs	Age
U6	STR	14	22.60	1989	1	0	0	2
12	STR	14	10.82	1989	1	0	0	2
13	STR	14	11.90	1991		0	0	0
E 1-3	STR	14	8.05	1989	1	0	0	2
E 4-8	STR	14	17.25	2003		0	0	
3AB EXP	STR	14	1.47	1987	3	10	3	4
1 A	STR	14	6.98	1985	5	126	46	6
2 C/D	STR	14	12.16	2002		0	0	
3 A/B	STR	14	3.19	1994		0	0	
3 A/B2	STR	14	5.60	1986	4	62	21	5
Ext. 17	STR	14	0.92	1984	6	22	9	7
P.B.	STR	14	1.51	1982	8	45	20	9
14	STR	14	13.30	1992		0	0	
15	STR	14	13.63	1992		0	0	
X	STR	14	25.00	1995		0	0	
		3000		3000		0	0	
		3000		3000		0	0	

Figure B

TAMBANKULU ESTATES: LONG RANGE CITRUS PLANNING MODEL CONTINUED

NOTES: Normal Operation: Enter N

Replanting an orchard with same variety: Enter Y in year of planting

Discontinuing an orchard: Enter X in year of last crop and in all the years thereafter

Replanting an orchard with a different variety: Discontinue it and restart a new one

Orchard	1990	1991	1992	1993	1994	1995	1996	1997
U6	N	N	N	N	N	N	N	N
12	N	N	N	N	N	N	N	N
13	N	N	N	N	N	N	N	N
E 1-3	N	N	N	N	N	N	N	N
E 4-8	N	N	N	N	N	N	N	N
3AB EXP	N	N	N	N	N	N	N	N
1 A	N	N	N	N	N	N	N	N
2 C/D	N	N	N	N	N	N	N	N
3 A/B	N	N	N	N	N	N	N	N
3 A/B2	N	N	N	N	N	N	N	N
EXT. 17	N	N	N	N	N	N	N	N
P.B.	N	N	N	N	N	N	N	N
14	N	N	N	N	N	N	N	N
15	N	N	N	N	N	N	N	N
X	N	N	N	N	N	N	N	N
	N	N	N	N	N	N	N	N
	N	N	N	N	N	N	N	N