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THE DEVELOPMENT OF A SPATIAL DECISION SUPPORT SYSTEM TO OPTIMISE AGRICULTURAL RESOURCE USE IN THE WESTERN CAPE[1]

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This paper describes the development of a decision support model for regional agricultural resource utilisation. The analysis was generated in a spatial context and the optimisation technique was interactive with a geographical information system (GIS). Economic and operational research methodologies were linked to the GIS in the process of determining the appropriate resource uses for the region. The optimisation technique was applied for the Western Cape Province for eight crops. The results of this research are discussed in this paper, with specific reference to its application value for the public sector and agri-business.

1. INTRODUCTION

The spatial decision support system (SDSS) developed by this research was constructed through an eclectic approach, utilising a number of features of economic models and geographic information systems. The FAO/IIASA (1994) study on resource optimisation in Kenya provided the starting point for the development of the optimisation methodology. A partial equilibrium multi-market model was used for the study.

Decision support systems provide policy-makers and entrepreneurs with means to analyse static and dynamic characteristics of the regional agricultural sector. The economically efficient utilisation of agricultural resources is an essential step towards achieving a competitive agricultural sector. The underlying approach to efficient regional resource allocation is therefore one of optimisation: the attainment of economic goals, but within the context of constraints fashioned by the ecological, technological and institutional characteristics of the region.

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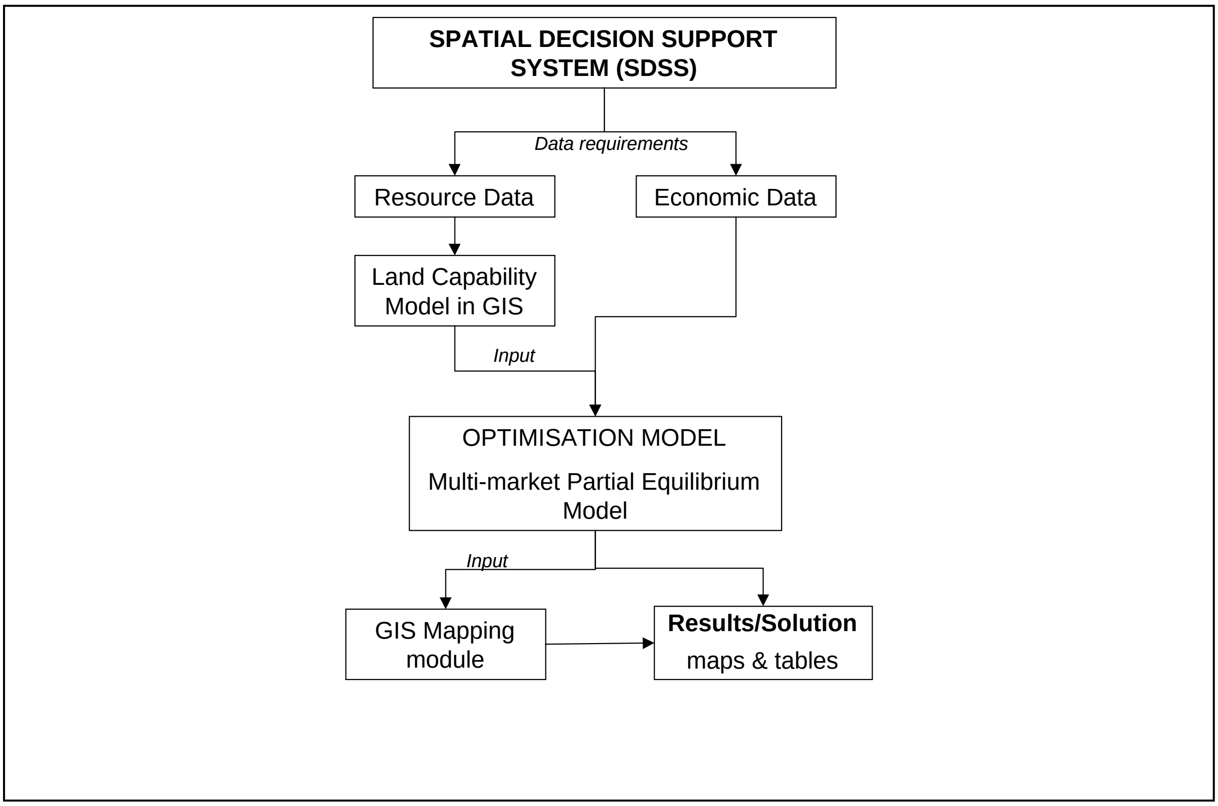


Figure 1: Diagrammatic depiction of the SDSS

Investors need to know *where* to locate in order to capitalise on existing static and dynamic comparative advantages. Entrepreneurs want to know whether production opportunities exist that are not currently exploited within a regional (spatial) context. From this, input-providers and output processors need to ensure that their location is spatially advantageous. In the same vein, government as provider of infrastructure and other public goods needs to ensure maximum effectiveness and efficiency in its activities.

In all these cases the different role-players aims to internalise the spatial context into their specific economic activity. No simplistic cause-effect relationships exist between a specific economic determinant, for example, resource quality according to the Ricardian tradition, and economic improvement. The evolution of theoretical paradigms from comparative advantages to competitive advantages indicates a greater complexity of factors.

The analytical tool was developed against this background. It was based on optimisation and incorporated the influence of resource quality, transport costs and demand relations. The particular decision support model also incorporated the spatial or location characteristics (the "address") of the resource units, in contrast with optimisation models where optimal resource allocation is calculated in terms of quantities only.

The purpose of the decision support system is not to develop a "blue print" for land-use on a regional scale since that could not be enforced in a market economy. The model should rather be utilised to indicate spatially where production potential exists and highlight areas where there is a discrepancy between the actual production pattern and the optimal production pattern. The analysis can also contribute to the identification of institutional obstacles, for example, the lack of technical assistance as a possible effect of traditional production patterns.

The SDSS was applied for the Western Cape Province. Both geographic information systems and linear programming models traditionally present the analyst with large data requirements. The fact that the spatial decision support system was a combination of the techniques and applied at provincial level, at a relatively disaggregated level, compounded the data requirements. However, a systematic approach to the collation of input data and utilising surrogate measures or proxies where data in the required format were not available, contributed to fulfilling the data needs of the combined model. The Division for Resource Utilisation at the Department of Agriculture: Western Cape (Knight, 1997) assisted in the evaluation of the spatial data. Various experts and institutions were consulted for the economic data (1996 prices).[1]

2. APPLYING THE SDSS

The model was applied for eight irrigated crops or product groups, viz. apples, citrus, olives, peaches, pears, plums, table grapes, and wine grapes. The linear programming (LP) matrix had 72 557 activities and 22 032 constraints. The results of the model - pertaining to the utilisation of resource units for specific crops were exported to a mapping module to enable the spatial representation of results.

A summary of the model results is given in Table 1. The summary pertains to area allocated, total production and market allocation.

2.1 Area allocated

A total area of 93737.1 hectares was allocated to the selected crops. This area represents only 0.6 percent of the total area that was available for crop cultivation in the model. According to the existing land-use statistics of the Resource Directorate of the Department of Agriculture: Western Cape Knight,

Table 1: Summary of results

	Apples	**Pears**	**Peaches**	**Citrus**	**Wine grapes**	**Table grapes**	**Plums**	**Olives**
Total Area (ha)	8,357.4	22,907.4	4,509.6	26,787.1	19,927.9	7,149.1	1,372.3	2,726.4
Total Production (t)	605,615.6	369,807.6	164,270.2	902,292.4	1,214,888.0	246,148.4	61,754.0	24,092.5
Ave. Yield (t/ha)	72.5	16.1	36.4	33.7	61.0	34.4	45.0	8.8
Total Exports (t)	25,960.4	150,000.0	37,500.0	345,000.0	201,000.0	150,000.0	37,500.0	12,592.0
Export price R/ton*	2,560.0	2,480.0	6,400.0	1,760.0	5,250.0	5,000.0	4,400.0	6,000.0
% Total Production	4.3	40.6	22.8	38.2	16.5	60.9	60.7	52.3
Total Western Cape (t)	470,000.0	163,204.9	44,770.0	209,465.0	906,275.1	85,174.4	24,000.0	3,000.0
WC Price R/ton*	1,390.0	870.0	1,606.0	900.0	1,437.0	2,364.0	1,770.0	3,910.0
% Total Production	77.6	44.1	27.3	23.2	74.6	34.6	38.9	12.5
Total Rest of SA (t)	109,655.2	56,739.8	82,000.0	347,827.4	107,613.0	10,974.0	254.0	8,500.0
SA Price R/ton*	1,512.0	886.5	1,720.0	926.4	1,403.0	2,091.6	1,792.0	3,932.0
% Total Production	18.1	15.3	49.9	38.5	8.9	4.5	0.4	35.3

** 1996 National and export prices were used in the analysis*

1997), 3.3 percent or 429 312 hectares are currently devoted to the production of deciduous fruit, citrus and grapes.

The relatively small area allocated to these crops in the optimisation model could be the result of more efficient land-use allocation simulated through mathematical programming, which did not take cultural and managerial aspects of production practices into account. More importantly, the optimisation model also did not deal adequately with risk in the production process making average yields higher than actual practice, with the consequence that the area used to supply in the quantity demanded was smaller in the model. This is a key area that needs to be included in future research and refinement of the optimisation model. The proportionate area allocated to the selected crops in the model is presented by the pie-diagram in Figure 2.

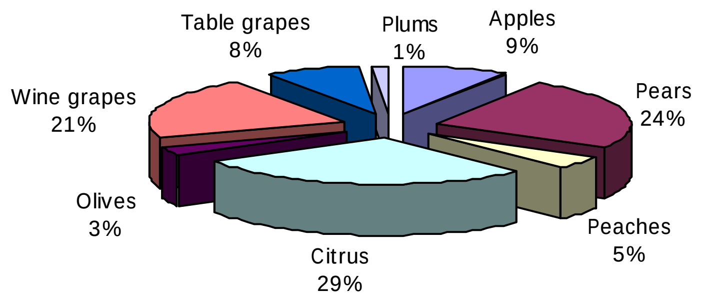


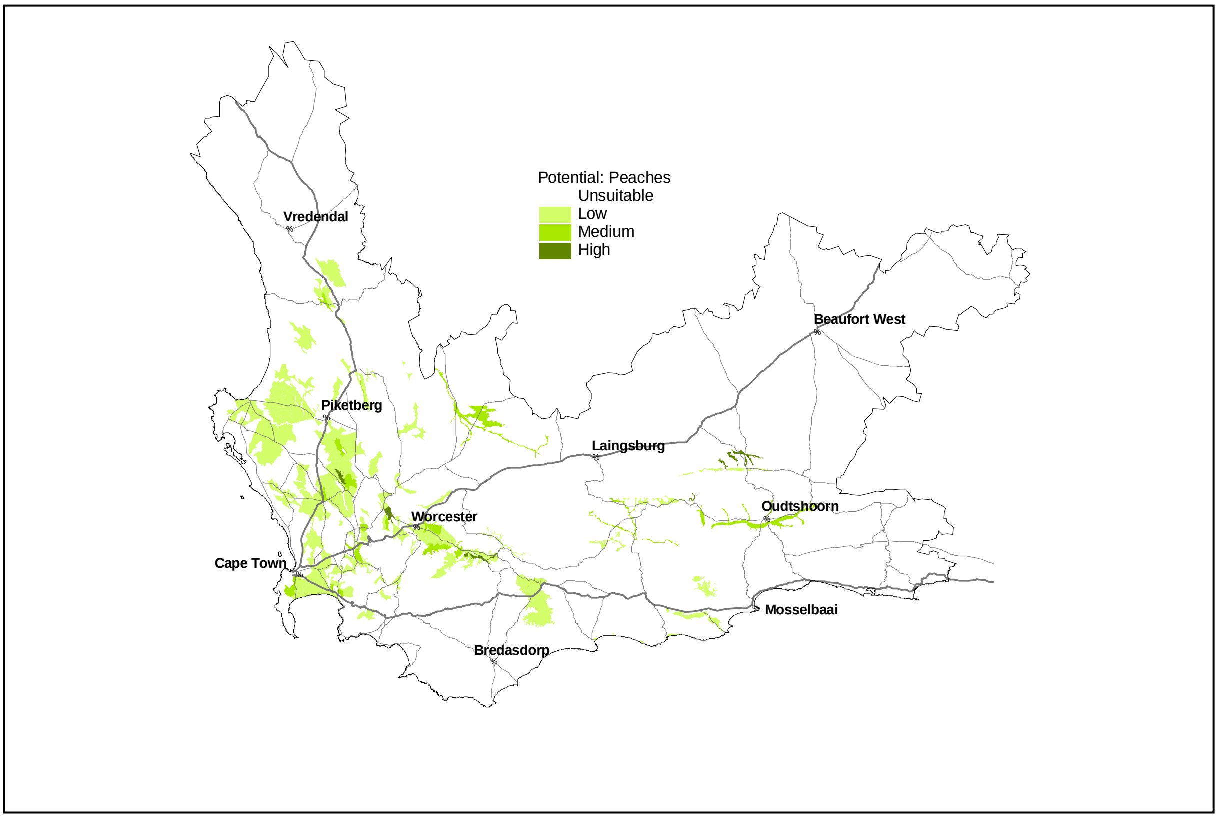
Figure 2: Percentage area allocated to selected crops

2.2 Total production

The total production and average yield obtained and for each crop is given in Table 1. The average yield per hectare obtained through the model were significantly higher than in the case of the average yield per hectare in the land capability model (for all the available resource units), implying that the high potential areas were first selected to fulfil the market quantity demands.

The average yield was calculated across all the resource units that were used for the particular crop. The volume of produce exported varied greatly between the different crops - from as little as 4,3 per cent for apples to just more than 60 percent for table grapes and plums. Most of the produce was traded on the Cape Town market.

Typical maps generated by the model are included in this paper as Map 1 and 2. Map 1 indicates the suitability of the resource base for a selected crop (peaches) and was generated in the land capability model in the GIS. Map 2 is the spatial representation of the model results and indicates the projected (optimised) production pattern for peaches. Two examples of the model results illustrate the utility of the model as decision support system. The first case supports the public sector information needs. Secondly, the model results are interpreted from an agribusiness perspective.



Map 1: **Resource potential for peaches**

2.3 Public sector perspective

The public sector, as provider of infrastructure and other public goods needs to ensure maximum effectiveness and efficiency in its activities. In a market economy, the public sector has a limited number of economic and other tools at its disposal to support the development of the agricultural sector. Most important are to provide incentives and infrastructure to guide farm-level decision-making - and thus resource-use patterns - towards efficient production systems at a national or provincial level. The public sector also needs to ensure that it obtains maximum 'returns' or impact on its expenditure. The spatial decision support system can be applied successfully in this regard by identifying and evaluating areas that need to be earmarked for future development for selected crops.

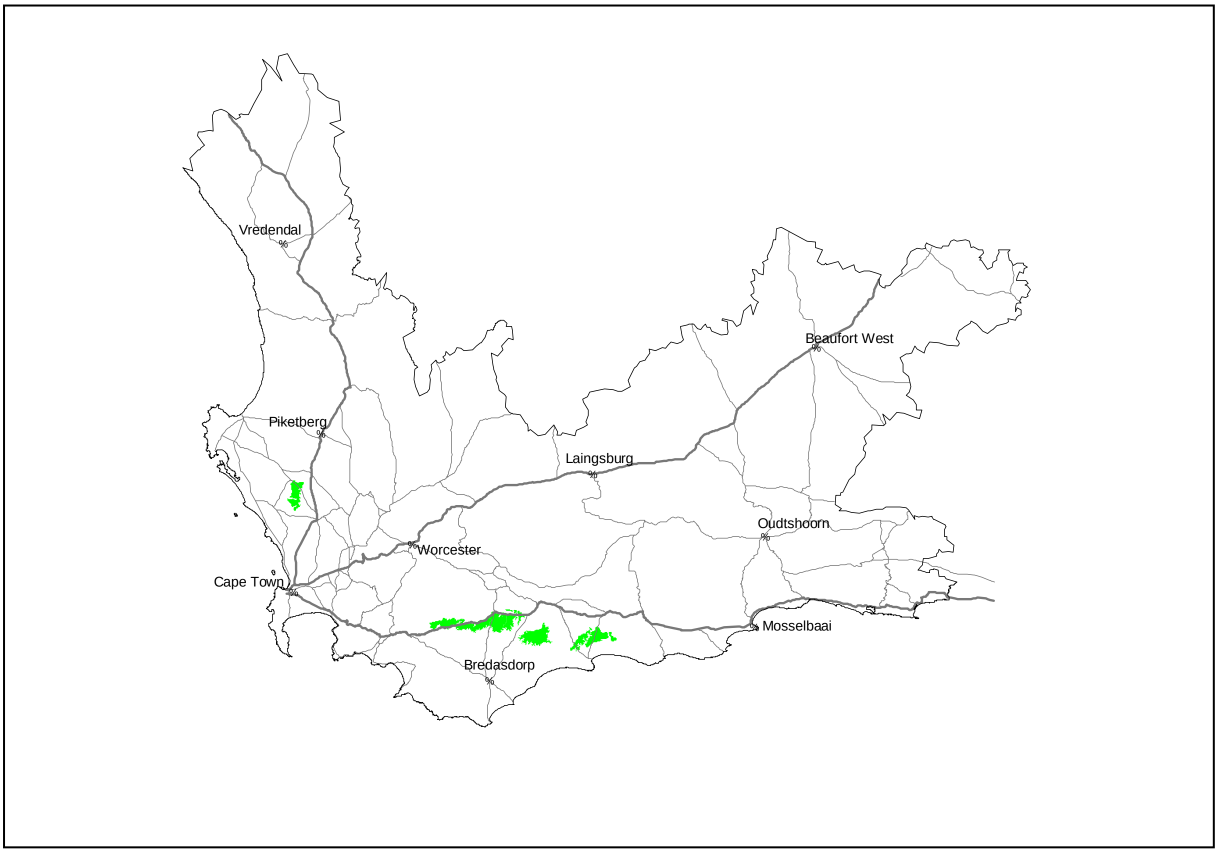
As can be seen from the analysis, substantial potential exists for peach production in the Riviersonderend area. The divergence between existing and predicted fruit production could be the result of traditional cultivation patterns combined with lack of required infrastructure and skills in such areas.

Given the results from the analysis, further research on the provision of infrastructure (especially improved transport networks) can be focused in the above-identified areas. Further public sector support can also involve training opportunities in the areas where stone fruit has not traditionally been produced.

Another aspect related to the provision and management of public goods is the supply of irrigation water. Water allocation to agriculture and the possible introduction of tradable water rights is currently the subject of much debate and research. The spatial decision support system can contribute to the debate in that it provides a region-wide allocation of water relative to the competitive advantages of the physical location qua resource characteristics and market structure. For example, the model results indicated that the expansion of irrigated agricultural production is in some areas restricted to the availability of irrigation water.

2.4 Agribusiness perspective

The spatial decision support system can also be applied to verify a planning decision of an agribusiness firm that would like to determine whether its proposed location (as an input provider or output-processor) is spatially advantageous. The model is also useful for firms that would like to explore production expansion opportunities. For example, in the case of deciduous fruit packaging and canning, a location closer to the source of the products could be profitable since the handling conditions are less restrictive for the processed product than the inputs. The land-use pattern foreseen for deciduous fruit production, for example peaches, can be examined in this regard.



Map 2: Area allocated for peach production

The land capability model identified approximately 2,5 million hectares with low to high suitability for peach production. The average yield for these polygons was 17.5 tonnes per hectare. A total of 4509.6 hectares from seven resource units - with an average yield of 36.4 tonnes per hectare and a total output of 164270.2 tonnes - were allocated to peach production in the optimisation model.

By constructing the optimisation model at district level, the number of alternative location options can be reduced in the initial phase of looking at new sites. A smaller number of activities in the problem formulation would enable the analyst to include additional decision variables pertinent to the firm's location decision in the model. For example, more detailed transport cost structures, industrial property costs, labour costs, and the like.

Through the GIS mapping module, maps with pie charts indicating the crop combinations for a district can also be generated. This provides the investor with a visual pattern of the district's crop production potential. Figure 3 indicates the crop combinations for a selection of polygons. The crop

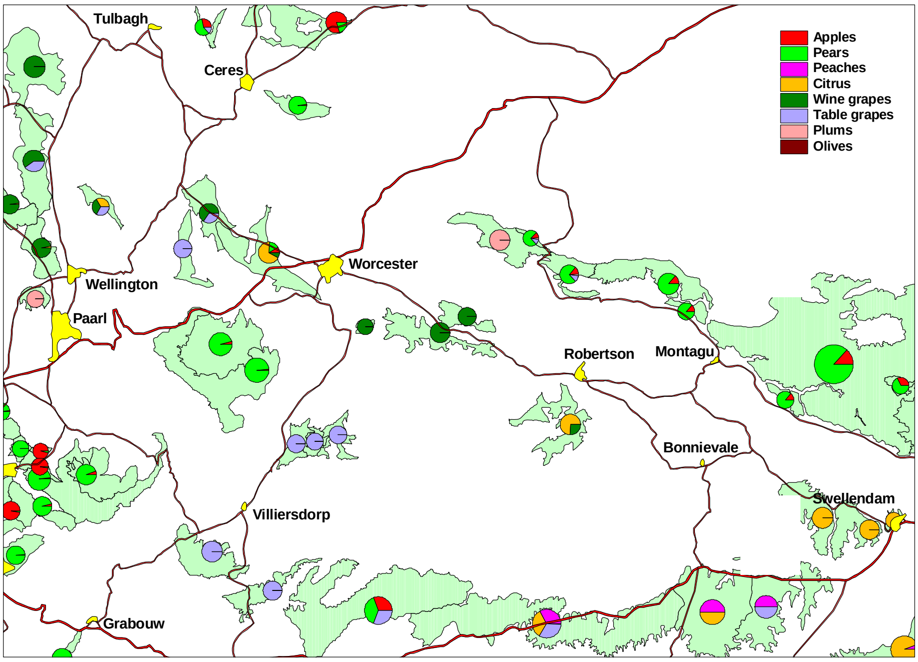


Figure 3: Crop combinations for selected polygons

combination pie charts indicate at a glance the percentage area per polygon allocated to each crop. For example, citrus in the Swellendam area dominated the optimum land use patterns, pears in Montagu and wine grapes in the Wellington district.

3. CONCLUSION AND FURTHER USE OF THE SDSS

The most apparent advantages of the optimisation technique can be summarised as follows:

a) The technique integrated resource potential and economic determinants in predicting land-use patterns. This interactive capability determined the relative profitability and competitive advantage of each of the selected crops vis-à-vis the resource units.

b) Each component enhanced the modelling capacity of the other - the GIS (in the land capability model) and linear programming (the multi-market partial equilibrium model) - in the optimisation technique.

Greater levels of detail concerning the particular characteristics of the resource units could be included in the optimisation model.

c) The visual representation of the solution of a mathematical model of this size greatly assisted the analysis and interpretation of the model results. The integration of the model results into the GIS makes further spatial analysis of the solution possible (for example, overlay analysis).

d) The visual representation also assisted in the verification of the model results. This was a major advantage of using a GIS indicate the spatial distribution or address of the model results that would otherwise be listed in tables in terms of quantities only.

Further applications of the optimisation model are possible through changes in any of its components and/or level of detail of the analysis. For example, the spatial decision support system could be applied to simulate the effect of global climate change on the (agricultural) resource-use patterns of a region. Changes to the resource characteristics in the land capability model could simulate the anticipated change in temperature and rainfall regimes. The subsequent change in resource potential for the selected crops can then be incorporated in the linear programming model.

Secondly, the effect of wide spread adoption of changes in technology can be determined in the spatial decision support system. The way in which technology changes are incorporated in the model depends on where in the production process it is developed.

The spatial decision support system was flexible with regard to level of detail of the analysis. The optimisation model can be applied for district, provincial, national and regional level analyses. Evidently, the decision-maker needs to be conscious of the trade-offs between level of detail of the spatial (and economic) data and model size. The large data requirements of the model are implicit to all spatial decision support systems and linear programming models.

Finally, the opportunities for developing the model to determine competitive advantages and guide agricultural development at national and regional level are numerous. Regional applications - for example, for Southern Africa - could also be useful for agribusiness, which are planning business expansion to the region. However, some generalisation of the resource and economic data would be necessary to keep the information load to manageable levels.

NOTES

1. *Agricultural statistics, National Department of Agriculture, Pretoria; KWV Head Office, Paarl; Combud Enterprise Budgets July 1995, compiled by Sub-directorate: Farm Management, Department of Agriculture Western Cape, Elsenburg; Ferrandi, C., Consulting agricultural economist, Somerset West; Liebenberg, F., Agricultural Research Council, Pretoria; Louw, T. TRADEX, Cape Town; Outspan/Citrus marketing board, Pretoria; SA Olive Growers Association, Paarl; Unifruco, Bellville.*

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