A Programming Model of Tongan Smallholder Agriculture: Profit-Maximisation, Subsistence Consumption and Risk[1]

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ABSTRACT

According to farm-household economics theory, the production activities of a farm-household can be analysed independently of its consumption activities, provided certain assumptions are made regarding the existence of labour and product markets. The farm-household is viewed as seeking to maximise profits from production, with the resulting revenue then forming part of its full income constraint, subject to which it maximises utility from consumption.

The first stage in developing a model of a representative farm-household in Tonga was to follow the above 'separable' approach. A linear programming (LP) model of farm-household production was developed, with the intention of linking the results to an Almost Ideal Demand System (AIDS) model of consumption behaviour.

However, perhaps not surprisingly, the optimal solution to the profit-maximising LP model bore little resemblance to actual practice among Tongan smallholders. The most likely causes of the divergence are (a) consumption requirements and preferences must largely be excluded from the production side of a separable model; perhaps some of the separability assumptions are invalid in the Tongan situation; and (b) the riskiness of production, and attitudes towards risk, must also remain generally unaccounted for in a separable model, whereas these may well be significant determinants of production patterns among Tongan smallholders.

An integrated LP model of production and consumption was therefore developed, in which risks in both subsistence production and cash crop production were incorporated. Farmers are assumed to strive first towards satisfying target levels of subsistence production across a range of 'states of nature', and then to maximise the expected return from growing cash crops. Target MOTAD was used to model subsistence needs, with targets set in terms of kilojoules. Additional consumption constraints were imposed to reflect variety preferences. The targets were then converted into ordinary constraints and a standard MOTAD formulation was used to model the risks and expected returns of cash crop production. Results of the programming exercises are discussed in the paper.

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1 POLICY ISSUES IN TONGAN SMALLHOLDER AGRICULTURE

Agriculture is the main source of livelihood for over two-thirds of the Tongan population and it is also the most important activity in terms of such indicators as GDP and export value. The main export crops are coconuts, bananas and vanilla, while a range of root crops, fruit and vegetables are grown for home consumption, domestic sale and export. The land tenure system ensures that most of the Kingdom's agricultural production is undertaken by individual households, farming relatively small areas of land and making their own decisions about production, consumption and marketing.

Mellor (1986) has outlined an agriculture- and employment-based strategy aimed at achieving sustainable economic development by increasing agricultural productivity and generating rural employment. Success of such a strategy depends, inter alia, on an effective agricultural research and extension network, a positive farmer response to new opportunities and a high marginal propensity to consume labour-intensive goods and services (particularly those produced in rural areas).

An alternative viewpoint (Bertram and Watters 1985) is that the nature and circumstances of small Pacific islands such as Tonga militate against the expansion of sustainable economic activity. In particular, it is claimed that a high degree of dependence on overseas aid and remittances reduces the incentives for agricultural production. The extent to which this may be true in Tonga has been discussed in an earlier paper (Delforce, Hardaker and Fleming 1988). It was concluded there that, while Bertram and Watters have indeed pinpointed some genuine difficulties, these need not seriously hinder the pursuit of an agriculture- and employment-based strategy. Moreover, there are positive aspects of Tonga's economic situation which could be used to advantage provided appropriate policies are implemented.

The objective of the study described in this paper is to identify policy options which might help to stimulate agricultural production and marketed surplus among Tongan smallholder farm-households. Five policy measures available to the Tongan government have been identified as warranting further investigation:

(a) increased support for agricultural research to develop improved technologies for particular commonly-grown crops;

(b) direct or indirect measures which change the relative prices of (i) staple food crops, (ii) export crops and (iii) imported foods;

(c) changes in agricultural wage rates brought about through direct legislation or through gradual changes in the macroeconomy (e.g. as a result of exchange rate manipulations);

(d) reductions in marketing costs for agricultural produce, brought about by increased expenditure on infrastructure such as roads and storage facilities, the development of new marketing opportunities, or market research resulting in other economies in marketing; and

(e) changes to land tenure regulations which assist in making land available, with security of tenure, to those willing and able to use it.

The data being used in the study were obtained by the South Pacific Smallholder Project[1]. Surveys were conducted in four Tongan villages over a 12 month period in 1984-85. Nearly 120 households participated in the project, providing information about, inter alia, their resource base, income and expenditure, time allocation, food consumption, crop production and other productive activities (Hardaker, Delforce, Sefanaia and Fleming 1986).

As indicated, most agricultural production and marketing in Tonga is undertaken by smallholders. Consequently, the impact of the above policy options on the agricultural sector as a whole will largely be determined by the responses of individual farming households. Farm-households are

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1 The Project was funded by the Australian Centre for International Agricultural Research (ACIAR) and involved intensive fieldwork in Tonga and Solomon Islands.

both production and consumption units and most participate in the labour market as buyers or sellers or both. A narrow production economics framework is therefore inadequate for analysing the behaviour of Tongan smallholders. An alternative framework, in which production, consumption and labour allocation decisions are integrated, is presented in the following section.

2 FARM-HOUSEHOLD MODELLING: THE SEPARABLE APPROACH

The theoretical framework for the study is known as farm-household economics. It is based on the household production function work of Becker (1965) and the subjective equilibrium theory of Nakajima (1969, 1986). The farm-household may be defined as a 'complex of the farm firm, the laborer's household and the consumer's household' (Nakajima 1986, pp. 1-2). The typical farm-household uses some of its own labour to produce farm output, part of which it then consumes and part of which it sells in order to fulfil cash requirements. In addition, some family labour may be hired out off the farm, or non-family labour may be hired in to work on the farm. The behavioural principle is assumed to be utility maximisation. While production and consumption decisions are in reality likely to be closely interdependent, the usual procedure in farm-household studies is to analyse them as separate components of a sequence (Singh, Squire and Strauss 1986a). Thus, the household is said to behave as if it seeks first to maximise production profits subject only to production function constraints, then to maximise utility from consumption subject to a full income constraint which includes production profits. This approach can be justified algebraically provided certain conditions are fulfilled. Most importantly, the farm-household must face competitive labour and product markets.

To maximise farm profits from a fixed land area, the household should use family and hired labour until the marginal revenue product of labour equals the market wage (Singh et al. 1986). Assuming fixed-price markets, decisions about total labour input, and hence total production, can be assumed not to be affected by household preferences concerning labour and consumption goods. Both can be freely bought or sold to enable the household to achieve the subjective equilibrium position corresponding to the predetermined level of production. 'In other words, the household can make its production decisions independently of its consumption and labor-supply decisions' (Singh et al. 1986a, p. 7). The reverse is not true, however. Household consumption and labour supply are partly determined by the level of farm production. This relationship has been termed the 'profit effect' (Singh et al. 1986a, p. 7), and a model based on the above assumptions is 'separable' or 'recursive'.

The recursive property does not hold if any prices in the model are affected by production decisions. This is the case when markets do not exist or are not competitive. If there is no labour market, for instance, the household will equate its labour demand and supply according to an 'implicit' or 'virtual' wage determined by 'all the variables that influence household decisionmaking' (Singh et al. 1986a, p. 8). Levels of production, consumption and family labour use will then all be simultaneously determined by the virtual price. A similar situation would arise if there were imperfections in a product market, such as restrictions on the volume of trade or marked differences between buying and selling prices. The separability assumption also generally breaks down if risk and risk aversion are recognised to be significant factors.

A separable model is relatively simple to estimate using standard econometric procedures. Abandoning the separability assumption results in a much less tractable model (Singh et al. 1986b, p. 52). Therefore, Singh et al. advise that separability should be assumed unless there is compelling evidence to the contrary. In many cases, it can be argued that the assumption of separability will result in only minor distortions, and should therefore be adopted in the interests of model tractability. Most farm-household modelling to date has been undertaken on this basis (e.g. Barnum and Squire 1979, Ahn, Singh and Squire 1981), although there are some recent exceptions (e.g. Lopez 1986, Roe and Graham-Tomasi 1986).

In the Tongan situation, there is some doubt about the validity of the separability assumptions (Delforce and Hardaker 1987). Market imperfections do exist, and there is evidence that production behaviour is not governed solely by motives of profit maximisation. In particular, the desire to meet staple food requirements from subsistence production appears to be strong. Moreover, in a risky production environment such as that of Tonga, where droughts and strong winds frequently cause crop losses, it seems unlikely that farmers would be totally oblivious to the riskiness of production, as assumed when using the separable framework.

Nevertheless, in view of the advice of Singh et al. (1986a), and by appeal to Occam's Razor, the obvious first stage in developing a model of a representative Tongan farm-household is to assume that the separability conditions are not seriously violated, and consequently, that production decisions can be analysed as if they were entirely independent of consumption decisions. The resulting model is described in the next section.

3 A PROFIT-MAXIMISING LP MODEL

The separable model developed for this study comprises a linear programming (LP) model of farm-household production and an Almost Ideal Demand System (AIDS) formulation of consumption behaviour. The latter includes seven expenditure categories: local staples, imported staples, local protein, imported protein, other food, beverages and tobacco, nonfood and leisure. An early version of the AIDS model was discussed by Delforce (1989) and will not be dealt with again here. The LP model is described in this section. The plausibility of the profit-maximising results and their suitability for integration into a consumption model are also assessed. Some shortcomings highlighted are dealt with in sections 4 and 5.

3.1 Structure of the LP Model

If the separability assumptions are valid, then farm-household utility is maximised by applying the principle of profit maximisation to production activities, subject only to technical constraints and some (short-run) resource constraints such as land and capital. Family labour is not considered to be constraining, since it is assumed that hired labour is available at the equilibrium market wage, and that the family and the market are equally acceptable sources of labour. Similarly, household consumption requirements are irrelevant since food can be purchased if enough is not produced. Buying and selling prices are equal and there are assumed to be no preferences for either home-produced or purchased foods.

With these considerations in mind, the LP matrix constructed comprises 114 activities and 130 constraints, with maximisation of production profits as the objective. Production activities in the model include the growing of staple and non-staple crops, crop processing (vanilla and coconuts), handicraft production, fishing and livestock husbandry. Six periods are identified, corresponding to peaks and slacks in the production cycles of the main crops. The periods are November-December (ND), January to March (JFM), April-May (AM), June to mid-July (JJ) mid-July to the end of August (JA) and September-October (SO).

The staple crops included in the model are yams (early and late varieties), *xanthosoma* taro (taro tarua, American taro), *colocasia* (common) taro, giant taro, cassava, sweet potato and plantain. Each of these crops has two or more alternative planting and harvesting dates, giving a total of 22 activities. The cash crops are bananas, watermelon, pineapple, tomatoes, capsicum, vanilla and pumpkin (13 activities in all). In addition, paper mulberry can be grown for use in tapa making. In accordance with the separability assumptions, all crops are valued at their market prices. Sales are assumed to take place in or soon after the period of harvest (depending on the storability of the crop).

Two types of handicraft production are included in the model: tapa and mats. The most common types of fishing activity practised in the study area, line fishing and the collection of reef foods, are also included. The livestock activities in the model are the keeping of pigs and poultry. Following an initial attempt at solving the model, a constraint was placed on the keeping of poultry, limiting it to 15 broilers (since few village households have more than this).

Although handicraft, fishing and livestock husbandry tend to be largely subsistence activities, they are valued in the objective function at market prices, in accordance with separability assumptions.

There are six land constraints, corresponding to the six production periods. These are set at 4.4 ha, which was the average area of land available to the households surveyed in three villages[2]. Rotational constraints are also included in the model, to ensure that the optimal cropping pattern does not violate the rotational sequences normally followed by Tongan smallholders. In particular, fallow land is constrained to be twice the area of the cropped land. Intercropping under coconuts is assumed to take place, with the legal requirement to maintain 60 palms/ha being guaranteed. Permissable rotations are summarised in Table 3.1.

Six activities monitor the use of labour for farm-household production[3]. In this separable model there is assumed to be a single source of labour, and it is all valued at the market wage.

Five cash transfer activities allow for the use of cash generated in one period to meet costs in the next period. The opportunity to borrow money, at the prevailing bank interest rate of eight per cent per annum, is also given. Funds are assumed to be available in any of the six periods for repayment with interest in the following period. Cash constraints for each period are included in the model; their right-hand sides are the amount of exogenous income available to the representative household.

It was clear from an initial solution to this model (which involved large-scale production of yams and tomatoes) that additional constraints were required to reflect market conditions. If all households in Tonga grew only yams and tomatoes, market saturation would quickly be reached. Farm mapping carried out as part of the South Pacific Smallholder Project showed that yams were present (monocropped or intercropped) on 25 per cent of the cropped land in one of the survey villages. This corresponded to

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2 The fourth village, on a relatively remote, land-scarce island, is very different from the other three, and is therefore excluded from this analysis of 'average' production conditions.

3 Labour costs could simply have been included as variable costs in the activity budgets. However, as well as facilitating subsequent modifications to the model (sections 4 and 5), the inclusion of labour use activities removed the need to calculate labour use <u>ex post</u> from the solution.

.3667 ha in the matrix. Tomatoes were found in just one village, on .385 per cent of its cropped land. To allow some scope for expansion (particularly since the matrix contained three tomato activities with different harvest dates), the market limit for tomatoes was set somewhat higher, rounded up to one per cent of cropped land, or .015 ha.

3.2 Results of the Profit-Maximising Model

The optimal solution to the profit-maximising model described above involves the maximum permissable cultivation of yams and tomatoes, plus .77 ha of vanilla (52.5 per cent of cropped land). This vanilla area is about twice that found in the main vanilla-growing village surveyed. However, all vanilla grown in Tonga is exported, and Tonga is a relatively small participant in the world market. Consequently, there do not appear to be any grounds for imposing market limitations on vanilla production. This cropping pattern was therefore accepted as a plausible strategy for the farmer whose sole objective (subject to the constraints specified) is profit maximisation.

The only non-cropping productive activity in the optimal solution is the keeping of poultry, which is at the maximum level allowed.

Labour is used as required for the four productive activities. The peak season (410 labour hours) is November-December. This is the harvest period for the yam activity in the basis. The period of lowest labour use (195 hours, is July-August.

Increasing the assumed market price of labour makes yams and tomatoes less profitable than vanilla, which, on an annual average basis, uses less labour. With labour at T$2/hour, vanilla is grown on all available land, it is no longer economical to keep poultry, and credit is needed between November and May.

3.3 Discussion

Under the assumptions embodied in this profit-maximising model, yams, tomatoes and vanilla are by far the most profitable crops to grow. Yet, when the farms of nearly 120 households were mapped, a much more diversified cropping pattern was found. This is summarised in Table 3.2. Cassava was the most widely grown crop, while xanthosoma taro was important in two villages and vanilla in one village.

There appear to be three main explanations for the discrepancies between the optimal and actual cropping patterns:

(a) the desire to grow staple foods for home consumption seems to be almost universal among the rural inhabitants of Tonga (see Delforce and Hardaker 1986); it is doubtful whether any village farmer would seriously contemplate putting all his cropped land into cash crop production;

(b) pests, diseases and climatic hazards can reduce yields substantially; such risks are no doubt well known to farmers, but cannot be adequately accounted for in a separable model; and

(c) the prices assumed to be received for cash crops are fixed in the model before the optimal production pattern is determined; farmers, of course, do not face such price certainty.

Thus, the separable approach to modelling production activities seems to have two major shortcomings in the Tongan context. First, it is apparent that household consumption requirements do influence farmers' production decisions. Second, it is likely that the relative riskiness of various crops - in terms of both yields and (for cash crops in particular), prices - is recognised to some extent by farmers, who are prepared to sacrifice some expected profit in return for a reduction of the risks associated with achieving that profit.

A major purpose in building the profit-maximising LP was to determine the effect on production of changes in the prices of some of the expenditure categories modelled in the consumption analysis. The relevant activities - locally produced staples and protein foods and labour use - are all present in the optimal solution. The 'profit effect' can therefore be calculated for these categories. In other studies utilising the separable approach (Barnum and Squire 1979; Ahn et al. 1981; Strauss

1986), incorporating the profit effect was found to change significantly the magnitude, and in some cases also the sign, of price elasticity estimates. However, in view of the rather unrealistic solution to the profit-maximising model in the current study, the usefulness and reliability of such an exercise appears doubtful. Instead, it may be more fruitful to seek ways of avoiding the restrictive assumptions of the separable approach. The two main issues, consumption requirements and risk, are addressed further in the next two sections, where the development of an integrated LP model of production and consumption is described.

4 AN INTEGRATED LP MODEL OF PRODUCTION AND CONSUMPTION

Alternative models, in which the separable approach of section 3 is abandoned, are described in this section. An integrated farm-household model is developed which incorporates both production and consumption aspects of farm-household activities. In the first version of the model, the risks associated with these activities are ignored. For the sake of brevity, this version is not discussed here. Rather, attention is focussed on two subsequent versions of the model. In the first (section 4.2), risk is dealt with in subsistence crop production only, while in the second (section 4.4), the riskiness of cash crop production is also accounted for. Results of the models are discussed in sections 4.3 and 4.5 respectively. First, however, procedures for integrating production and consumption in a revised version of the profit-maximising model are outlined.

4.1 Integrating Production and Consumption Decisions

The integrated model is based on the profit-maximising model described in section 3, but several major modifications were required. Some of these are listed below.

(a) The assumption that all produce is sold at market prices was dropped. While the 'grow and sell' crop activities were retained, a new set of subsistence crop production activities was introduced. Also, the keeping of poultry was re-defined to be purely a subsistence activity, and handicrafts were assumed to be produced for home use or gift-giving only. Since the handicraft activities incurred a cost but earned no cash return, it was necessary to put a minimum requirement on their production.

(b) Storage activities were developed for most of the staple crops, to reflect usual practices among Tongan farmers. All of the staples except sweet potato and plantain can be stored to some extent, either in the ground or after harvest. Yams are usually harvested all at once and then may be stored for several months. The three taro species and cassava are best stored in the ground, from where they are harvested as needed. These patterns are reflected in the storage activities.

(c) Ten intercrop activities were defined. These all involve the growing of yams with either giant taro or both giant taro and plantain. This is the traditional '<u>ma'ala</u>' or yam garden pattern. Intercrops are assumed here to require slightly less land per plant than when grown as monocrops. While other intercrops combinations are also common, there is no information on joint production requirements. Therefore, it is simply assumed that crops in the optimal solution may either be monocropped or intercropped with each other, with additive resource requirements and output.

(d) A 'minimum energy from staple foods' requirement was added for each period. Earlier, an overall energy constraint had been used, but this proved to be inadequate since such foods as coconuts, fish and meat were providing adequate energy, but not the bulk which is a feature of the Tongan diet.

(e) Variety constraints were added to ensure that the pattern of consumption in the model reflected actual patterns fairly closely. Thus, no more than forty per cent of the total kilojoule intake of staple foods in each period could come from any one source, and minimum annual consumption levels of yams, taro, giant taro and plantain were stipulated.

(f) The 'use labour' activities of the profit-maximising model were converted into 'hire labour' activities, and off-farm work options were added, constrained to a realistic level. The right-hand sides of the labour constraints became the amount of family labour available.

Further modifications associated specifically with the introduction of risk into the model are described below.

4.2 Risk in Subsistence Production

The first stage in the development of a model accounting for risk was to consider risks in the production of subsistence crops. It is assumed that the representative farmer's objective is to maximise profits from production activities, subject to resource constraints and subject to approaching target levels of subsistence crop production, across a number of different 'states of nature'. Target MOTAD (Tauer 1983), which is a version of discrete stochastic programming, was used to model this scenario. Risk constraints are defined which usually contain a set of activity net revenues observed over a number of years (or 'states of nature'). Each risk row is constrained to satisfy a specified target level. Shortfalls below the targets are measured, and a parametric constraint is placed on the total level of shortfall. Thus, the optimal solution can be obtained for any given level of target satisfaction. Such solutions are almost certain to be second degree stochastically efficient (Tauer 1983, Watts, Held and Helmers 1984).

For the Tongan case (Table 4.1), the usual Target MOTAD formulation was modified, with targets being set in terms of energy units (joules) rather than net revenue dollars. Thus, cultivation of 1 ha of a staple crop produced a yield of energy, which varied across six 'observed' states of nature. The target level of energy corresponded to average consumption of local staples recorded in the four survey villages.

The procedure for obtaining the yield 'observations' was as follows:

(1) triangular distributions (most likely, minimum and maximum yields) were elicited for each of the subsistence crops from an expert informant (S. Sefanaia, former Head of Planning Unit, Ministry of Agriculture, Forests and Fisheries)[4];

(2) the values were scaled so that the mean yields were in accordance with the net yields (with planting material deducted where appropriate) assumed in the model[5];

(3) the mean and standard deviation of each yield distribution was calculated;

(4) records of crop supplies at the fresh produce market from 1982 to 1987 were used to provide estimates of covariances between the yields of the different crop activities;[6] this was done by normalising the market supply data (mean = 0, standard deviation = 1), then reconstructing the series with the means and standard deviations calculated in (3) above;

(5) the reconstructed yield streams of each crop activity were multiplied by the energy value of that crop;

(6) the six observations on energy yields of each crop activity were incorporated into the LP model as the 'risk rows' of Table 4.1.

Crop buying activities were added to the model to allow shortfalls in subsistence production in a 'bad' year to be made up by purchasing root crops. Purchases were constrained to be no greater than the total

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4 Although it might have been more appropriate to elicit such information from the smallholder farmers themselves, this was not attempted as part of the Smallholder Project, and experience with elicitation of other subjective information (Delforce and Hardaker 1986) suggest that the task would have been extremely difficult.

5 No specification was made, during the elicitation of triangular distributions, regarding production conditions such as plant density, level of inputs, etc. The scaling of the responses simply ensured that the expected yields corresponded to the production conditions assumed in the model.

6 While this may perhaps not be an ideal source of covariance information, it is very difficult to elicit covariances, and there are no other data which could be used to proxy yields of a range of crops over several years in Tongan conditions.

shortfall, and average annual purchases were distributed as required between the six periods in the model.

The Target MOTAD model comprises 370 activities and 254 constraints.

4.3 Results of the Target MOTAD Model

The optimal pattern of production and consumption in the Target MOTAD model was obtained for seven scenarios: the household satisfying its target consumption levels in zero to six out of six states of nature. The tradeoff between maximum revenue achievable and the satisfaction of target consumption in shown in Figure 4.1.

At one extreme, with no production towards target satisfaction, the cropping pattern resembles that of the profit-maximising model, and all consumption requirements are purchased. With a lower shortfall allowed, such that the target is just achieved in one of the six years, the cropping pattern is as illustrated in Figure 4.2(a). Most of the land remains devoted to cash crop production, but cassava, plantain, giant taro, sweet potato and two types of intercropped yam are also grown, in addition to the paper mulberry and coconuts (not shown) which are constrained to enter the solution. Areas are left uncultivated for short periods between January and August so that cassava can follow crops harvested earlier. Otherwise, all land is utilised. Consumption targets and diversity constraints are satisfied through staple crop production and purchases of late yams, taro and plantain. Protein requirements are met through a combination of line fishing, reef collection, poultry products and purchased protein foods. The off-farm work options are taken up at the maximum level allowed.

The other extreme of the target satisfaction possibilities is that targets are fully satisfied across all six states of nature. No staple crop purchasing is allowed under this scenario. The crop production pattern is as shown in Figure 4.2(b). The main differences between this solution and the one described above are that <u>xanthosoma</u> taro is now grown and there are larger areas of plantain, sweet potato and giant taro, replacing some of the vanilla. While there is now just a single cassava activity, compared to six in the other solution, the total area covered is about the same.

4.4 Risk in Both Subsistence and Cash Crop Production

While the target MOTAD model described above ensured that production risks in subsistence crop production were accounted for, the strong specialisation of cash crop production, involving only yams, tomatoes and vanilla, remained unaffected. As shown in Table 3.2 above, farmers on average adopt a rather more diversified portfolio of cash cropping activities. In order to assess the importance of yield and price risks in determining optimal cash crop production, a method was sought of allowing for risky net revenues of cash crops, while retaining the risky energy yields of subsistence crops.

The most appropriate method of modelling cash crop risks, given the data available and the desire to avoid unnecessary complexity in model formulation, was standard MOTAD. With this method, negative deviations from expected net revenue are minimised subject to a parametric constraint on expected net revenue. A range of farm plans can then be identified along the expected revenue (E) / total absolute deviation (TAD) frontier. The structure of the cropping section of the MOTAD model developed is shown in Table 4.2. The procedure described above for generating energy yield streams for subsistence crops was repeated for the cash crops (which included 'grow and sell' staple crop activities), with appropriate modifications. Thus, triangular yield distributions were elicited and modified to correspond with the specific activities in the model, and means and standard deviations were calculated. Annual market supplies from 1982-87 were normalised and reconstructed so as to have the means and standard deviations of the triangular distributions. Sales from each crop activity were assumed to take place during or soon after the period of harvest. Market prices for the period(s) appropriate to each crop activity were converted to 1985 dollars (to correspond with the period of data collection) and multiplied by the yield streams, then the costs of production (assumed not to vary) were subtracted, giving six net revenue observations for each cash crop. The mean of each set of observations was calculated, and deviations from the mean entered into the model in the risk rows (see Table 4.2). The objective function used in previous versions of the model was converted into a parametric constraint on expected total net revenue, and a new objective, the minimisation of negative deviations from the mean, was defined.

Clearly, it would have been impossible to combine the target MOTAD described above for subsistence crops with the ordinary MOTAD for cash crops without some degree of simplification, since otherwise too many parameters would need to be varied simultaneously. Therefore, instead of allowing parametric variation of the shortfall below the subsistence crop targets, the risk rows were simply re-defined as absolute constraints which had to be satisfied in a given number of 'years' (or states of nature). The objective of the model became the minimisation of negative deviations from the mean net revenue generated from cash cropping, subject to (inter alia) a parametric constraint on expected net revenue and also subject to minimum requirements for subsistence consumption being satisfied from subsistence production activities, across some or all of six states of nature. (Solutions were obtained for the seven alternatives of satisfying subsistence consumption in zero to six of the six years modelled.) As noted above, additional consumption constraints ensured that consumption was evenly distributed across the six periods, and that a reasonably varied diet was maintained.

4.5 Results of MOTAD model

In view of the large number of solutions obtained for the combined Target MOTAD / MOTAD model, it was essential to identify those most likely to appeal to the surveyed farmers. While all Target MOTAD solutions are second-degree stochastically efficient, this is not necessarily the case with MOTAD solutions. Therefore, having obtained a range of solutions along the E-TAD frontiers for each of the target-satisfaction scenarios, tests of first and second degree and generalised stochastic dominance were performed, using a computer routine described by Goh, Raskin and Cochran (1986). As shown in Figure 4.3, only those solutions in the upper portion of the feasible set are stochastically efficient. In particular, within the range of risk aversion coefficients typically found among small-scale LDC farmers (e.g. Dillon and Scandizzo 1978, Herath, Hardaker and Anderson

1982), the farm plans which would be preferred are those with the maximum possible expected revenue. In other words, risk does not appear to be an important determinant of the optimal production pattern, within the range of crops included in the model and given the subjective judgements elicited regarding the riskiness of crop yields.[7]

The 'maximum revenue' farm plans obtained with the MOTAD model are, not surprisingly, almost identical to the Target MOTAD results for the corresponding target-satisfaction scenario. Therefore, the more interesting comparison is between the MOTAD plans with maximum expected revenue and those further down the E-TAD curve. While the latter may be less stochastically efficient than the former under the risk and revenue assumptions used in the model, it is possible that risks may be underestimated and expected revenues overestimated, in which case some of the less risky plans may in fact be more appealing to farmers in the study area.

Two optimal land use patterns along the second E-TAD curve of Figure 4.3, in which target consumption is satisfied in 3 of 6 years, are compared in Figure 4.4. The first corresponds to the upper limit of the E-TAD curve; the second occurs at the point marked Y, where the curve begins moving sharply upward.

The main changes that occur as the acceptable level of risk is reduced are that pineapple cultivation enters the basis and tomato leaves, while vanilla is increasingly cured before sale rather than being sold

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7 An earlier version of the model included kava and peanut growing activities, both of which appeared from the available data to be highly profitable but also fairly risky. Solutions to this model showed that some reduction in expected revenue, in return for a reduction in risk, would be the preferred option for the moderately risk averse farmer. However, data on actual production patterns in Tonga suggested that either the expected profitability of kava and peanuts was grossly exaggerated in the activity budgets used in the model, or that the riskiness of these crops was severely underestimated, or that other factors such as requirements for specialised knowledge or limited market capacity prevented the 'average' farmer from growing them. It was therefore decided to restrict the crops in the model to those for which the available production data seemed reasonably reliable and which were not specialist crops.

green. Similarly (not shown in the figure), more coconuts are processed into copra rather than being sold as whole nuts.

5 POLICY ANALYSES

Five policy issues were identified in section 1 as warranting investigation in this study. These related to agricultural research, prices of foods and agricultural produce, wage rates, agricultural marketing and land tenure. Each of these issues will be addressed by carrying out appropriate experiments with the MOTAD model described in section 4.4 above. Such experimentation is as yet incomplete; however, two preliminary analyses are described below.

5.1 The Reservation Price of Family Labour

Bertram and Watters (1985) have argued that in a small island nation such as Tonga, which is characterised by high levels of migration, heavy reliance on aid and remittances and a large government sector, the reservation price of family labour may be considerably higher than the returns to labour in agriculture. Since villagers are familiar with wage rates obtainable in the urban centres or overseas, they feel little incentive to expand agricultural production. The result, say Bertram and Watters, is the observable stagnation or decline of village agriculture.

The possible impact of a high reservation price of labour was investigated with the aid of the MOTAD model in which consumption targets were satisfied in 3 of 6 years and expected revenue was constrained to be approximately at its highest feasible level (Figure 4.4(a)). In the first experiment, the reservation wage was set at twice the off-farm work rate. The 'leisure' activities were very popular in this solution, with over 62 per cent of total available labour time being devoted to leisure. Not surprisingly, off-farm work activities were no longer in the basis. Some yams, giant taro, cassava, sweet potato and intercropped yam were grown to satisfy the consumption constraints set, but there was no cultivation of yams or tomatoes for sale. Instead, vanilla was grown on twice as much land as in the farm plans of Figure 4.4. Small areas of land were left idle in two periods. Line fishing was no longer undertaken, so fish for consumption had to be purchased. Cash revenue obtained under this scenario was about T$5450 per year, compared to T$8070 in the 'no reservation price' model.

With the reservation wage at five times the off-farm work rate, about 68 per cent of the annual labour supply was diverted into leisure. Vanilla was still grown on a large area, but purchasing and consumption patterns were altered such that only cassava, sweet potato and plantain were grown for subsistence purposes. Annual cash revenue in this case was about T$4840.

5.2 Access to Land

In the basic models, the farm-household was assumed to have access to 4.4 ha of land, of which about 1.15 ha could be cropped (aside from coconuts) at any one time. There has been much debate in Tonga in recent years concerning land tenure issues, and suggestions have been made both of decreasing the average allotment size and of increasing access to land for 'dedicated growers' (Crocombe 1975, Hardaker 1975, Kunzel 1988). The effect of both decreasing and increasing the total land availability was therefore examined by experimentation with the MOTAD model. It was found that the highest achievable expected revenue would nearly double (from T$8070 to T$15 630) if the available land area doubled. The total absolute deviation would more than double (from T$2554 to T$5683). However, the optimal cropping pattern remained virtually unaltered except for an expansion of the vanilla area from .49 ha to 1.63 ha, utilising all the extra cropping land available. The additional labour required was obtained by abandoning line fishing and reducing the amount of off-farm work undertaken.

With the land area halved to 2.2 ha, the maximum expected revenue which could be obtained was about T$4170, with a total deviation of T$3340. Again, the pattern of subsistence crop production did not alter, because constraints still had to be achieved. Instead, the area of yams grown for sale was reduced from .365 ha (with farm size at 4.4 ha) to .271 ha, and the vanilla area declined from .489 ha to .007 ha.

Tests of stochastic dominance have not yet been carried out with these solutions. While it would be anticipated that the solution with the highest expected revenue would be dominant in the case of reduced land size, this may not be true when the land area is expanded.

6 DISCUSSION AND CONCLUSIONS

The development of a model of a Tongan smallholder farm-household has been described in this paper. The initial premise, that production and consumption activities could be analysed separately, was rejected in the light of the unrealistic production patterns in the solution. Instead, an integrated LP model was formulated incorporating both production and consumption activities. Through an innovative merging of Target MOTAD and ordinary MOTAD, the riskiness of both subsistence and cash crop production was accounted for. While the latter did not appear to be of great significance in determining optimum production patterns, the method nevertheless has considerable potential for policy analysis. For instance, the likely impact of new production technologies or marketing innovations can be assessed in terms of their effects on both the expected returns to crop production and changes in the variability of those returns. Similarly, the long-term potential of 'new' crops which farmers may be encouraged to grow can be investigated[8]. Some of the factors influencing food consumption patterns can also be identified.

While the policy analyses to be conducted with the aid of the model are still at an early stage, some preliminary results have been presented in the paper. These show the effects of labour and land supply on production patterns, marketing, food consumption and the tradeoff between expected revenue and risk.

8 For the past two or three years, for instance, a concerted effort on the part of the Ministry of Agriculture, Forests and Fisheries to take advantage of a newly identified market for pumpkins in Japan has led to a rapid expansion of the are planted to pumpkins. However, the available data suggest that pumpkins have neither revenue nor risk advantages over other, more established crops.

REFERENCES

Ahn, C.Y., Singh, I. and Squire, L. (1981), 'The model of an agricultural household in a multi-crop economy: the case of Korea', Review of Economics and Statistics 63(4), 520-5.

Barnum, H.N. and Squire, L. (1979), A Model of an Agricultural Household: Theory and Evidence, World Bank Staff Occasional Paper No. 27, Johns Hopkins University Press, Baltimore.

Becker, G.S. (1965), 'A theory of the allocation of time', Economic Journal 75(299), 493-517.

Bertram, I.G. and Watters, R.F. (1985), 'The Mirab economy in South Pacific microstates', Pacific Viewpoint 26(3), 497-519.

Crocombe, R. (1975), 'Land tenure in Tonga - the process of change: past, present and future', in S.H. Fonua (ed.), Land and Migration, Proceedings of a seminar organised by the Tonga Council of Churches, Nuku'alofa.

Delforce, J.C. (1989), Expenditure patterns of smallholder farm-households in Tonga: an application of the Almost Ideal Demand System. Paper presented at the 33rd Annual Conference of the Australian Agricultural Economics Society, Christchurch, February.

Delforce, J.C. and Hardaker, J.B. (1986), Modelling the smallholder farming sector in Tonga, Paper presented at the 30th Annual Conference of the Australian Agricultural Economics Society, Canberra, February.

Delforce, J.C. and Hardaker, J.B. (1987), Progress in modelling economic behaviour of smallholder households in the Kingdom of Tonga. Paper presented at the 31st Annual Conference of the Australian Agricultural Economics Society, Adelaide.

Delforce, J.C., Hardaker, J.B. and Fleming, E.M. (1988), Alternative strategies for development in Tonga. Paper presented at the 32nd Annual Conference of the Australian Agricultural Economics Society, Melbourne, February.

Dillon, J.L. and Scandizzo, P.C. (1978), 'Risk attitudes of subsistence farmers in Northeast Brazil: a sampling approach', American Journal of Agricultural Economics 60(3), 425-35.

Goh, S., Raskin, R. and Cochran, M. (1986), A generalised stochastic dominance program for the IBM PC, Unpublished paper, University of Arkansas Division of Agriculture, Fayetteville.

Hardaker, J.B. (1975), Agriculture and development in the Kingdom of Tonga, PhD thesis, University of New England, Armidale.

Hardaker, J.B., Delforce, J.C., Sefanaia, S. and Fleming, E.M. (1986), Outline of Data Collection Procedures in Tonga, Research Note No. 1, South Pacific Smallholder Project, U.N.E., Armidale.

Herath, H.M.G., Hardaker, J.B. and Anderson, J.R. (1982), 'Choice of varieties by Sri Lanka rice farmers: comparing alternative decision models', American Journal of Agricultural Economics 64(1), 87-93.

Kunzel, W. (1988), Land tenure in Tonga: a sampler of ideas and arguments. Unpublished paper, South Pacific Smallholder Project, Nuku'alofa.

Lopez, R.E. (1986), 'Structural models of the farm household that allow for interdependent utility and profit-maximization decisions', ch.11 in I. Singh, L. Squire and J. Strauss (eds), Agricultural Household Models: Extensions, Applications, and Policy, Johns Hopkins UP, Baltimore.

Mellor, J.W. (1986), 'Agriculture on the road to industralization', ch. 2 in J.P. Lewis and V. Kallab (eds), Development Strategies Reconsidered, U.S.-Third World Policy Perspectives No. 5, Overseas Development Council, New Brunswick, N.J.

Nakajima, C. (1969), 'Subsistence and commercial family farms: some theoretical models of subjective equilibrium', in C.R. Wharton (ed.), Subsistence Agriculture and Economic Development, Aldine, Chicago, 165-84.

Nakajima, C. (1986), Subjective Equilibrium Theory of the Farm-Household, Developments in Agricultural Economics 3, Elsevier, Amsterdam.

Roe, T. and Graham-Tomasi, T. (1986), 'Yield risk in a dynamic model of the agricultural household', ch.9 in I. Singh, L. Squire and J. Strauss (eds), Agricultural Household Models: Extensions, Applications, and Policy, Johns Hopkins UP, Baltimore.

Singh, I., Squire, L. and Strauss, J. (1986a), 'Introduction', in I. Singh, L. Squire and J. Strauss (eds), Agricultural Household Models: Extensions, Applications and Policy, Johns Hopkins University Press, Baltimore, 3-14.

Singh, I., Squire, L. and Strauss, J. (1986b), 'Methodological issues', in I. Singh, L. Squire and J. Strauss (eds), Agricultural Household Models: Extensions, Applications and Policy, Johns Hopkins University Press, Baltimore, 48-69.

Strauss, J. (1986), 'Estimating he determinants of food consumption and caloric availability in rural Sierra Leone', ch.4 in I. Singh, L. Squire and J. Strauss (eds), Agricultural Household Models: Extensions, Applications, and Policy, Johns Hopkins University Press, Baltimore.

Tauer, L.W. (1983), 'Target MOTAD', American Journal of Agricultural Economics 65(3), 606-10.

Watts, M.J., Held, L.J. and Helmers, G.A. (1984), 'A comparison of Target MOTAD to MOTAD', Canadian Journal of Agricultural Economics 32(1), 175-85

Table 3.1

Permissable Crop Sequences[a]

Crop	Previous crop	Next crop
Yam	Fallow	Taro Sweet potato Paper mulberry Vanilla Pineapple Plantain Fallow
Taro	Fallow Yam Sweet potato Plantain	Sweet potato Cassava Vanilla Plantain Pineapple Fallow
Cassava (1)	Sweet potato Plantain Taro Banana Tomato Capsicum Pineapple Watermelon	Cassava (2) Pineapple Fallow
Cassava (2)	Cassava (1)	Fallow
Sweet potato	Yam Taro Plantain	Taro Cassava Plantain Vanilla Pineapple Fallow
Plantain	Fallow Yam Sweet potato Taro Watermelon Tomato Capsicum Pumpkin	Sweet potato Taro Cassava Vanilla Fallow

/cont'd

a Permissable rotations were specified in the matrix for each individual crop activity, such that 'following crops' started in the period immediately after 'preceding crops'. Where appropriate, one-period fallows were allowed between the crop activities in a rotation.

Table 3.1 (continued)

Crop	Previous crop	Next crop
Banana	Fallow Watermelon Tomato Capsicum Pumpkin	Cassava Fallow
Watermelon	Fallow	Plantain Banana Cassava Pineapple Fallow
Pineapple	Fallow Yam Taro Cassava Sweet potato Watermelon Pumpkin	Cassava Fallow
Paper mulberry	Fallow Yam	Fallow
Tomato) Capsicum)	Fallow	Cassava Banana Plantain Fallow
Vanilla	Fallow Yam Taro Sweet potato	Fallow
Pumpkin	Fallow	Plantain Banana Pineapple Fallow

Table 3.2

Land Use on Tongan Farms

	Village				Average excl. village K	Average in 1.15 ha[a]
	H	K	M	N		
	ha	ha	ha	ha	%	ha
Total farm area	108.989	68.353	134.017	143.353		
Fallow	73.136	45.271	107.276	114.038	76.21	
	%	%	%	%		
Cropped	100.000	100.000	100.000	100.000	100.00	
Monocrop:						
Yam	4.753	3.033	2.977	1.320	3.14	.036
Xanthosoma taro	10.903	1.434	.314	16.108	9.48	.109
Colocasia taro	.237		.138		.13	.002
Giant taro	1.244	.910	2.390	1.242	1.58	.018
Cassava	37.484	46.655	5.819	32.560	26.70	.307
Sweet potato	1.436	.026			.56	.006
Banana	9.564	2.443	.434	2.163	4.55	.052
Plantain	.767	1.061		.368	.42	.005
Paper mulberry	1.199			6.938	2.68	.031
Vanilla	.092		26.611	3.623	8.93	.103
Pumpkin	.106		3.553	.055	1.09	.013
Watermelon			.927	1.712	.82	.009
Pineapple	.374		.942	.447	.56	.006
Tomato				.385	.12	.001
TOTAL MONOCROPPED	68.159	55.563	44.105	66.921	60.77	.699
Intercropped:						
Yams & subsistence intercrops (*ma'ala*)	3.300	7.690	13.358	2.511	5.97	.069
Other subsistence combinations	6.072	15.345	14.506	12.424	10.55	.121
Other combinations of crops in model	5.021	0	4.248	.246	3.27	.038
TOTAL INTERCROPPED	14.392	23.035	32.112	15.180	19.80	.228
% OF TOTAL CROPPED AREA	82.551	78.598	76.216	82.101	80.56	.926

[a] Of the 4.4 ha available in the model, about 2.93 ha is constrained to be fallow and .315 ha is occupied by coconuts.

Table 4.1

Structure of Crop Production Section of Target MOTAD Model

Rows	Grow staple crops (ha) X1	X2	X3	Negative deviations from target D1	D2	D3	D4	D5	D6	Grow cash crops (ha) X4	X5	Fallow (ha)	RHS
Objective (T$)	-a	-a	-a							a	a		Maximise
Land (ha)	1	1	1							1	1	1	< 4.4
Labour (hours)	a	a	a							a	a		< b
Cash (T$)	a	a	a							-a	-a		< b
Rotation X1	1											-.5	< 0
Rotation X2	-1	1									-1	-.5	< 0
Rotation X3	-1	-1	1								-1		< 0
Rotation X4											-1	-.5	< 0
Rotation X5	-1	-1									-1	-.5	< 0
Fallow	1	1	1							1	1		
Expected shortfall from target (GJ)				.167	.167	.167	.167	.167	.167				= λ
Risk rows (GJ)													
Year 1	6.3	5.5	13.2	1									> 17.13
Year 2	4.1	6.2	15.6		1								> 17.13
Year 3	9.8	5.3	12.1			1							> 17.13
Year 4	5.0	7.0	14.3				1						> 17.13
Year 5	6.2	5.1	11.6					1					> 17.13
Year 6	9.2	6.8	13.8						1				> 17.13

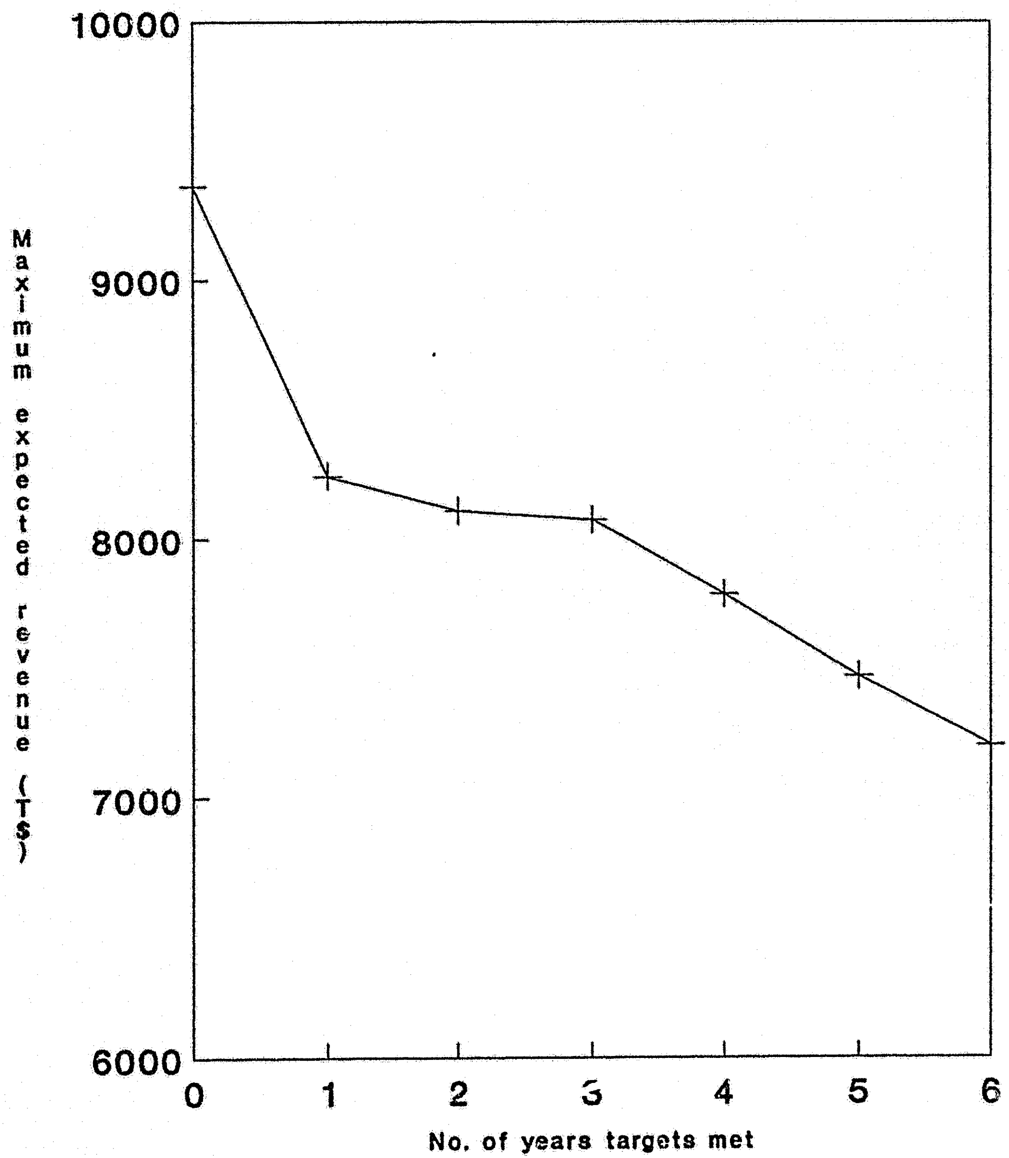

Figure 4.1 Max E when meeting targets

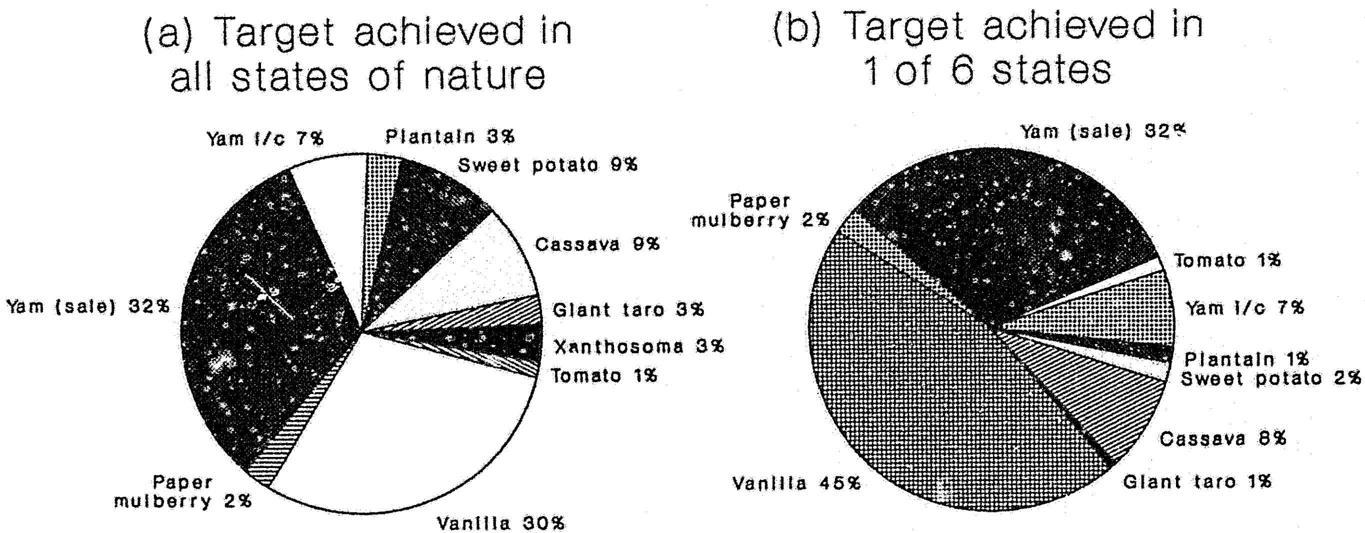

Figure 4.2 Target MOTAD solutions

Table 4.2

Structure of Crop Production Section of MOTAD Model

Rows	Grow staple crops (ha)			Negative deviations from target						Grow cash crops (ha)		Fallow (ha)	Negative deviation counters						RHS
	X1	X2	X3	D1	D2	D3	D4	D5	D6	X4	X5		Z1	Z2	Z3	Z4	Z5	Z6	
Objective (T$)													1	1	1	1	1	1	Minimise
Expected total gross margin (T$)	-a	-a	-a							25.3	51.6								= λ
Land (ha)	1	1	1							1	1	1							< 4.4
Labour (hours)	a	a	a							a	a								< b
Cash (T$)	a	a	a							-a	-a								< b
Rotation X1	1											-.5							< 0
Rotation X2	-1	1									-1	-.5							< 0
Rotation X3	-1	-1	1								-1								< 0
Rotation X4											-1	-.5							< 0
Rotation X5	-1	-1									-1	-.5							< 0
Fallow	1	1	1							1	1								
Expected shortfall from target (GJ)				.167	.167	.167	.167	.167	.167										= b
Subsistence targets																			
Year 1	6.[illegible]	5.5	13.2	1															> 17.13
Year 2	4.1	6.2	15.6		1														> 17.13
Year 3	9.8	5.3	12.1			1													> 17.13
Year 4	5.0	7.0	14.3				1												> 17.13
Year 5	6.2	5.1	11.6					1											> 17.13
Year 6	9.2	6.8	13.8						1										> 17.13
Risk rows (GJ)																			
Year 1										3.9	51.0		1						> 0
Year 2										-.6	-12.3			1					> 0
Year 3										17.3	-6.3				1				> 0
Year 4										6.0	13.7					1			> 0
Year 5										-7.4	-5.3						1		> 0
Year 6										-13.8	-40.8							1	> 0

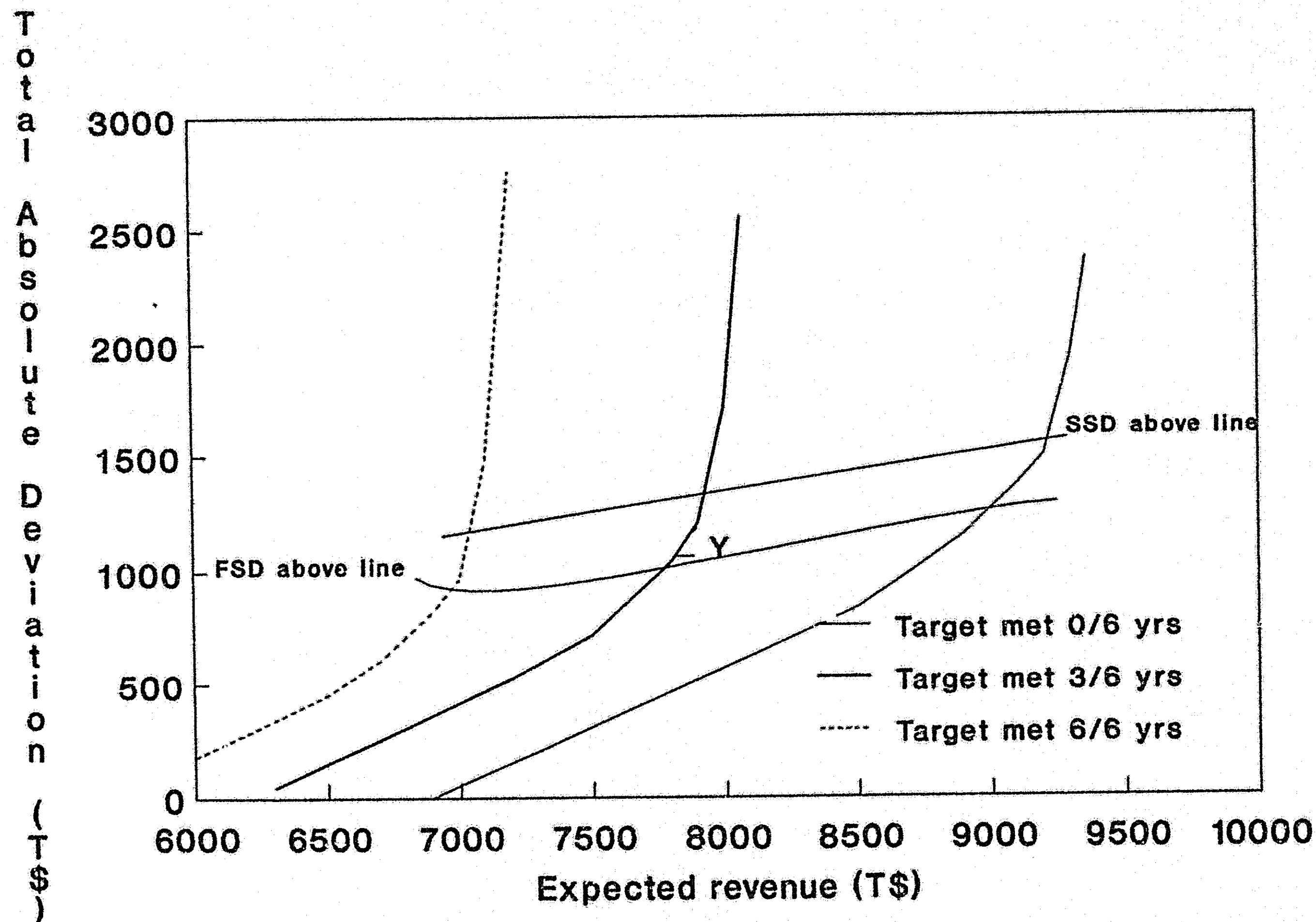

Figure 4.3 E-TAD tradeoffs

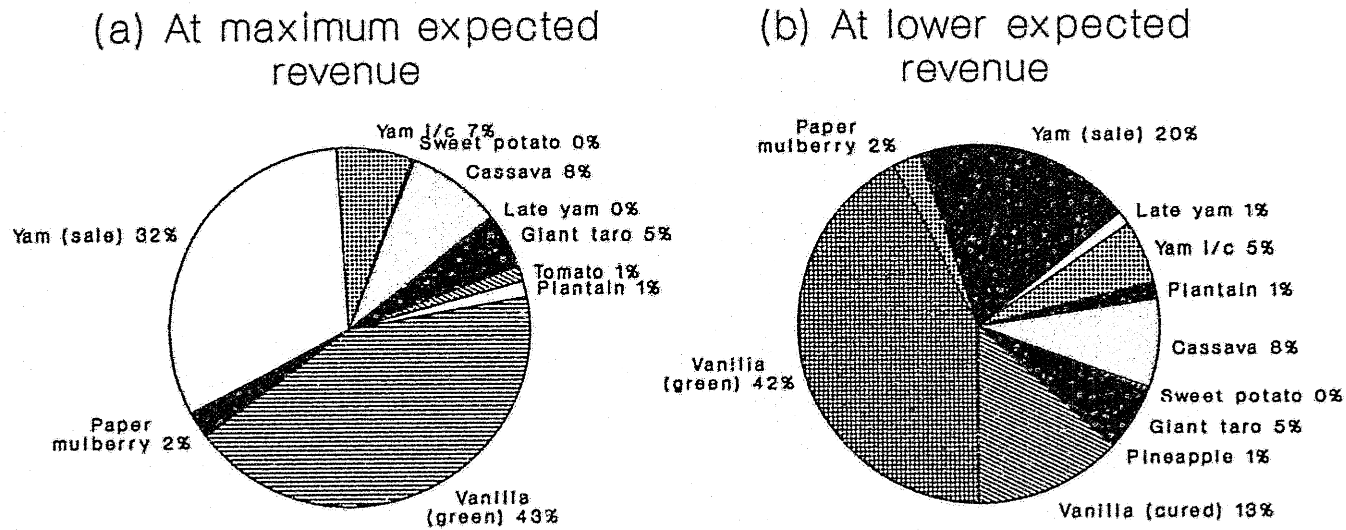

Figure 4.4 MOTAD solutions