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An application of Target MOTAD Model to crop production in Zambia: Gwembe Valley as a case study

Phiri Maleka

Rural Development Studies Bureau, University of Zambia, Lusaka, Zambia

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ABSTRACT

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The Zambian Government encourages crop production in the Gwembe Valley without taking into consideration the risks involved. These risks mainly originate from the stochastic nature of rainfall. This paper, therefore, identifies optimal cropping patterns in the Gwembe Valley by using Target MOTAD Model. The results of the Target MOTAD Model indicate an optimal cropping pattern of growing sorghum, rice and soyabeans. This is different from the existing cropping pattern of sorghum, sunflower, cotton and maize. The overall policy implication of adopting the cropping pattern obtained from the model solution is that some resources allocated to the production of current crops have to be reallocated to the production of new crops. Moreover, since people in the Gwembe Valley are used to growing of cotton, sunflower and maize, the adoption of the suggested new crops will entail the education of the people (through extension services) in the crop husbandry of these crops.

INTRODUCTION

Crop production in Gwembe Valley is risky. This is because it is generally carried out under the stochastic nature of rainfall (Scudder, 1962, 1986; Watts et al., 1984; Banda, 1985). However, despite the risky situation which prevails in the production of crops under rainfed conditions, the people of Gwembe Valley continue to grow a variety of crops. Prominent

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Correspondence to: P. Maleka, Rural Development Studies Bureau, University of Zambia, Box 23279, Lusaka, Zambia.

among these crops are: maize, cotton, sunflower and sorghum. Whilst sorghum is grown as a staple food, cotton, sunflower and maize are grown as commercial crops. Since agricultural research in the Gwembe Valley has demonstrated that soyabeans, rice and wheat can grow well under draw-down and furrow irrigation, households in the study area are being persuaded to grow these crops. So far, the production of these crops has not yet started (Department of Agriculture, Lusaka, 1991).

Although the Gwembe Valley is currently growing maize, cotton, sorghum and sunflower, these crops are produced without identifying the optimal manner of growing them. The identification of such a cropping pattern demands the use of mathematical programming models. This is because mathematical programming models take into account efficient utilization of resources (Anderson, Dillon and Hardaker, 1977; Hazell and Norton, 1986). The objectives of this paper, therefore, are:

(1) To identify optimal cropping patterns in Gwembe Valley using Target MOTAD Model. Reasons for choosing this model will be explained later.
(2) To indicate implications of the Target MOTAD Model results on household food security.
(3) To ascertain whether households in the Gwembe Valley are risk averse.

DESCRIPTION OF GWEMBE VALLEY

Gwembe Valley, is about 200 km south of the Zambia's capital city Lusaka. It is bounded by Lake Kariba to the south and the escarpment to the north. The nation of Zimbabwe lies to the east of the Gwembe Valley. The valley extends about 400 km stretching between the southern and northern ends of Lake Kariba (Scudder, 1962; Handlos and Williams, 1985). Although the term Gwembe Valley is loosely used in this paper, this study is confined to the middle and northern sections of Gwembe Valley.

The soils of the Gwembe Valley as described by Scudder (1962) are of pre-karoo and alluvial formation. Some scientists, such as Maclean (1969), describe the soils of Gwembe Valley as micaceous sandy loam and clay loam containing fine and medium subangular blocky structure.

The valley is generally hot throughout the year with the hottest temperature reaching 40°C in the months of October and November. The cold months are between May and August, with the coldest month being July registering an average mean temperature of 15°C. The hot and cold temperatures of the valley coincide with the general broad categories of the wet and dry seasons. The wet season is from November to April, the dry season from May to October (Sharma and Nyumbu, 1985).

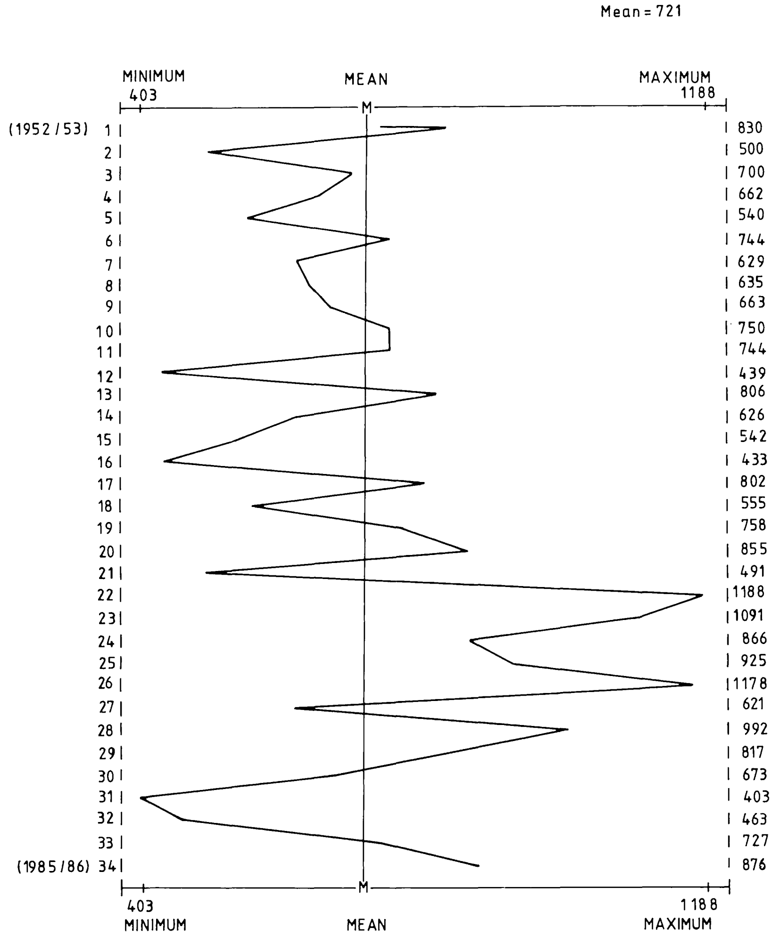

Fig. 1. Annual rainfall pattern in Gwembe Valley 1952/53–1985/86 *Source:* Department of Meteorology, Harare, several issues.

The pattern of rainfall in Gwembe Valley on annual basis between 1952/53 and 1985/86 is illustrated in Fig. 1. According to this figure, the mean annual rainfall is about 721 mm with a maximum of 1188 mm and a minimum of 403 mm. Furthermore, observations in Fig. 1 indicate that rainfall in the valley is free of any trend and does not follow a regular pattern of occurrence.

The vegetation in the valley is dominated by open deciduous canopy and mopani trees. The dominant species of canopy are *Acacia, Agansonia* and *Combretrum*. The fauna predominantly consists of a wide-ranging species of birds and herbivores such as monkeys including baboons, deers, zebras, and giraffes. While large herbivores such as the elephants and the buffaloes are found, the fauna is predominantly made up of carnivores such as lions, leopards and rhinos.

POPULATION AND ECONOMIC ACTIVITY

Some 12 000 families are dispersed amidst the medium-density forest areas and are concentrated in small sets of communities that display subsistence agriculture. At present, approximately 20 000 ha of land are cultivated in the form of small holdings, that is approximately 1.7 ha per household (Rural Development Studies Bureau, 1990).

The extreme low annual per-capita income relative to the volume of agricultural output and the estimated population size of 84 000 (Handlos and Williams, 1985) suggests a high degree of underemployment in the study area. Surveys in the area by the Rural Development Studies Bureau also indicate that the caloric intakes in the valley are well below recommended levels and frequent droughts no doubt exacerbate these problems.

Output for maize, sunflower, cotton and sorghum is illustrated in Table 1. In this table, one observes instability in all the four crops. For example, maize output fluctuates from 15 367 t in 1976 to 5858 t in 1982, and then rose again to 14 554 t in 1985. Similarly, while no output is recorded for sorghum between 1976 and 1981 (this is due to the fact that no official pricing and marketing policy existed in the country during that period), it rose from 860 t in 1982 to 8916 t in 1985. The same can be said for cotton and sunflower. Since crops recorded in Table 1 are grown during the rainy season and thus solely depend on stochastic rainfall, which usually starts in November and ends in April, any analysis of instability in crop output in

TABLE 1

Crop output in Gwembe Valley (t) from 1976 to 1986

Year	Maize	Sunflower	Cotton	Sorghum	Total output
1976	15 400	1 700	7 600	–	24 700
1977	11 700	2 900	8 700	–	23 300
1978	11 500	1 100	7 100	–	19 700
1979	15 400	1 400	14 100	–	30 900
1980	9 000	1 500	13 000	–	34 500
1981	8 100	890	1 500	–	10 490
1982	5 900	600	3 300	900	9 800
1983	7 800	700	2 200	1 000	11 700
1984	9 800	700	5 800	2 900	19 200
1985	14 600	3 100	20 100	8 900	46 700

Source: Department of Agriculture, Choma/Lusuka, several reports.

the Gwembe Valley should examine the relationship between rainfall and crop output. Thus, this paper examines this relationship by plotting crop output data against rainfall data (see Fig. 2). Plotting is done to capture the trend between output of each crop and rainfall availability. As no official recorded output data for sorghum existed prior to 1976, the rainfall data extracted from Fig. 1 are from 1976 to 1985. This is done to march rainfall data with crop output data. The graphical representation of the relationship between crop output and rainfall data is presented in Fig. 2. The general observation of this figure indicates a general correlation between crop output instability and rainfall instability. This observation conforms to the ones by such scientists as Scudder (1962), Watts et al. (1984) and Banda

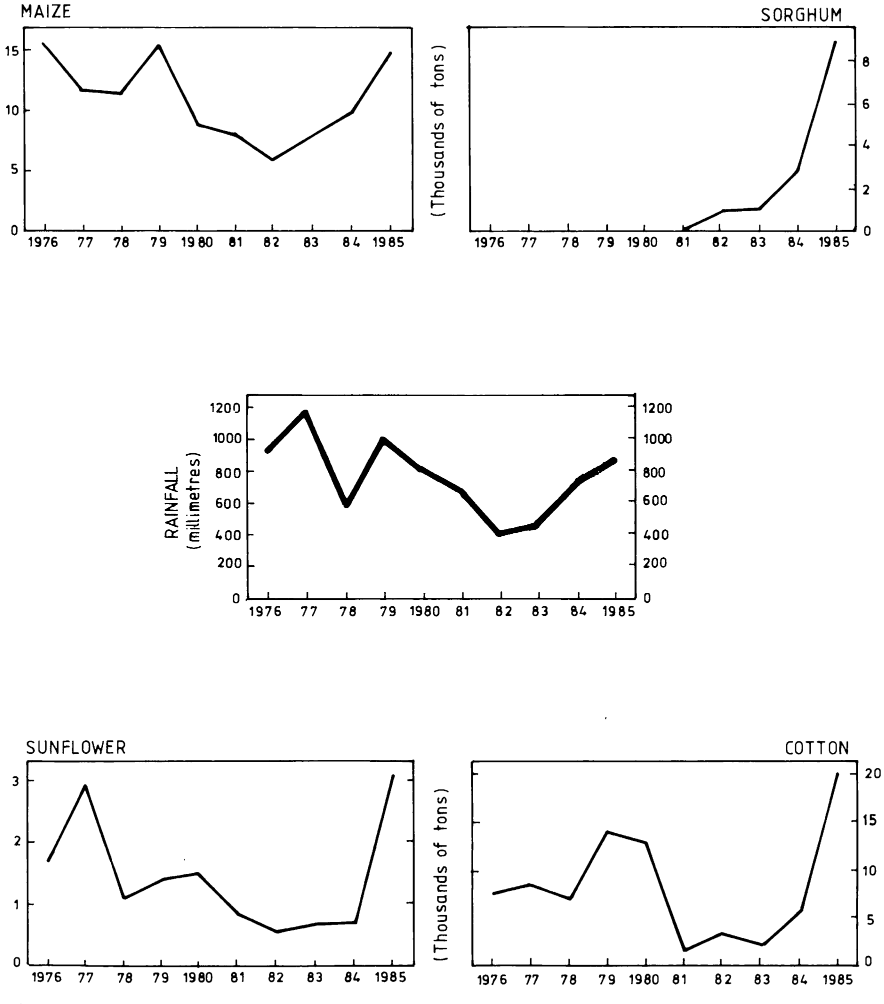

Fig. 2. Relationship between crop production and rainfall in Gwembe Valley.

(1985). These scientists also observed a strong correlation between crop output and rainfall instabilities in Gwembe Valley. They further observed a correlation between crop production instability, rainfall instability and famine in the valley. According to them, famine occurred in the valley whenever there was shortage of rainfall, which in turn created inadequate supply of staple food crops.

MODEL SPECIFICATION

Studies on agricultural development in drought-prone areas are explicit on the need to incorporate the risks and uncertainties that are associated with drought (Anderson, Dillon and Hardaker, 1977, Hazell and Scandizzo, 1978; Hazell and Norton, 1986). These studies also favour the use of mathematical programming models for the determination of land-use decisions that involve the spatial allocation of resources. This is primarily governed by the ability of mathematical programming models to evaluate an infinite set of resource allocation patterns from a set description. Problems involving risks and spatial patterns of resource allocation are best resolved by quadratic programming models. In their application to agricultural land use decisions, these models are formulated to maximize the expected revenue from various land uses minus the cost of risk taking, subject to the usual resource endowments of land, labour, capital and soil moisture. The quadratic form is due to the costs of risk taking being defined in terms of a variance–covariance matrix of returns from land use. Although quadratic programming is theoretically adequate, its applicability is limited due to the inaccessibility to suitable algorithms and difficulties associated with the computation of variance–covariance matrices.

However, a simplification and a more readily applicable transformation of the quadratic programming model was presented by Hazell (1971) where the variance–covariance matrix was replaced by mean absolute deviations. This replacement enables the model to be linear instead of quadratic. These models referred to as MOTAD are more readily applicable due to the availability of a wide-ranging variety of linear programming algorithms. In this paper, a variant of Hazell's MOTAD model, namely Target MOTAD, is used. Whilst the original MOTAD models measure risk in terms of absolute deviation of income from mean income, Target MOTAD models measure risk as absolute deviations from prespecified values of target income (Tauer, 1983). The relevance of Target MOTAD is mainly due to the fact that mean income need not necessarily satisfies basic needs, whilst target incomes do. Thus, it is possible to define the risks that are prompted by droughts in terms of failing to meet the basic needs of households food security in Gwembe Valley.

The general specification of the Target MOTAD model for this paper follows that of Watts, Held and Helmers (1984), Romero and Rehman (1985), Zimet and Spreen (1986), McCamley and Kliebenstein (1987) and Maleka (1990). This is illustrated below as:

MAXIMIZE
Revenue = [Expected value of gross margin from cropping]–[Cost of credit]

SUBJECT TO: the constraints of land, labour, soil moisture, capital and credit, deviation from target revenue and risk aversion levels
Hence, the model solution reveals: (a) the mix of crops to be grown: (b) the amount of credit to be given to the farmer; and (c) the expected gross margins to be realized.

The objective function of the Target MOTAD Model concerns the maximization of expected gross margins from seven crops, namely maize, cotton, sunflower, soyabeans, sorghum, rice and wheat. The constraints pertain to the availability of land, labour, cash capital, soil moisture, and cost of risk taking. The last constraint is set within the framework of a decision maker wanting to seek a trade-off between maximizing crop output (and hence revenue) on the one hand, and minimizing the risk of undertaking cropping activities on the other. The risk herewith is assumed to be caused solely by the uncertainty pertaining to the amount of rainfall.

The description of the model is presented below.

OBJECTIVE FUNCTION

It is assumed that the uncertainty pertaining to the amount of rainfall during the rainy season influences only the amount of crop output (and hence the gross margins from crops). The objective function for this paper is mathematically specified as follows:

$$\text{MAXIMIZE } Z = \sum_{q=1}^{5} \sum_{j=1}^{7} \left[\mathrm{E}(C_{qj})(X_{qj})\right] - \sum_{q=1}^{5} \sum_{j=1}^{7} Ib_{qj} \qquad (1)$$

where $[\mathrm{E}(C_{qj})\ (X_{qj})]$ represents the expected gross margin from crop j in zone q that is grown under rainfed conditions; q represents zones 1 to 5 as illustrated in Fig. 3; j represents seven crops, namely maize, cotton, sunflower, soyabeans, rice, sorghum and wheat; b_{qj} represents the amount of cash credit in K obtained for crop j grown under rainfed conditions in

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K, Zambian Kwacha = US\$0.50 (1986).

zone q; and I represents annual interest charge on the cash credit obtained from loan lending institutions.

CONSTRAINTS

Each of the above mentioned constraints is now considered in turn.

Land constraint. The land in the study area is divided into five zones. This division is based on Scudder's study (1962), which divides the land in Gwembe Valley into various physiographic zones. These five zones are shown in Fig. 3 and Table 2. Also shown in Fig. 3 is a proposed reservoir that was suggested by the World Bank (Report 39, Rome, 1983) and the AGRINDCO Report (MAWD, Lusaka, 1987) to store water for possible irrigation purposes in the study area.

Scudder (1962) outlines the topographical characteristics of Gwembe Valley as follows: (a) flat land from the shore of Lake Kariba to about 15 km inland; (b) killy and rugged land starting from around 16 km from the

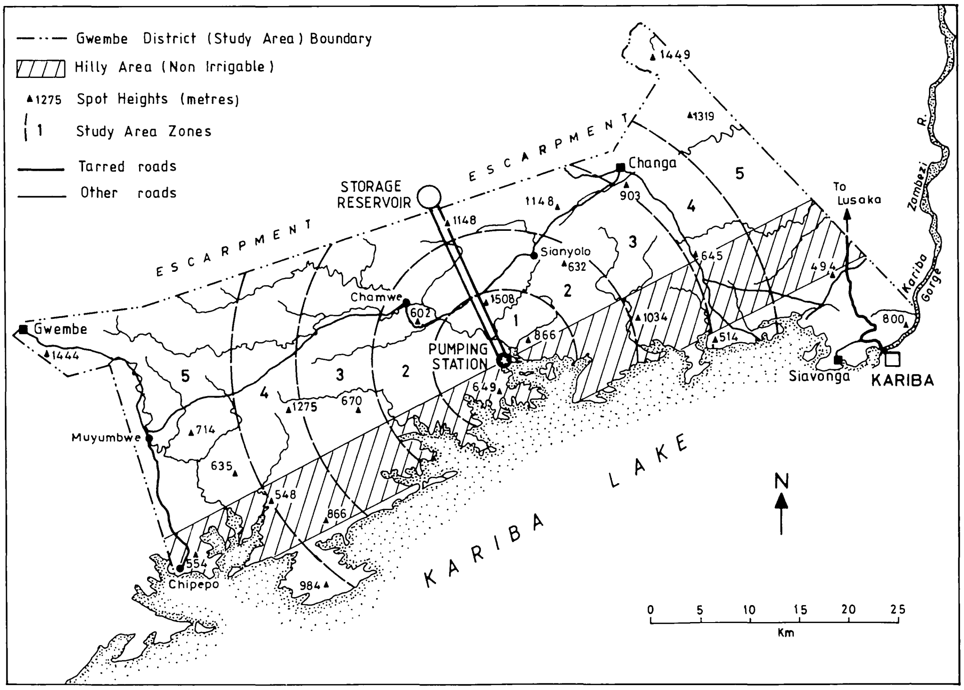

Fig. 3. Estimated zones in Gwembe Valley. *Source:* Calculated from Scudder's study of 1962.

TABLE 2

Proposed zones of land in the Gwembe Valley

Zone	Estimated cultivable hectarage	Existing cropping pattern
1	13 260	sorghum, maize, sunflower
2	32 340	sorghum, maize, sunflower
3	49 860	sorghum, sunflower, cotton
4	30 000	sorghum, sunflower, cotton
5	36 600	sorghum, sunflower, cotton

Source: Department of Agriculture, 1986, 1990; Rural Development Studies Bureau, 1991.

lake up to about 35 km in land; and (c) flat land from about 36 km from the lake to the foot of the escarpment.

The specification of the land constraint for season *i* is as follows: Let the amount of land available for crop production in a given zone be denoted as L_q. Hence, all land use enterprises compete for the use of this land area L_q. Let the amount of land required to produce one unit of crop *j* under rainfed agriculture in zone q be denoted as q_{qj}. Thus the land constraint is:

$$\sum_{q=1}^{5} \sum_{j=1}^{7} a_{qj} X_{qj} \leqslant L_q \tag{2}$$

Labour constraint. A statement of the amount of labour required per ha to produce crop *j* in zone *q* under rainfed conditions is written as:

$$\sum_{q=1}^{5} \sum_{j=1}^{7} A_{qj} X_{qj} \leqslant l_q \tag{3}$$

where l_q is the amount of labour in man-days that is available in zone *q*, and A_{qj} is the amount of labour in man days-day required to produce one hectare of crop *j* under rainfed conditions.

Credit constraint. Let Q_{qj} represent the amount of cash capital required for the production of one unit of crop *j* in one *q* under rainfed conditions, and let M_{qj} represent the amount of cash capital available at the start of the cropping season in zone *q* for crop *j*. Given that b_{qj} represents the amount of money borrowed during the cropping season for crop *j* in zone *q*, the credit constraint is:

$$\sum_{q=1}^{5} \sum_{j=1}^{7} Q_{qj} X_{qj} - \sum_{q=1}^{5} \sum_{j=1}^{7} b_{qj} \leqslant M_{qj} \tag{4}$$

Soil moisture constraint. Variables in the soil moisture constraint are defined as follows: Let R_{qj} represent the amount of rainfall from the simulated rainfall values measured in ha-mm in zone q for crop j, and let t_{qj} represent in mm the per-hectare crop water requirements for crop j during the cropping season in zone q. In summary form, the soil moisture constraint is specified as:

$$\sum_{q=1}^{5} \sum_{j=1}^{7} t_{qj} X_{qj} \leqslant R_{qj} \tag{5}$$

Negative deviation from a prespecified target revenue constraint

This constraint specifies the following aspect of a decision maker's behaviour as explained by Tauer (1983), namely that, whilst wanting to maximize expected income from various activities, decision makers are also concerned about their revenue falling below a critical target. So, the deviation of revenue below a target measures one aspect of the decision makers' risk, and is hence defined as:

$$\sum_{q=1}^{5} \sum_{j=1}^{7} c_{qj} X_{qj} + Y_K \leqslant T \tag{6}$$

where Y_k represents deviations below target revenue during the rainy season for the kth state of nature, and T represents target revenue during the rainy season. Herein, a state of nature is defined as a particular set of rainfall values during a year.

Sum of negative deviations multiplied by the probabilities of the states of nature constraint

Following Watts, Held and Helmers (1984) and Hazell and Norton (1986), the second aspect of a decision-maker's perception of risk is that the expected value of total deviations below the target over a planning period should be confined to a specific value. To define this aspect of risk perception, Tauer (1983) equates the sum of the product of the probabilities of each state of nature and the deviation associated with the appropriate state of nature. This is specified as:

$$\sum_{k=1}^{s} p_k Y_k = \beta \tag{7}$$

where s represents the number of states of nature, p_k represents the probability of the kth state of nature, and β is a risk parameter which represents the sum of expected negative deviations below target revenue.

EMPIRICAL ESTIMATION OF VARIABLES OF THE ABOVE TARGET MOTAD PROGRAMMING MODEL

Estimation of variables in the above specified Target MOTAD Model is done by first empirically estimating the objective function, and then the constraints.

Objective function

Several studies (Rae, 1971a, b; Anderson, Dillon and Hardaker, 1977; Hazell and Norton, 1986) have suggested using subjective methods in estimating the incomes of decision makers in situations where data are sparse. these methods normally rely on past subjective experiences of decision makers. The above writers argue that decision makers, on the basis of their past experience, know the approximate amount of income to expect should conditions recur which are similar to the ones occurred in the past. Hence, because of the sparseness of data in the Gwembe Valley, the expected gross margins of this study are estimated by relying on subjective knowledge of decision makers in the study (Anderson, Dillon and Hardaker, 1977) it is the only meaningful one in this situation. Hence, using this method, the expected gross margins of this paper have been estimated for each of the seven crops. The following procedure was used during the field survey.

First, farmers and agricultural officers were asked to indicate in millimetres the amount of rainfall they thought constituted a good, medium and bad year for each of the seven crops being dealt with in this paper. This understanding of good, medium and bad is based on the crops growing the normal full maturity.

Secondly, farmers were asked to subjectively indicate the gross margin that they would get from each crop for various states of nature (that is, simulated values of rainfall). Their subjective estimates were validated by consultation with agricultural officers in the area. If the subjectively estimated value of gross margin for crop j during the rainy season for state of nature k is denoted as G_{jk}, and the probability of the state of nature k during the rainy season is P_k; then the expected gross margin is $(P_k(G_{jk}))$. To estimate the expected gross margins for the seven crops, the actual rainfall data presented in Fig. 1 were simulated using the Monte Carlo method. Then, after simulating these actual rainfall data, three scenarios were created from the simulated data. Each of these scenarios represents a planning period of 6 years and hence contains six sets of randomly selected rainfall values. Each set that is subsequently defined as a 'state of nature' has one rainfall value for the rainfed season.

The choice of three scenarios (see Appendix) is based on the assumed average length of time of drought in the study area. According to Scudder (1962), Watts (1984) and Banda (1985) drought in the Gwembe Valley lasts an average of 3 years.

Cost of credit

Although interest rates vary widely in the Zambian economy, herein it is equated to the government bond rate of 5%. This is done on the premise that the bond rate manifests the social productivity of capital.

Model constraints

Land constraints. It is assumed that each of the seven crops in the model has an equal chance of competing for available land in each zone. Hence, the coefficient of the land constraint acquires a value of one.

Labour constraint. Labour requirement and availability are calculated in man-days per ha per season and according to crop. Data for this variable are obtained from field survey (see Table 3).

Cash capital. The information on these items was derived through field surveys. The values of cash capital requirement for the various crops are summarized in Table 3.

TABLE 3

Resource requirements per ha of various crops in Gwembe Valley

Resource	Ma	Cot	Sun	Soya	Sor	Rice	Sheat
Labour (man-days)	22	42	15	16	37	33	18
Cash capital (discounted kwacha)	36	20	10	25	8	14	30
Soil moisture (mm)	740	640	690	790	550	990	890

Ma, maize; Cot, cotton; sun, sunflower; soya, soyabeans; sor, sorghum.
Source: Estimated from Farm Management Studies (several issues) and from discussions with Agricultural Extension Officers.

Soil moisture constraint. The soil moisture constraint is defined on the basis of crop water requirements for each of the seven crops in the model. Data for crop water requirements were derived from Nanga National Irrigation Report (1985) and Farm Management Annual Reports (1982–1986). These data are presented in Table 3.

Cost of risk taking constraints

The constraint pertaining to the cost of risk taking falls into two categories, namely: (a) negative deviation from a prespecified target revenue; and (b) sum of negative deviations multiplied by the probabilities of the states of nature.

The empirical estimation of target revenue was done in consultation with farmers, agricultural experts and policy makers during the field survey. A target revenue of K20 million was arrived at for the Gwembe Valley. The deviations below the target revenue were estimated by subtracting the expected gross margins from the subjectively estimated values of gross margin that are associated with each state of nature. A sample of these deviations can be observed from the three scenarios presented in the Appendix.

Two methods have normally been used to get the values of the risk parameter (β). The first method which has been used by Tauer (1983) and Zimet and Spreen (1986) involves the parameterization of the risk parameter (β) from zero to a very large number. The parameterization of β is continued until the model gives the same solution despite increasing the value of β, that is until the model solution does not display any further changes.

The second method which has been used in several studies (Dillon and Scandizzo, 1978; Thampapillai, 1980, O'Brien 1981; McCamley and Kliebenstein, 1987) predetermines a fixed value for the risk parameter. This is done either through direct interaction with decision makers or from secondary data. For example, Dillon and Scandizzo (1978) undertook questionnaire surveys among small-scale farmers in Northeast Brazil to arrive at the risk value which was used in the quadratic programming model. Thampapillai (1980) used the risk value of 0.5 for the MOTAD model following information obtained from the Australian Bureau of Agricultural Economics.

In this paper the value of β is defined as K4 million. The rationalization of this value is based on the premise that people in Gwembe Valley generally tolerate losses which amount up to one-fifth percent of revenue. Given that the decision makers of the study area have specified a target of K20 million, the amount of risk (losses) that can be permitted is K4 million.

RESULTS AND DISCUSSION

Results of the Target MOTAD Model are presented in Table 4. These results were derived as follows: as already explained above, the Target MOTAD Model was formulated with the target revenue of K20 million and the risk parameter β specified as K4 million. This Target MOTAD Model was then applied across the three scenarios presented in the Appendix. A simple average was taken from the results obtained from the solution of these three scenarios. According to the results in Table 4, sorghum is allocated 45 614 ha, rice 30 070 and soyabeans 43 570 ha, respectively. The expected revenue from such a cropping pattern is K18 million. To finance a cropping pattern of this nature, about K1.9 million of cash capital would be required.

The similarity of results to the existing cropping pattern as shown in Table 2 is very obvious. For example, the model results and the cropping pattern of Table 2 show diversification of crops, and according to Heady (1952) and Anderson, Dillon and Hardaker (1977) farmers who diversify their cropping pattern are risk averse, therefore farmers in Gwembe Valley are risk averse. Like the current cropping pattern, the model solution results indicate allocation of land to crops which guarantee both household food security and income. Thus, whilst household food security under the current cropping pattern is guaranteed by producing sorghum, food security under the model solution is also guaranteed by the production of sorghum. Similarly, under the current cropping pattern household income is ensured by the production of cotton, maize and sunflower, and potential saleable surplus maize and sorghum. Likewise, cash income in the model results is guaranteed by the production of soyabeans and rice.

TABLE 4

Results of Target MOTAD model at risk parameter of K4 million and target revenue of K20 million

Zone	Land allocation			Credit required (K)	Expected gross margins (K million)
	Sor	Soya	Rice		
1	0	6 225	7 000	253 625	18
2	0	20 420	23 070	873 480	
3	18 230	10 410	0	407 090	
4	22 270	4 515	0	291 035	
5	5 144	2 000	0	90 912	
Total	45 614	43 570	30 070	1 916 142	18

Source: Obtained from the above Target MOTAD Model Solution.

Despite the above-pointed-out similarity of results and the current cropping pattern, the differences between them exist too. For example, maize, sunflower and cotton are not allocated land in the model solution. These crops are replaced by soyabeans and rice in the model solution. The absence of maize and cotton in the model solution is surprising given the fact that these crops require less water than rice and soyabeans (see Table 3). It is possible that maize is not in the model solution because it requires more fertilizer and pesticides and thus is more expensive to produce than rice and soyabeans which require less of these agricultural inputs. Cotton is not in the model solution possibly because its inputs requirements such as labour and soil moisture compete unfavourably with those of rice and soyabeans.

IMPLICATIONS OF RESULTS ON HOUSEHOLD FOOD SECURITY

The overall policy implications of the above results is that resources that are currently allocated to the production of current crops have to be reallocated at both regional and household levels.

Among household implications of these results are:

(1) The introduction of soyabeans and rice in the model solution entails the adoption of a new cropping pattern by households in the study area. The adoption of such a cropping pattern involves time to learn it and this might adversely affect overall household food security.

(2) Whilst maize, cotton and sunflower are prominent cash crops in the study area and while their market is already guaranteed, the market of soyabeans and rice is not yet guaranteed and thus their role as sustainable source of household income and hence of food security becomes uncertain at least in the short run.

(3) The absence of maize in the model solution and that of sorghum in zones 1 and 2 implies that households in these zones might have to import these crops from surplus producing areas within or outside the study area so as to meet household food security requirements.

(4) The credit requirements of K1.9 million of K158 per household as observed in the model solution may boost crop production thus enhancing household food security in Gwembe Valley.

(5) The model's expected income of K18 million or K1500 per household shows a more significant improvement over the welfare of individual households compared to the estimated current income of K15 million or K1250 per household (Department of Agriculture, 1991). The increase in household income is expected to enhance household food security through augmenting the purchasing power of individual households.

The above results should not be taken as conclusive because of problems in estimation of coefficients of certain parameters used in this paper. For example, coefficients of the cost of credit and the cost of risk are difficult to estimate with accuracy. This might be true for the coefficients of other parameters in the model. To safeguard against the uncertainty in the estimation of some model parameters, sensitivity analysis is used on certain parameters. The application of sensitivity analysis to this model's results also contributes to the test of validity of the above results. However, because of limitation of time, this paper applies sensitivity analysis only to cost of credit and cost of risk taking.

Sensitivity analysis pertaining to interest rates

Interest rates fluctuate widely in Zambia. The results presented above were based on an interest rate of five percent. However, some Zambian decision makers indicate that it is plausible for private money lenders to charge interest rates as high as eighty percent. For example, Lele (1975) has noted that noninstitutional interest rates can be more than 50% in certain African countries. Hence, the sensitivity of the results to varying interest rates between 5% and 80% was tested, and the results of these tests are reported in Table 5 and Fig. 4. The results of Table 5 and Fig. 4 indicate that revenue and cropping pattern are sensitive to variation in interest rates charges. For example, increases in interest rates were accompanied by decreases in the expected gross margin and changes in the pattern of resource allocation. That is, more land was allocated to sorghum as cost of credit increases.

The importance of the credit facility was also tested by removing the credit variable from the objective function and the cash capital constraint.

TABLE 5

Summarized results of sensitivity analysis for cost of credit

Cost of credit Ib_{qij} (%)	Location allocation			Gross margin (K million)
	Sorghum	Soyabeans	Rice	
0.05	45614	43570	30070	18.2
0.10	50857	50857	0	18.0
0.15	50857	50857	0	18.0
0.30	54750	48614	0	17.8
0.50	55131	46504	0	17.5
0.60	60605	44504	0	16.9
0.80	62352	40006	0	15.8

Note: Summarized from solution of the three scenarios in the appendix.

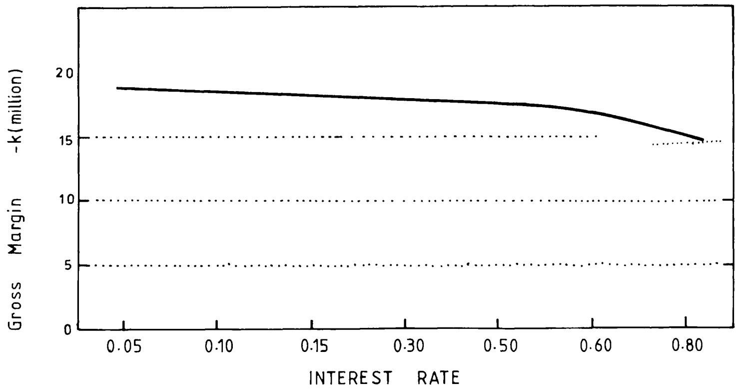

Fig. 4. Sensitivity analysis for cost of credit.

The solution of the Target MOTAD model dictated the allocation of 80 000 ha of land to grow only sorghum, and the value of the expected gross margin amounts to K9.2 million. Given that the size of the expected gross margin when credit is available is K18 million, the removal of the credit facility results in halving of the gross margin.

Sensitivity analysis to cost of risk taking, β

To recapitulate, the above Target MOTAD Model was specified to have a fixed risk value (β) of K4 million and a target revenue of K20 million. This is because decision makers in the Gwembe Valley are assumed to tolerate losses amounting to one-fifth of the target revenue. This assump-

TABLE 6

Summarized results of sensitivity analysis for the risk parameter

Risk parameter, β (K million)	Target revenue (K million)	Expected gross margin (K million)	Land use allocation to crops (ha)		
			Sorghum	Soyabeans	Rice
0	20	14.1	59714	15812	0
4	20	18.2	45614	43570	30070
6	20	18.2	45614	43570	30070
8	20	18.2	45614	43570	30070
10	20	18.8	75110	51234	0
12	20	18.8	75110	51234	0
14	20	19.4	142514	0	0
16	20	19.4	142514	0	0

Note: Summarized from the solution of the three scenarios in the appendix.

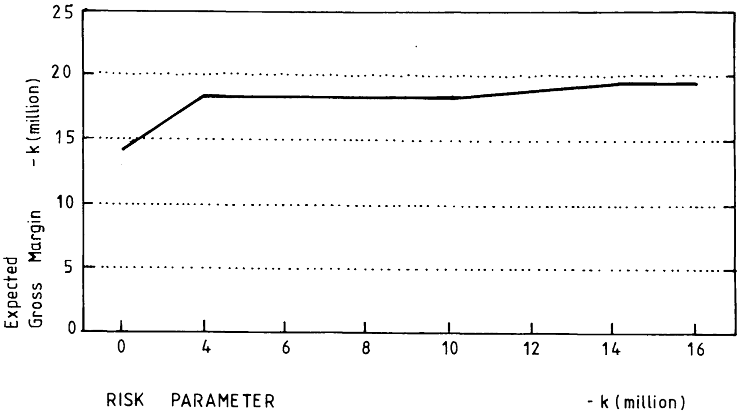

Fig. 5. Risk parameter β and expected gross margin.

tion is tested by varying the value of β from zero to K16 million. The results of this sensitivity analysis are presented in Table 6 and Fig. 5.

According to Table 6 and Fig. 5, expected gross margin rises initially when β increases from zero to K4 million. Then it remains the same until when it reaches K10 million. However, there is a slight increase in revenue when β increases further from K10 million to K16 million. As this increase in revenue takes place, the cropping pattern changes from diversified cropping of rice, sorghum and soyabeans to the specialization in the production of sorghum. This specialization in the production of sorghum. This specialization in sorghum, despite it being a low-valued crop, occurs because sorghum requires less soil moisture than any other crop in the Gwembe Valley. Moreover, the allocation of all land to the production of sorghum ensures the optimal utilization of limited soil moisture in the area which is caused by the stochastic nature of rainfall. To sum up, the results of this sensitivity test indicates that if risk-taking behaviour is on the increase, then in the context of no irrigation, land should be allocated to the crop that displays the least moisture requirement. In this case it is sorghum.

CONCLUSIONS

The objectives of this paper are:

- to identify optimal cropping pattern in the Gwembe Valley using the Target MOTAD Model;
- to indicate implications of the results of Target MOTAD Model on household food security; and
- to test whether households in the Gwembe Valley are risk averse.

Results of the model indicated a cropping pattern of sorghum, rice and soyabeans as opposed to the existing cropping pattern of maize, sorghum, cotton and sunflower. The absence of maize, cotton and sunflower in the model solution has implications on household food security in the Gwembe Valley. One of them is that households in the study area might have to import these crops in order to meet household food security needs created by the absence of these crops in the study area.

The Target MOTAD model results confirm that households in the Gwembe Valley are risk averse. This is proven by crop diversification which is observed both under existing and the model solution's cropping patterns.

Sensitivity analysis, which was undertaken to test the validity of the results of the model, indicated that the model was very sensitive to variations in cost of credit and cost of risk taking. This means that when the cost of credit and the cost of risk are very high, the model solution indicated a cropping pattern of allocating all resources to the production of sorghum. This is because sorghum is the most drought-resistant crop in the study area.

APPENDIX

TABLE A1

Expected gross margins and deviations for selected scenarios, Scenario 1

Year	State of nature (rainfall) (mm)	P_{ik} Probability of state of nature (%)	Maize			Cotton		
			G_{ijk} (K)	$P_{ik}G_{ijk}$ (K)	Y_{ik} (K)	G_{ijk} (K)	$P_{ik}G_{ijk}$ (K)	Y_{ik} (K)
1	945	0.12	400	48	211	150	18	−30
2	405	0.09	50	5	−139	100	9	−80
3	1035	0.06	300	18	111	250	15	70
4	585	0.20	150	30	−39	200	40	20
5	675	0.23	250	58	61	250	58	70
6	585	0.23	150	30	−39	200	40	20
Total			-	189		-	180	

$Y_{ik} = G_{ijk} - \Sigma(P_{ik})(G_{ijk})$

TABLE A2

Expected gross margins and deviations for selected scenarios, Scenario 2

Year	State of nature (rainfall) (mm)	P_{ik} Probability of state of nature (%)	Sunflower			Sorghum		
			G_{ijk} (K)	$P_{ik}G_{ijk}$ (K)	Y_{ik} (K)	G_{ijk} (K)	$P_{ik}G_{ijk}$ (K)	Y_{ik} (K)
1	675	0.23	200	46	58	300	69	124
2	495	0.12	50	6	−92	150	18	−26
3	405	0.09	20	2	−122	150	14	−26
4	1035	0.06	300	18	158	200	12	24
5	855	0.12	200	24	18	200	24	24
6	675	0.23	200	46	18	300	69	124
Total			–	142		–	176	

TABLE A3

Expected gross margins and deviations for scenarios, Scenario 3

Year	State of nature (rainfall) (mm)	P_{ik} Probability of state of nature (%)	Wheat			Soyabeans			Rice		
			G_{ijk} (K)	$P_{ij}G_{ijk}$ (K)	Y_{ik} (K)	G_{ijk}	$P_{ik}G_{ijk}$	Y_{ik}	G_{ijk}	$P_{ik}G_{ijk}$	Y_{ik}
1	675	0.23	0	0	−84	150	35	23	0	0	−54
2	495	0.12	0	0	−84	0	0	−127	0	0	−54
3	405	0.09	0	0	−84	0	0	−127	0	0	−54
4	1035	0.06	300	18	216	350	21	223	500	30	446
5	855	0.12	200	24	116	300	36	173	200	24	146
6	675	0.23	0	42	−84	150	35	23	0	0	−54
Total			–	84		–	127		–	54	

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