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A LINEAR PROGRAMMING MODEL FOR PEASANT AGRICULTURE IN KENYA

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by

Judith Heyer

A. Introduction

The object of this paper is to present an outline of a linear programming model for use in the analysis of limits on production among peasant cultivators in Masii location, Machakos District, Kenya. The data for the model were collected during the agricultural year 1962-3, and the analysis of these data is still in progress. The final details of the model to be used are not yet decided, but its basic features are now clear, and tentative decisions have been made for the rest. It is proposed to present the model as it stands and to indicate some of the problems encountered in its formulation.

Linear programming is a special case of an input-output model in which there is choice. It is also a special case of mathematical programming in which the functions used are linear. Where a problem can be stated as a problem of maximising or minimising a linear function subject to linear constraints, where there are several alternative possibilities with respect to these constraints, the problem can be formulated as a linear programme. In the present model the problem is to maximise production subject to resource constraints and certain basic minimum and maximum requirements of the farmer, where there are several alternative crop and other activities that can be pursued. The objective function or criterion is the value of production and this is used as a yardstick for choosing between various alternative possible activities. The resource constraints include labour and land constraints, and other factors which limit production. The alternative possible activities include various crop activities, livestock activities, and non-farm activities between which there is a choice for the farmer. Production is extended to include the outputs of the non-farm activities as well.

The programmes will be solved for several individual typical farms, rather than any average situation, and the results from these will eventually be considered as a whole.

The assumptions of linearity do not present major difficulties in peasant agriculture. For the objective function to be linear, it is only necessary that the outputs per unit of the activities remain constant irrespective of the level at which the activities are operated, i.e. the average expected value of an acre of output does not change with the number of acres that are grown. For an individual farmer this is usually satisfied, but if the programmed solutions are likely to be implemented on a widespread basis, this should be investigated further. On a macro-scale, the number of acres

that are grown is very likely to affect the value of an acre of output, a large acreage tending to depress the average price over the years, and vice versa. It is quite possible to programme for a range of possible values where this occurs, to see how stable the programme is, and what changes might take place if the value of output is affected in this way. This procedure will be followed in the model wherever the linearity condition is violated.

The other assumption is that the production functions with respect to the resource constraints are linear over the relevant range, i.e. the input-output coefficients are constant per acre. This is generally so, partly because the ranges in question are small. Where there are cases of increasing or decreasing returns, these functions can be treated as series of straight line approximations over given ranges.

Linear programming solutions give the maximum value of output attainable within the given resource constraints, and the farming pattern required to achieve this. The solutions also show which resources are effective limits to production in their order of importance. In the final solution, the marginal return for an extra unit of the resource is shown for each resource. The higher this is, the more limiting the resource. Where this is zero, the resource is not limiting at all.

B. The Objective Function or Criterion Equation

The objective to be maximised in this study is production. It is important to establish whether this is likely to correspond to the objective of the farmers, and whether there are likely to be major qualifications. The objective of peasant farmers is often to maximise production, subject to certain qualifications: i.e. provided that they do not have to take high risks; provided that they do not have to reduce their numbers of cattle below a certain point; provided that they do not have to work too hard; provided that they do not have to sacrifice certain local traditions and customs; etc. etc. There are situations where the farmers are not motivated by the desire to maximise production at all. The central objective can be minimum risk, subject to a certain minimum level of income; or minimum work subject to a certain level of subsistence.

In Masii location, and the present model, farmers are more concerned with increasing production than with anything else, but there are two important qualifications:

- (a) a certain maximum level of risk
- (b) a certain minimum food supply

Hence the model has maximum risk and minimum food supply constraints in addition to the value of production as the objective function. For the purposes of the analysis, these additional constraints can be included or excluded at will.

C. Resource Constraints

The resource constraints are the limits on production. It is important to decide which of the resources used on the farm might be effective limits on production, and to discard those which could not possibly be scarce. A short-list of probable limits on production has to be prepared and from these the computer can select the operative ones in order of importance.

The most important resources in peasant farming of the kind observed in this study, are labour and land. Within each of these categories it is necessary to decide how many subdivisions should be considered. Neither land nor labour can be treated as homogeneous resources in production. Land should be divided up according to soils, topography, past history and improvements on the plot and according to the different seasons in which it is available for use. There are two seasons in the year in Masii, and two crops can be grown in a year. The major rains, contrary to the rest of Kenya, are the November Rains, or 'Short Rains', and the minor rains are the March Rains, generally known as the 'Long Rains' in the country as a whole. Land in the short rains is not interchangeable for land in the long rains, and one has to make sure there is no over-lapping of crops from one to the other unless this is explicitly allowed for. It is difficult to consider different types of land in detail, and in this model the only distinctions made in this respect are between arable and non-arable land. The difficulties in going into further distinctions involve not only the assessment of available resources, but also the corresponding input-output coefficients for these. Hence it is assumed that soil differences, topographical differences, and the past histories of plots are all of minor importance and can be neglected. In Masii location, among the farms studied, topographical differences are not marked, but there are two distinct types of soil, one more sandy than the other, and there is a considerable variation in the quality of soil conservation works on different plots, soil erosion and the extent to which the fertility of the land has been depleted or maintained on different plots. The soil differences are taken into account purely verbally, in noting unexplained yield differences between farms; the land improvements or disimprovements tend to be uniform within a farm, but different between farms, and thus they can be noted as characteristics of the individual farms but do not need to be incorporated in the models for each farm. Thus, land constraints in the model are: short rains arable, long rains arable, and non-arable, as you will see in appendix II

Labour is even less homogeneous than land. It is in the nature of agricultural production that labour requirements are seasonal. Labour in one month cannot be used in another month. Labour available in July, a slack period, cannot be saved up and used for ploughing in October. Thus it is necessary to distinguish between labour at different times of the year, in the model. It is assumed that it is immaterial at which end of the time-period the labour input takes place, but that the output is affected if the labour input takes place outside this period. Thus if the month of March is treated as one time-period, it must make no difference to the output if the labour input concerned takes place at the beginning of March, or if it is delayed until the end of March. But it cannot take place in February or April. Often a month is too long a period. It does materially affect the output at which part of the month a crop is planted, for instance, and thus it is necessary to take smaller periods than a month in this model. In the preliminary analysis labour was split into 22 different periods over the year, but not all of these 22 labour resources needed to be included in the model as limits. Many of them could never be limiting, and only a few remained as possible constraints. With two growing seasons during the year, there are two ploughing periods, two weeding periods, etc. At ploughing time labour is scarce; also at weeding and harvesting times. The timing of both ploughing and weeding is critical in Masii. The rainfall pattern is such that it makes a considerable difference to output if the crop is planted, say, more than nine days after the rain begins; and it makes a further big difference if the crop is planted as much as 16 days afterwards. Thus a distinction is made between labour in the first 9 days after the rain; labour 10-15 days after the rain; and labour later than 15 days after the rain. It is vital for a farmer to do as much ploughing and planting (these are done together as one operation) as possible in the first 9 days; then as much more as he can in the next 10-15 days; and then to decide if it is worth planting at all after that. In the model there are two labour constraints at ploughing time in the short rains. After 15 days the farmer can plough as much as he likes. The constraints are all shown in appendix II.

There are similar considerations for weeding: early weeding is advised, both for its beneficial effects on the crops, and because it decreases the total amount of weeding required. Late weeding is hard work because the weeds are well established. Hence the model distinguishes between early weeding 27-44 days after the rain; weeding 45-65 days after the rain; and very late weeding after 63 days, on which there is no limit. There are two weeding constraints.

Harvesting must take place within a certain period for some crops. The first crops in this case present no problem unless there is a very great deal of beans, millet and early sorghums planted on the farm. The maize harvest is the only one in the first season that is rushed. It is important to get the

maize in before it is spoilt by the March rains; and it is important to get it in time to plant more crops in these rains. March is thus divided into three parts: early March before the rains when maize must be got in and early crops planted to get the best results; mid-March when planting takes place in earnest with average results on the crops; and late March when the late planting takes place for poor crops. Maize harvesting continues into April by which time it is so late that there is no point in hurrying.

The second season crops are less extensive than the first, partly because the rain is poorer, partly because the maize cannot all be cleared away in time for second-season planting, and partly because there is one crop, pigeon peas, which extends through both rains, taking up some of the land. Weeding in the second season is not especially demanding and there is no constraint on weeding labour here.

The last peak period in the year comes with the pigeon pea harvest in September, when the crop needs to be harvested before the next rain begins, and in time to prepare for the beginning of the next year. This brings one more restriction into the model: pigeon pea harvesting labour in September.

Finally, the introduction of cotton, a new crop in the area, changes the labour pattern in the months April-August. The cotton harvest is continuous over these months, and demands a great deal of labour. Thus, a possible limit on the increased production of cotton is labour constraint in the model.

You will see a full list of labour and land constraints in appendix II.

The other resources used in peasant agriculture are working capital in the form of seeds, fertilisers, manure, pesticides, insecticides, casual labour, etc.; fixed capital such as tools, implements, oxen, stores, etc; fixed capital in land improvements, soil conservation works, etc.; and managerial or entrepreneurial ability.

Working capital does sometimes cause difficulties, and cash is not always available at the right time of the year for this. This is particularly true for casual labour which is used almost entirely according to the amount of cash or payments in kind available at the time. If the solutions to the model indicate that it would be worth employing casual labour at certain times of the year, or that it would be worthwhile for the families that provide casual labour to withdraw their labour at these times, it will be necessary to consider the constraint of cash availability. If the marginal return from an extra unit of labour is greater than the casual labour payment rate, in critical periods, then there may be a case for short-term loans to the farmers. Otherwise short-term cash availability is not important, and not considered in the first programme

until the extent of the labour shortage at critical periods is known.

The other important shortage of working capital is the periodic shortage of seeds after years of poor crops and famine, which occur fairly frequently in this area. In some years the availability of seed has quite definitely determined the crops that have been planted, and the varieties of seeds have not always been appropriate either. After serious famine, the only maize seeds that are available, for instance, are either from other parts of Kenya, or from America. It hardly needs emphasising that these seeds are not generally suited to the semi-arid conditions in this area. The local strains that have evolved which are in some ways suited to the area, are seriously depleted in famine years. This constraint on production can best be dealt with on a District level, not so much as a problem of a cash shortage, as a problem of preserving seed supplies, to be distributed free if necessary. It is not included as such in the model - it is a problem that only occurs in some years anyway - but it is explicitly discussed elsewhere in the analysis.

Fertilisers are not used at all, and it is unlikely that their use would be warranted in an area where yields are so badly affected by inadequate rainfall. Manure is used, but only within the farm from farm livestock. The model does not consider the purchase of manure as a possibility, but the value of manure is included in the output of the livestock activities, and in the input of the crop activities. Pesticides and insecticides are used in small quantities, but the amounts of cash involved are so small that they can hardly be considered limiting.

Fixed capital in the form of oxen and ploughs is an important constraint on some farmers, and fixed capital in the form of dips, milking sheds, improved cattle, cotton spray pumps, and other more advanced investments is a possibility for a very different class of farmers. Only the very poor have no oxen or plough, and there is no doubt that their production suffers considerably from this. Their crops are usually planted late, after everyone else has finished using their oxen and ploughs, or they pay very high prices to compete with the demand for oxen and ploughs early in the rains. The people who can pay high prices for the service of oxen or ploughs can usually afford to own oxen and ploughs themselves anyway. The others who cannot afford to pay are nearly always the very bad farmers, who suffer as much from poor husbandry as from poor land or poor rains. Lack of oxen and ploughs does make their situation worse, but it is doubtful whether people would benefit from being given loans to get oxen and ploughs alone. They would benefit far more from learning to improve their farming standards, and learning the importance of good husbandry. If loans to these farmers were to be considered it would have to be in conjunction with close supervision of farm practices if it were to have any success. Managerial ability is much more important a limit than fixed capital in these cases.

The other class of fixed capital for more advanced systems of farming, is quite different. The farmers who consider building dips, milking sheds, buying improved cattle, and using cotton sprays, are good farmers who can make a success of these enterprises. But those who can succeed in these enterprises, have also succeeded in the traditional ones in the past, and are relatively wealthy. They can all muster enough cash if they want to, and they can all do these things without credit if they have to, in Masii. Those who cannot, probably do not deserve to go into these new enterprises anyway. This natural selection is likely to be more efficient than the arbitrary selection of the Agricultural Department deciding who deserves credit, and giving it to people who cannot use it, and finding that they fail to repay or to benefit. Further, the cost of credit is much better removed by encouraging a man to use his own means instead. There is insufficient understanding among the farmers of what is involved. They all think they would like credit, and they think of it as easy money without any real obligation to repay.

Land improvements do not warrant inclusion in the model, as they can be implemented by using off-peak labour with a zero opportunity cost. There are no serious restrictions on this kind of improvement.

Managerial ability, one of the most important of all factors, is not included directly in the model, but it comes in the input-output coefficients used for any particular farmer, and it should be considered in assessing the advised patterns of farming in the solutions, to decide if they are too complex, or outside the managerial abilities of the farmers. They may be all right for some, but limited by managerial ability in other cases, in which case additional restrictions might be included in the programme for poor managers: minimum number of different activities, and/or exclusion of 'modern' activities such as cotton.

Thus, the model includes only labour and land restrictions in the first place, with the possibility of including cash at different times of the year if casual labour proves to be worth employing.

Levels of Resources

The amount of land available can be measured and the problems of definition are straightforward. The amount of labour available requires definition: what constitutes a working day, a working week, and how much leisure time is necessary; what allowances to make for communal labour exchanges which are not always reciprocal; what should be the standard unit of labour, and how should men, women and children, and different age groups be compared. In the present model, an 8-hour day is taken, and a 6-day working week, allowing very little time for leisure because these are peak periods where labour is limiting, and the pressure is considerable. People are prepared to work hard for important periods, and then slacken at off-peak times. However

some adjustments have been made for the effects of prolonged hard work, and allowances have been made in certain other periods for widespread sickness which appears to be seasonal. It was interesting to observe a high incidence of sickness towards the end of the weeding period. After hard work ploughing, followed by hard work weeding, many people broke down with endemic diseases. This seems to indicate some sort of physical limit that had been reached, and bears out the assumptions of what the physical maximum is. Communal labour exchanges have been treated as reciprocal, with the additional consideration that in periods of unforeseen pressure these can be called upon to provide the flexibility required in any programmed plan. The standard unit of labour taken is somewhat arbitrary, as there are no measures of work rates, or comparative productivities, but allowances have been made for age, and for sickness and pregnancies, in assessing the appropriate weights. The actual levels of available resources vary from farm to farm of course.

Restrictions on Resources

The resources themselves may be subject to certain restrictions. For example, land tenure arrangements may affect the use to which land is put, and conventional divisions may restrict the interchangeability of male and female labour. These were investigated and considered for the present model, and it was decided that in no case in question was land tenure restrictive, but some allowance for the division of labour between the sexes might be made on the more backward farms. It has disappeared on the majority.

D. Alternative Activities

The alternative activities in the model are the alternative possible enterprises or ways of using resources in production. It is here that the element of choice enters, and that the farmer has to make decisions. He has to decide what crops to grow by what methods, and he has to decide how much of his resources should be used for livestock and non-crop enterprises as well. The linear programming model selects the best combination of activities to maximise the value of production.

In this model there are certain basic crops and crop mixtures considered, and for each of these there are various methods of treatment open to the farmer. The crop mixtures considered include maize, beans, pigeon peas, millets, sorghums, improved varieties of these crops and many mixtures of some or all of them. A full list is given in appendix III. Each of these crops can be grown more or less intensively, early or late in the season, and with or without certain optional treatments. The important different methods of growing the crops are distinguished, and the choice is posed as a choice between each crop grown in any of several different ways. The appendix shows these alternatives in detail.

In addition to the basic food crops, there is the possibility of growing cotton, a new crop in this area. Two cotton activities are included in the model, the first one giving cotton priority over all other crops: early planting, early weeding, and intensive cultivation throughout. The second cotton activity assumes that food crops are given some priority and cotton does not get such good treatment as a result.

Various other possible new crops are also included in the model. Commercial varieties of beans, castor, citrus fruits, grains, coriander, chillies, onions, vegetables, etc. All of these and possibly more, are alternatives to the crops grown at present. It is difficult to get input-output data for these crops, since they are not already grown very widely in the area, but estimates will be used from the available information, adjusted to peasant conditions known from the rest of the study.

Crop activities will be accompanied by cattle and livestock possibilities, sisal, and various other local income-receiving activities such as crafts, contract services, beer brewing, petty trade, etc. Alternative marketing policies for the individual farmers will also be considered.

The choice of patterns of farming is limited by certain agricultural requirements as to crop rotations, and maximum proportions of soil depleting crops. The model will include these as minimum requirements, but many solutions will be computed in which these are neglected. At present little thought is given to these considerations in Masii location. I knew of no case where a crop rotation in any sense was practised. Long-term depletion of the soils is not considered by the farmers, except through visible erosion against which soil conservation measures are taken.

E. Input-Output Coefficients

The input-output coefficients form the bulk of the data required for activity analysis, and they present the major data problems. It is necessary to know exactly how much of each resource is used per unit of activity. The column of resource requirements is usually called the activity vector, and the array of all these columns is called the technology matrix. They are all technological coefficients.

Input-output coefficients for land are difficult to measure, because there are no official or unofficial land measurements in the area. Each small plot, or half-plot under a different crop activity had to be measured in the field.

The unit of analysis used is one acre. Each activity is measured by the number of acres involved. Hence all the input-output coefficients for land are one, and all the other input-output coefficients are expressed per acre of activity.

Labour coefficients are even more difficult to measure than land. It takes a great deal of time and patience to record exactly how much labour is spent on each particular activity at different times of the year, and there are the additional problems of standardisation of labour units already mentioned.

Fixed and variable capital requirements are relatively easily assessed, where necessary, and the data on these is there for use as required.

Input-output coefficients were measured in detail for actual activities being undertaken on holdings studied in 1952-3. Abstractions from these are being made to get standard activities without the irregularities of the particular year, and without the minor distinctions that can be neglected. Programmes are done for individual case-studies, so to some extent the actual activities observed on the individual farm are kept to, but some amalgam activities and some activities observed on other farms are also used.

Accuracy of Input-Output Coefficients

Obviously the input-output coefficients for peasant farms are subject to all kinds of inaccuracies, but if the orders of magnitude are right, and the comparative relationships are right, it is possible to get meaningful and accurate programming results in spite of quite considerable inaccuracies in the data. The figures need to be treated with care, using a good deal of judgement and knowledge of the local situation. Where this is not done, it is possible, as with any other analytical method, to get meaningless results. One thing which is essential, is that one uses input-output coefficients from ordinary peasant farms, and not from experimental stations or exceptionally good small-holders. The differences between these and ordinary peasant routines and standards are so large as to make them untransferrable. For example, for cotton harvesting, the local official estimates for a particular yield and acreage were: a maximum of 30 days labour; my own observation for the same yield and acreage was 160 days. This is a somewhat extreme case, but shows the orders of magnitude involved. I have good reason to believe that my own figure was the more correct one.

F. Valuation of Output

The yields and prices corresponding to units of output give the criteria for choosing between the activities with respect to resource use. They are key variables in the model.

It is difficult to decide on one average expected yield, and difficult to decide on one price to take as an average over the years. Fortunately though, yield-price combinations vary less than the yields and prices taken separately. In Masii, there is usually a relationship between the two: high prices are associated with low yields and vice versa. For example, local maize prices vary from 52/- to 16/- from year to year, whereas yields on one farm may vary from 2½ to 8 bags. Returns at the two extremes are thus 130/- and 134/-. The variations in the middle ranges may be considerably wider than this, but not as great as the variations in prices alone.

In deciding what prices to take, future market trends are considered, as well as variations from year. The influence on price of any widespread adoption of the solution to the programmes is also taken into account.

Subsistence or Producer or Consumer Prices

Producer prices are an indication of the value of marketed produce to the farmer who has a surplus. Consumer prices are an indication of the value of growing crops for home consumption rather than buying them. Subsistence might be valued higher still as the highest prices that would otherwise have to be paid for crops to feed the family, or even as the price of not getting any food at all in times of famine. In this model producer prices are used, with a basic minimum requirement already mentioned, that the farmer produces his own subsistence requirements of food.

G. Sociological Factors in the Model

There is a common complaint that linear programming is too precise and too mathematical to deal with the problems of peasant farmers where sociological factors play such an important part. This is partly due to an insufficient understanding of the scope of the model. The sociological factors can be extremely important and their neglect can lead to economic statements of little practical value. It is important to know whether if a man plants a cash crop, such as cotton, his brother employed in Nairobi is likely to return and claim half; it is important to know about cattle rights, and how far a man can control the number of cattle on his holding; it is important to know whether a man who gets rich will be ostracised by the community and forfeit his rights to communal labour; it is important to know if crops have a non-economic value in the tribe; etc.etc. All of these factors can be incorporated into the model, and they can even be assessed: the increase in production that would result from their absence can be shown.

H. Variable Coefficients and Variable Values

In some cases values seem so indeterminate that one hesitates to judge an activity entirely by one value. A technique has been developed to vary the values attributed to an activity, and to see how widely the values can vary before the solution to the programme is affected. This can be carried further to see at what critical values the solution changes, and what the change is like. Often it is found that solutions are remarkably stable over wide ranges, and it is unnecessary to rely on one precise value: all that is needed is a range within which that value falls. In this model, several values will be varied where there is doubt as to their reliability.

A similar procedure will be followed for uncertain input-output coefficients.

I. Dynamic Considerations

In this model, the time period used is one year, and the effects of one year's results are not taken into account for the following years. It is important to remember however that there might have to be sizeable adjustments in any one year because of the unexpected events of the previous year. This might well affect the average maximum production attainable. This has already been mentioned in the case of seed shortages after famines. Similarly price changes as a result of the adoption of the programme in the area, and also improvements in health and hence additions to the labour resources must be mentioned.

Capital availability is even more critically affected by the success of the previous year, and questions of timing are basic to capital problems.

Finally changing technology and improving levels of husbandry cannot explicitly be brought into a one-year model. There is no doubt that this is an important limitation to the model. The assumption of constant given input-output coefficients and constant activities is unrealistic for any length of time.

These dynamic factors will be discussed verbally in the analysis, but cannot be incorporated into a static model such as this.

J. Solutions to the Programmes

The model will be solved for different assumptions. These solutions will show the following:

- (a) optimum patterns of farming under different assumptions
- (b) marginal revenues attached to units of each resource
- (c) underemployment of resources (from b)
- (d) limiting resources in order of importance (from b)
- (e) effects of changes in: resources, prices, input-output coefficients
- (f) effects of errors

Thus it will have normative value showing the optimum systems of farming, and descriptive value showing the limiting resources. The possibilities of changing these limits can then be considered, and the effects of postulated changes can be shown in further solutions. Information on the costs of changing limits can lead to conclusions about whether these changes would be worth while. Similarly, thought can be given to the use of underemployed resources. Further analysis can be done on the effects of changing the input-output coefficients, for example through the introduction of labour-saving tools.

The model has great potential. It remains to be seen whether it can be used effectively enough for the results to be convincing.

APPENDIX I

Basic Equations of the Linear Programming Model for Peasant Agriculture

Problem:

A. to maximise the objective function

$$c_1 x_1 + c_2 x_2 + \dots + c_n x_n$$

where c_j = net value of unit of output of activity j

x_j = level of output of activity j

n = number of alternative activities in the model

(maximise net value of production);

B. Subject to the conditions:

$$x_1 > 0$$

$$x_2 > 0$$

⋮

⋮

⋮

$$x_n > 0$$

(Non-negative outputs)

C. and:

$$a_{11} x_1 + a_{12} x_2 + \dots + a_{1n} x_n \leq b_1$$

$$a_{21} x_1 + a_{22} x_2 + \dots + a_{2n} x_n \leq b_2$$

⋮

⋮

$$a_{m1} x_1 + a_{m2} x_2 + \dots + a_{mn} x_n \leq b_m$$

where a_{ij} = number of units of resource i to produce one unit of output j

b_i = maximum number of units of resource i available

m = number of resources in the model

(use not more than the amount of the resource that is available)

D. and:

$$s_{11} x_1 + s_{12} x_2 + \dots + s_{1n} x_n \geq r_1$$

$$\begin{array}{r}
 s_{21} x_1 + s_{22} x_2 + \dots + s_{2n} x_n > r_2 \\
 \vdots \\
 s_{k1} x_1 + s_{k2} x_2 + \dots + s_{kn} x_n > r_k
 \end{array}$$

where s_{lj} = number of units of basic requirements in one unit of output j

r_l = minimum basic requirement of farmer

k = number of basic requirements in the model

(Farmer stipulates basic minimum requirements)

APPENDIX II

RESTRICTIONS IN THE MODEL:

Resource Restrictions:

- Land - Arable land Nov. rains b_1
- Arable land Mar. rains b_2
- Non-arable land b_3
- Labour - 9 days after beginning of rain b_4
- 10-15 days after beginning of rain b_5
- 27-44 days: early weeding b_6
- 45-63 days: middle weeding: b_7
- Early March: early planting b_8
- Middle March: middle planting b_9
- End March: latest planting b_{10}
- Per month cotton harvest b_{11}
- September: pigeon pea harvest b_{12}

- Possible additions - Oxen
- Plough
- Cash at different times of year

- Possible Refinements - Male/Female labour division
- Soil differences
- Land improvements/disimprovements

Minimum and Maximum Requirements:

Minimum subsistence food s_1
Maximum level of risk s_2
Maximum acres of maize (fertility condition) s_3

Possible additions - Minimum number of cattle

APPENDIX III

ALTERNATIVE ACTIVITIES

Crops and Crop Mixtures:

Maize	Millet
Beans	Millet/Peas
Maize/Beans	Wimbi/Peas
Maize/Peas	Millet/Sorghum/Peas
Maize/Beans/Peas	Wimbi/Sorghum/Peas
	Millet/Sorghum/Wimbi/Peas
Cotton	
Commercial beans	Improved varieties:
Grams	Taboran maize
Castor	Katumani maize
Chillies	Tada sorghum
Onions	etc.
Corriander	
Citrus fruits	

Various Methods of Growing Crops:

- (a) early, medium, late planting
- (b) early, medium, late weeding
- (c) high, low or medium quantity of weeding

Combinations of these three with the different crop mixtures give up to 50 alternative possible activities to be considered, some of which can soon be rejected as obviously inefficient from the start.

(Note: the number of activities in the final solution can never be more than the number of restrictions, but some can only be rejected by the computer, not by simple inspection).

Further variations in methods of treatment include varying intensities of harvesting, but data inadequate here; various amounts of manure and fertiliser; various amounts of pesticides applied. Manure and pesticides will be considered for the model, but not fertilisers.

Livestock Activities:

Oxen	Poultry
Grade Cattle	Goats
Sahiwal Cattle	Sheep
Other Cattle	

Various different policies and ways of looking after these.

Non-Farm Activities:

Sisal	Brick making
Ox-cart Hire	Marketing activities
Beer Brewing	Petty trading
Woodwork	Casual Labouring
House-building	Labour employment