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ALTERNATIVE DEVELOPMENT STRATEGIES FOR LOWLAND MACHAKOS FARMS

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The aim of this paper is to show how a linear programming analysis of a group of small farms in lowland Machakos is able to throw light both on the potential for improvement through the modification of farm production constraints, and on the relative merits of alternative crop innovations on the farms.[1]

The paper begins with a description of lowland Machakos and a summary of the linear programming model and the data on which it relies. A discussion of the results of the farm production analysis follows this, and the paper then ends with a summary of conclusions about the use of linear programming in the analysis of small peasant farms.

1. Lowland Machakos

Lowland Machakos is an area of low and uncertain rainfall and poor soils, marginal for agriculture, but too densely populated for the people to depend on livestock activities instead. It is an area where a semi-subsistence agriculture produces substantial surpluses in years when rainfall is high, but where there are serious famines when rainfall is low, roughly once in every five years. Masii, the location of the study, is about 18 miles east of Machakos town, in the centre of the district. It has a population density of over 300 per square mile and a livestock population of nearly 200 as well. The average holding is roughly 10 acres, some of it unusable gullies and sand rivers, as much as possible cultivated, and the remainder poorly eroded 'grassland' left for cattle. The group of farmers studied cultivated from ½ to 6½ acres each, and had widely varying residual areas of grazing for their undernourished cattle. The ownership of both arable and grazing land is individual, or shared between brothers who will later subdivide. The traditional system, with its communal grazing rights, has been discouraged since the 1930's, as part of the Government soil conservation campaign.

The crops, grown almost exclusively in mixtures, are maize, pigeon peas, beans, finger millet, bulrush millet, and sorghum. Cassava, sweet potatoes, cowpeas, grams, melons, pumpkins, gourds, and bananas all appear in scattered patches, but these are minor and regarded as negligible in the mixtures treated here. The major innovation is cotton, which was reintroduced in Masii in 1962/63 after a gap of over 20 years.[2] The other important development has been in drought-resistant maizes which have been continually improved at the local experimental station, and which now appear to be attractive for field conditions on small farms.

There are two agricultural seasons each year in Masii, the major season from October-November to March, and the minor season from March to August-September again. Most crops are planted in October-November, but some can be harvested in time for a second planting in March, when maize and beans are grown. Cotton is planted in October-November and harvested from May to September. Pigeon peas also take two seasons in the ground.

Livestock are of very poor quality, but they are used for ploughing by everyone, and also for milk. One of their major functions, however, appears to be as a store of wealth, the family savings reserve. Goats and sheep are kept as well as cattle. Small quantities of manure find their way onto the land, but there are no crop rotations bringing livestock into a fully mixed farming pattern.

Sisal, which is used to mark plot boundaries everywhere, is a useful supplementary source of cash, particulary in times of famine. Decortication, mainly the work of women and children, takes place in seasons that are slack on the farm, and sisal supplies are too limited to occupy people for more than a small part of the year. Farmers and their families also engage in other part-time activities such as beer-brewing, petty-trading, and local crafts.

Masii is generally regarded as one of the more progressive of the lowland locations in the district, and both Masii and the area as a whole have a history of intensive administration and agricultural development, centred on efforts to arrest the gradual deterioration of the soil. Soil conservation work started in the 1930's and there was an unprecedented effort throughout the 1950s in Machakos, which is celebrated. Standards of cultivation are now high, and the extent of soil conservation works is impressive.

In Masii as elsewhere there is a keen demand for education, probably intensified by the poor quality of life at home, an active community organisation based on traditional clans, and an enormous amount of self-help activity directed towards the building of schools, roads, clinics, etc. It is against this background of intense pressure for a better life, combined with extremely adverse natural conditions that the analysis of production on Masii farms should be seen. While farming is still at the subsistence level, this is the result of adverse physical conditions rather than any lack of incentive to put in hard work.

11. <u>The Model</u>

The model used to analyse the group of farms was decribed in some detail in an earlier paper[3] and also in the full account of the final analysis.[4] Briefly, it involves the maximisation of the value of production, subject to resource constraints on the farm, given a range of alternative crop activities among which there is choice.

The model can be summarised as follows:

x_j is the number of acres of activity j;

A_{ij} is a matrix containing elements a_{ij} which represent the number of units of resource i used in the production of one acre of activity j;

b_i is the number of units of resource i available.

The model is used to show the way in which physical constraints limit production, the sorts of returns attainable, and the impact of cotton and drought-resistant maize, on Masii farms. In maximising the value of production the model gives results for farm patterns in which resources are optimally allocated between the crop mixtures considered, and in this sense it is unrealistic. But if it is remembered that the discussion is always in terms of attainable returns and income levels, and that in practice there is not very much difference between actual and optimal patterns, this does not present any serious difficulties.

The objective function maximised in the model is the market value of production. Although the economy is predominantly a subsistence economy it is assumed that market values do reflect adequately the values of the main crops grown. Farmers are well aware of market prices and have frequent contact with the market at all times. If market prices were substantially different from local values, they could specialise and exploit the difference. Otherwise, it seems fair to assume that their values are much the same.

The resource constraints considered in the model are land and labour at different times of the year. Management is also considered important, but this is treated by using different basic matrices representing different management levels, rather than directly in the model. It was not possible to quantify management factors sufficiently well to incorporate them directly as constraints. Capital was not considered a constraint, given levels of knowledge and techniques available in Masii at present. There is no reason why capital should not become an important constraint as research and education bring new possibilities within reach of Masii farmers in the future, though.

Activities between which there is choice with respect to the objective function include crop activities alone, mostly crop mixtures cultivated in different ways. Livestock and other activities which compete for labour or land are compared with crops activities through the shadow prices of resources involved in both, rather than directly, here.

The linear programming model involves various limiting assumptions, the most important of which are that there are no economies or diseconomies of scale, that input-output coefficients are fixed for any one programme, and that activities can be represented as discrete rather than continuous choices. Each version of the model is static, but it is possible to use the model parametrically, running series of programmes with changing assumptions about prices, input-output coefficients, etc. to introduce variations in basic conditions. The assumptions of constant returns to scale are more serious, although even here one can take discrete ranges of a non-linear function where scale effects are important. Within the range of farm sizes considered in this study, returns to scale could reasonably be considered constant, though. Discrete activity choices do present problems, making choices and farm patterns appear more rigid than in fact they are. There is little that can be done about this.

there was choice, and resource constraints. The procedure used for resource constraints was to programme for a range of land and labour resources in every case, assuming a given distribution of labour available through the year. As constant returns to scale were assumed, it was only necessary to programme for the relevant ratios of labour to land. The results for any particular combination could easily be deduced from these. The range for which most programmes were run was from 0 - 6 acres ofland with 1 unit of labour, a labour unit being an adult-equivalent available through the year. This corresponded to a range of 0.8 to 4.2 acres per unit of labour in the field.

More difficult was the treatment of the management variable. There was a wide variety of input-output relationships which necessitated a recognition of management variations. A given set of inputs produced substantially different outputs on different holdings, because factors other than those measured were also influencing outputs obtained. Land was measured in acres and labour in hours on different operations in different times. The quality of land and labour could not be taken into account. Other factors excluded were the quality of seed, the density of plant populations, the efficiency of pest control measures, and the condition and training of oxen in the ploughing team. The most important of the excluded factors were felt to be the quality of land, the condition and training of oxen, and the methods and intensity of work put in per hour. All of the items excluded were lumped together in a residual 'management' variable, the argument being that themost important items were susceptible to change and depended on whether the farmer had managerial ability or not. These 'management' differences were incorporated in 5 hypothetical management levels, from among a range of input-output relationships observed. For each management level input-output relationships were changed. These hypothetical management levels were chosen in preference to the more usual procedure of taking typical farms, as it was felt that this accentuated the real differences involved.

Crop activities were defined according to the time of planting, the time and intensity of weeding, and the crop mixture concerned. Activities have to be discrete points rather than continuous production functions, as already mentioned, and it is necessary to decide how fine the distinctions should be. Here, three different times of planting were allowed, and three different times and intensities of weeding. Crop mixtures were defined by the crops they contained, but no variations in crop proportions were allowed. There are problems involved in translating field observations into activity vectors, but these are too technical to discuss in detail here. On the whole, frequency distributions of individual coefficients were used, and modal values then taken for the model.

IV. Some Major Analysis Results

The linear programming model well suited to an analysis of constraints that operate on farm systems, their relative importance, and theyway in which they govern production patterns. It is also valuable as a means of identifying optimal farm systems, in different situations, and thus as a means of comparing alternative innovations that are possible.

In lowland Machakos the alternative production possibilities are limited, and the problem of resource allocation does not appear to be a complex one. It was felt that there was more to be gained from a detailed analysis of constraints, and a thorough understanding of the working of the farm systems, and attention was therefore focussed on constraints. Nevertheless, there were two important innovations which were investigated, cotton and drought-resistant maize. There is thus some analysis of alternative farm production patterns in addition to the major analysis of constraints.

The detailed analysis, in which many different situations were covered, would take far too long to present fully here. Only some of the more important results are summarised to give illustrations of the sort of results that were obtained.

a) Returns to Land:

Diagram 1 shows the shadow price per acre of land over the range of land/labour ratios found in Masii, when traditional food crops alone are grown, assuming the model level of management. Shadow prices are shown for high rainfall, average rainfall and low rainfall years. At high labour/land ratios shadow prices in the different rainfall conditions vary substantially, but as lower ratios of labour to land are reached the values converge. When cotton is introduced, the shadow price of land at high labour/land ratios rises considerably, beginning above Sh. 500/- in the high rainfall years, but after $1\frac{1}{2}$ acres per unit of labour there is little difference between the value with cotton and without. When Katumani maize, the drought-resistant maize, is allowed, land values show a general tendency to increase, particularly in the low rainfall years.

These shadow prices can be compared with the value of land in alternative uses. As the sale of land in lowland Machakos is rare, and little renting or hiring of land takes place, there is little to be gained from a comparison between shadow prices and market values though.

The major alternative use for arable land in Masii is in livestock, and some farmers still keep livestock on part of their arable land. It is not easy to estimate returns to livestock, but rough estimates from Masii field data suggested a maximum of Sh. 60/- per acre of arable land, in years when rainfall is high. It does not thus appear to be worth keeping livestock on arable land in Masii, except at land/labour ratios considerably higher than those found in general, and while livestock do sometimes compete with crops, they are much more often kept on poorer land that is not fit for cropping at all.

This comparison takes livestock as they are at present, and it is quite possible that improved livestock could yeild higher per acre returns.

It is also possible that livestock could make a valuable contribution in a rotational system including fallow breaks on arable land. But until these alternatives are investigated, it appears that livestock cannot compete with crops on Masii arable land.

b) Returns to Labour:

We consider here the value of labour permanently on the farm, labour that is available throughout the agricultural year. The role of labour at different times of the year is discussed in the next section. Here again it is interesting to compare the average return over the year with alternative possibilities.

Annual returns to farm labour vary as Deagram 2 shows. Returns per labour unit are shown for different acreages of arable land, in high, average, and low rainfall years, for systems with and without cotton. (Note the relatively small improvement when cotton is grown. This is brought up later in the paper.) Even with 6 acres of land per unit of labour, a man can only get Sh. 400/-, Sh. 700/- or Sh.900/-, depending on rainfall conditions. This is equivalent to Sh.32/-, Sh.59/- and Sh.75/- a month, including the value of food, and only with relatively high land acreages. These returns can be compared with wages of Sh.50/- and Sh.70/- in Masii, and anything from 120/- in Kenya's urban areas.

The farm returns given are for model levels of management but the model level is likely to be comparable with minimum wage jobs. People with higher management abilities can undoubtedly command higher wages too, and the opposite is probably true for those whose management abilities are poor. They might find it difficult to get a job at all.

The figures suggest that farming is unattractive in Masii, and this is born out by the fact that about 67% of Masii's adult males are absent at any one time. For those who remain, and for the women who make up the majority of farmers in Masii, the alternative opportunities are few. It is extremely difficult for a peasant woman to get employment elsewhere, and many of the men who are left are likely to be unemployable too.

c) <u>The Role of Land and Labour in Determining Production Patterns</u>:

The way in which labour and land govern production patterns is shown in Deagram 3 for the high rainfall situation in which cotton and traditional food crops are allowed as activities between which there is choice. Production patterns that are optimal change as the ratio of land to labour increases, as shown. Deagram 4 shows the corresponding changes in the shadow price values of constraints.

In Diagram 3, crop mixtures are identified as shown in the key. The groups of letters associated with the food crop mixtures show whether the particular mixture is planted early (E), medium (M), or late (L); weeded early, medium or later; and weeded high (H), medium (M), or low (L). With cotton the time of weeding distinction is slightly different, the numbers referring to early and medium weeding (1), and medium and late weeding (2) respectively. Cotton is generally weeded twice in Masii.

Optimal production patterns change as different constraints become limiting. The levels at which the differnt limits enter are indicated on the right of the diagram, with land always limiting, then each of the 7 labour constraints entering in turn. Early planting labour is the first to limit, at less than ½ an acre, and the production pattern then changes from early planted cotton alone to some early and some medium planted cotton. The medium planting constraint limits next, and some late planted cotton is included as a result. When early weeding also becomes limiting some of the cotton is replaced by maize/beans/peas mixtures which use less early weeding labour. Just after 2 acres per unit of labour, both medium weeding and September harvesting labour begin to limit production possibilities and the pattern is adjusted again. Finally, as labour becomes really scarce, more food crops enter and cotton is reduced to a relatively small acreage on the farm.

Thus we have an example of continually changing optimal patterns, governed by the degree of limiting constraints. It is not only labour as a whole that is important, but more particularly labour at different times of the year, and in order to make the most of the resources available, the production patterns are continually adjusted according to the relevant resource constraints.

Diagram 4 shows the corresponding changes in resource constraint values. For land, we have the familiar decreasing marginal returns as the quantity of land is increased, and labour remains at a constant level, the pattern already shown in Diagram 1. For labour, we have marginal products rising and then falling and then rising again, in some cases, as the supply decreases relative to land. This is due to the simultaneous variation of all the labour factors together, relative to the quantity of land. Any rising shadow price of labour, as its supply increases, can be traced to other labour factors the scarcity values of which are decreasing, allowing the factor concerned to increase towards its full value in relation to land. Similarly it is possible for the marginal values to fall and then rise again, through the interaction of other labour factors that are scarce.

The shadow prices of labour constraints can be compared with casual labour hiring rates, and returns to labour in part-time activities at different times of the year. The values of planting resources have to be treated slightly differently, though, because while they are measured in terms of man-days of labour, their availability pre-supposes the availability of oxen and plough, so they really represent the value of all three, labour, oxen and plough, rather than the value of labour alone.

The casual labour rate is about Sh.4/- a day at peak seasons, and this can be used as a basis for comparison. At first sight it would appear to be worth hiring casual labour, in the situation represented, for weeding at many land/labour ratios, and for September harvesting for ratios of land to labour that are **high** but not for any other operations. But this is only so for a high rainfall year, and the hiring of labour has to take place at a time when the outcome of the year in question is unknown, so it can only really be decided in the light of high, average and low rainfall considerations taken together. This is done in the full analysis, where it is shown that in general it is hardly worth hiring casual labour, and that the times of the year when labour is really scarce are so few that the hire of permanent labour appears to be even less worth while. There is also a comparison of part-time activity returns, in which it is shown that beer-brewing and crafts which require unusual skills are the only activities which can compete with labour at peak periods; but that many rural activities can compete at other times of the year.

In general, it is clear that given present levels of management, knowledge and techniques, and given the climate and ecological conditions and therefore the crop possibilities, returns to labour in Masii are extremely low. While it may be true that "shortages" of labour at particular times of the year govern production patterns, it is not true that there is a labour shortage in any economic sense. Rather, there is a problem of finding more remunerative occupations for labour already around.

d) <u>Management in Masii</u>:

One of the major results of the analysis was its demonstration of the central importance of the management variable. There was an investigation of the role of management in traditional food crop systems in high rainfall conditions. (This was the only situation for which sufficiently detailed information on management variations was available.) Diagram 5 shows the range of management levels (labelled A to E) that was found. The best managers in the group observed were able to make 3-4 times as much as the worst, with any given level of land and labour resources. This is a wide range, and indicates the vital role of this residual variable. Considerable space was given in the full analysis to a discussion of the major compononents of the management variable, the room for improvement in this area, and the policy implications that follow. It was suggested that a great deal could be gained from an expansion and improvement in the agricultural extension services, but that there was also a need for much more basic research into such things as the development of improved tools and implements, improvements in methods of work, the suitability of different husbandry techniques applicable to small farms, and the development of crop rotations to improve the long-term fertility of the soil.

e) The Introduction of Cotton and Katumani maize:

We have already seen, in diagram 2 and the section on returns to labour above, that cotton does not represent very much of an improvement over traditional food crops, and that systems in which cotton is grown give only slightly higher returns at the lower land/labour ratios. At the higher land/ labour ratios, the advantage of systems with cotton is almost completely eliminated, because cotton is a labour-intensive crop which cannot play a prominent part on holdings where land is plentiful and labour is scarce. Cotton was assumed to command its 1963 price, for the purposes of the analysis, and when the likelihood of reductions in the cotton price in the future are taken into account, its position becomes even less favourable. Clearly cotton is not a very attractive innovation, especially when its yield advantages over food crops in years when rainfall is low are obscured by a substantial rise in the major food crop price.

In discussing both cotton and the new Katumani maize it is important to consider briefly the maize price structure as it affects farmers in Masii. The maize price in Kenya is set in such a way as to fluctuate widely depending on whether the district as a whole has a surplus or a deficit at any one time. When the district has a surplus of maize, the national producer price of about Sh.20/- (1963) rules; when the district has a shortage, the national consumer price of Sh.50/- (1963) becomes operative. The surpluses and shortages of Masii farmers tend to follow those of the district as a whole: in years when rainfall is high, the maize price is low; in years when rainfall is low, the maize price is high. Although maize yeild fluctuations are wide, returns to maize do not vary very much.

This maize price structure is somewhat artificial, in that it relies on the control of all inter-district marketing which can only take place through the national marketing board at the official rates. It has the unfortunate effect of encouraging maize production in areas such as Masii, where natural conditions are unfavourable, and discouraging specialisation in areas where maize grows well. Areas which frequently have maize shortages because natural conditions are unfavourable have production determined by a higher effective price than areas which always produce surpluses. In the best maize-producing areas, which do not suffer shortages, the price is always about Sh.20/-. In the less favourable areas the price is sometimes Sh.20/- and sometimes Sh.50/-, and maize production is influenced to a considerable extent by the Sh.50/- price.

The relative advantage cotton has over maize, in dry areas, in that its yield is much more stable, is obscured by the distortion in the present maize price. Conversely, the new drought-resistant Katumani maize is substantially more attractive when the present Kenya maize price structure rules. Katumani maize gives considerably improved yields when rainfall is low, without very much of a reduction over local maize when introduced this figure was raised from 3 to 7. Thus the introduction of Katumani maize represents a clear advantage in many ways.

However, there are disadvantages which also need considering. Katumani maize appears to be so attractive, that there may be a danger of people in lowland Machakos moving into patterns of farming that include maize and virtually nothing else. The optimal farm patterns when Katumani maize is introduced in the analysis all contain Katumani maize, mixed with a little pigeon peas and no other crops. A virtual mono-culture of Katumani maize while appearing to solve a lot of problems in the short run, could have very serious consequences for the long-run fertility of the soil. This is a possibility which has tobe borne in mind as long as the present maize price structure rules.

Also, if lowland Machakos farmers really do move into maize production to the exclusion of all else, this will result in the production of maize surpluses, even in the famine years, and the maize price facing these farmers will change. Farmers will no longer be able to take advantage of the high maize price of the famine years, exchanging some of their maize for the other foods they eat, and the improvement in their food position will then be somewhat less substantial than that indicated. Instead of being able to feed 7 people per until of labour with unit 6 acres of land, even in a low rainfall year, they will be able to feed 5 to 6.

It is now instructive to consider the effect of a constant price for maize. This could come about through the surplus production of Katumani maize in the low rainfall as well as the high rainfall years, or it could be the result of a deliberate price policy.

For the purposes of comparison, a constant maize price of Sh.20/-, the price which rules in the maize surplus years at present, was assumed in some versions of the model. With these constant maize price assumptions, cotton becomes attractive, both when compared with traditional food crop possibilities and when compared with Katumani maize. Patterns in which substantial quantities of cotton appear, supplemented by some traditional food crops, but not much Katumani maize, become optimal in all rainfall conditions. As Table 1 shows, though, the values in low rainfall years are substantially reduced even compared with traditional food crop systems. The food position in famine years in these cotton systems, is slightly better than when traditional food crops alone are grown, it now being possible to grow cotton and exchange it for maize at a much a lower price. It is possible to feed 4 people per unit of labour with 6 acres of land, as opposed to 3 at present with traditional food crops and a high maize shortage price.

Thus if cotton is to be at all successful in lowland Machakos in the longer run, something must be done to make Katumani maize less attractive. This can be done by changing the maize price structure as it affects farmers in Masii. If, on the other hand, it is decided that it is not worth pursuing cotton, but that Katumani maize should be promoted as the best answer to the famine and food position, care must be taken to ensure that this does not endanger the long run position of the soil.

V. Conclusions

We have shown how the linear programming model can be used to throw light on the structure and working of peasant farm systems through an analysis of the way in which constraints determine production patterns. In lowland Machakos, in Masii location, the analysis has been able to show the value of arable land, and the importance of a thorough understanding of the relationship between livestock and crops, because otherwise livestock cannot be justified; it has shown that returns to labour are extremely poor, and that while the shortage of labour at particular times of the year does determine production patterns labour cannot be considered scarce at present return levels; and it has indicated the major importance of factors included in a residual management variable, many of which are subject to influence in a way that has been discussed in the full account. It has brought out the interrelationship between cropping patterns and resources, and the way in which cropping patterns change with different resource constraints. It has also indicated the impact the introduction of one new crop can have, in requiring adjustments right through the farming system.

While the more important results in lowland Machakos relate to constraints, it has also been shown that the linear programming analysis can throw light on choices where major crop innovations are concerned. This has been illustrated here with cotton and Katumani maize and a comparison between systems including these and systems in which traditional food crops alone are grown. Whereas in Masii, the scope for choice between different innovations is limited, in other part of East Africa, this aspect of a linear programming analysis could be much more important. In Kenya, the guidance it could give to the choice of farm patterns for settlement schemes, and the choice of crop and livestock combinations for high potential areas where the possibilities are numerous are two important examples. Others could undoubtedly be found for Uganda and Tanzania.

J. Heyer
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<u>REFERENCES</u>

1. The analysis has been presented in full in: J. Heyer, <u>Agricultural Development and Peasant Farming in Kenya</u>, Ph.D. Thesis, London, 1966, unpublished.

2. Cotton had been tried for a short time before the war, but by 1940 it had completely disappeared and no attempts were made to revive it until the 1960s in Masii.

3. J. Heyer, <u>A Linear Programming Model for Peasant Agriculture in Kenya</u>, E.A. I. S. R. Conference papers, January 1965.

4. J. Heyer, <u>Agricultural Development and Peasant Farming in Kenya</u>, op. cit.

5. Op. cit. again.

6. Kenya Government, <u>Population Census</u>, <u>1962</u>.

DIAGRAM 1: SHADOW PRICES OF LAND IN HIGH, AVERAGE AND LOW RAINFALL YEARS, TRADITIONAL FOOD CROP SYSTEMS

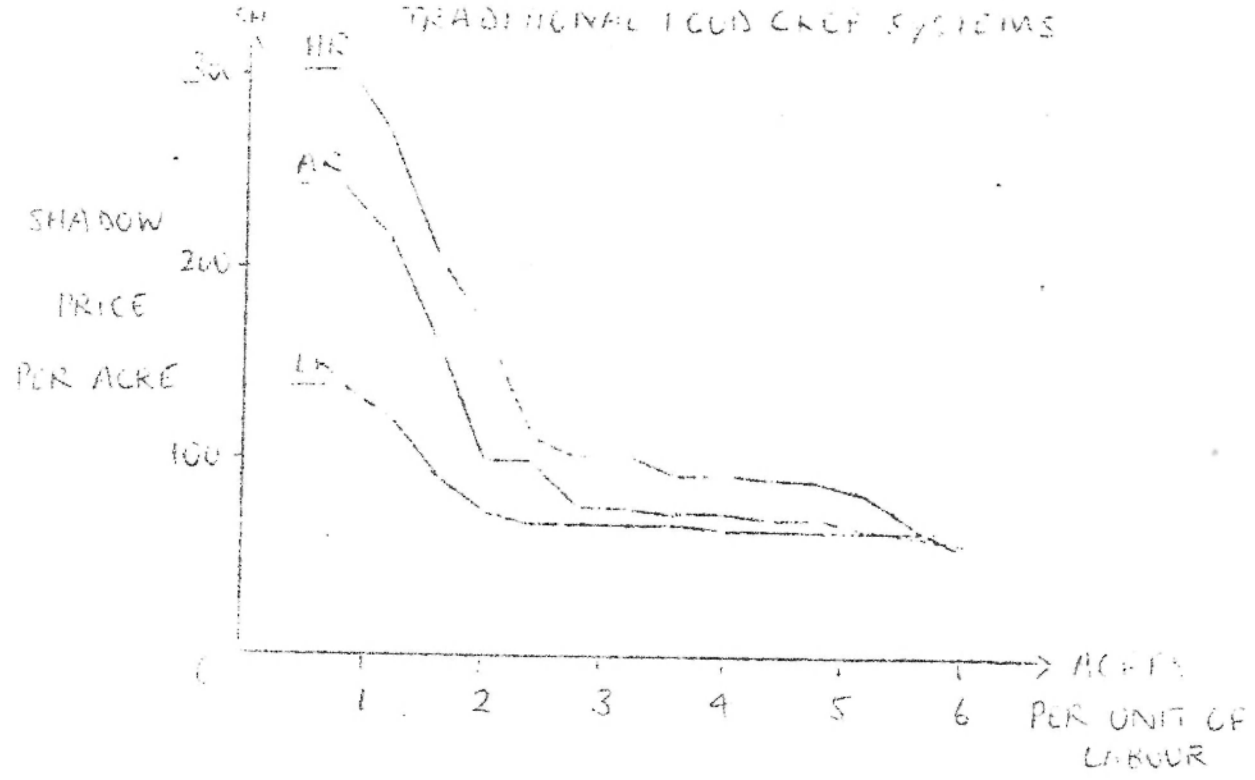


DIAGRAM 2: RETURNS TO LABOUR IN HIGH, AVERAGE AND LOW RAINFALL YEARS

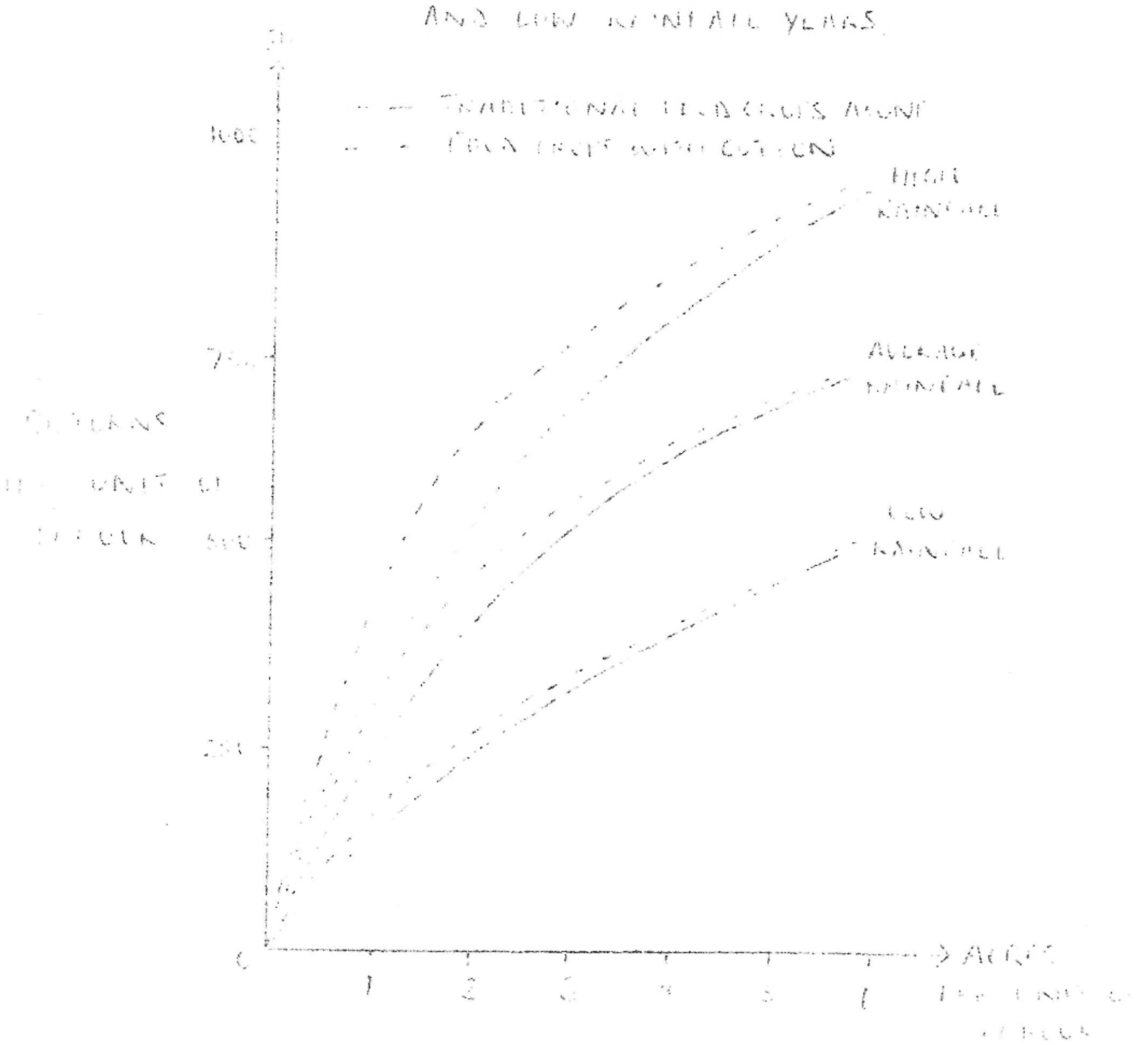


DIAGRAM 3. CHANGING PATTERNS OF OPTIMAL LAND USE AS LAND PER LABOUR UNIT RISES.

TRADITIONAL FOOD CROPS WITH COTTON, HIGH RAINFALL YEAR

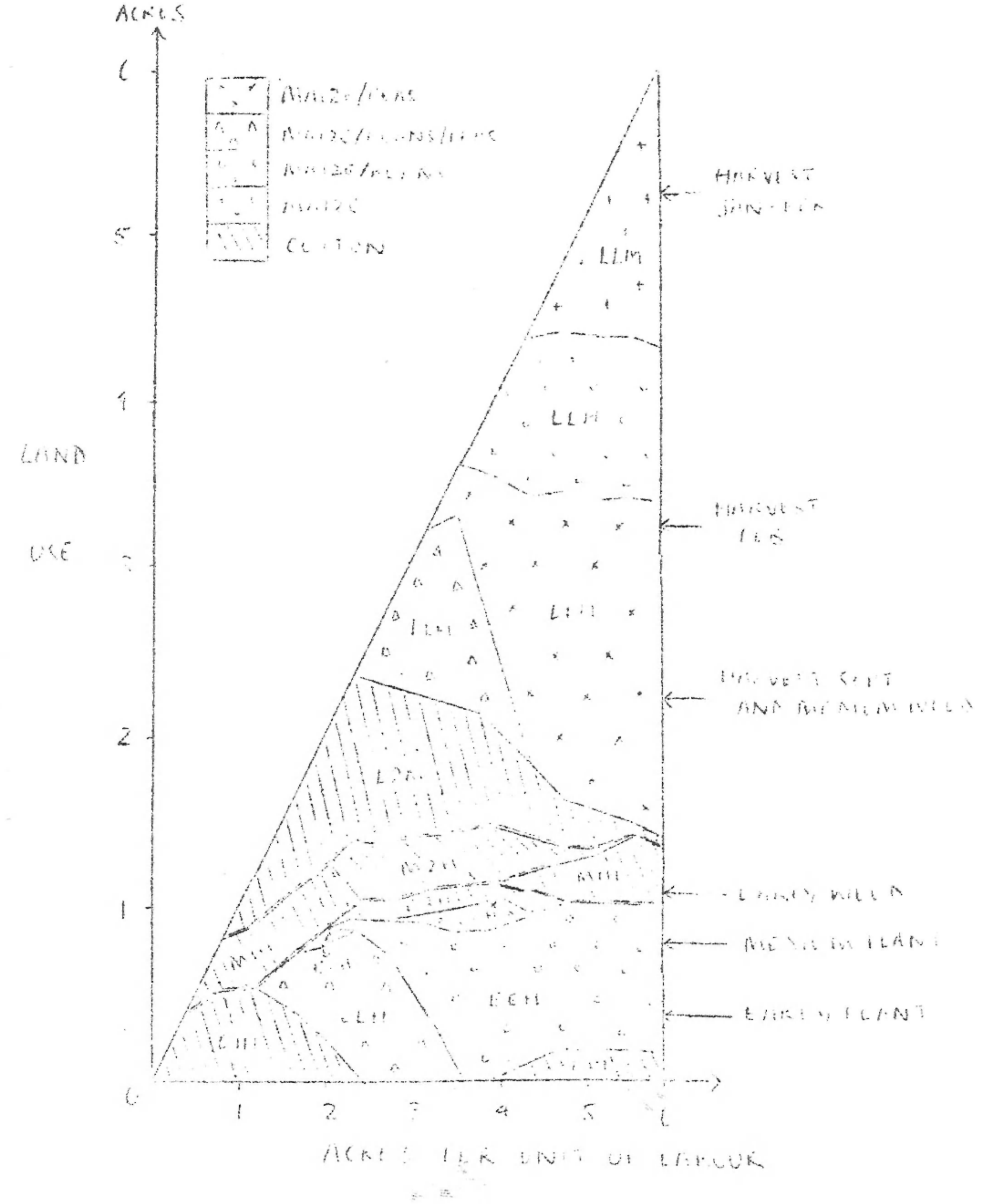
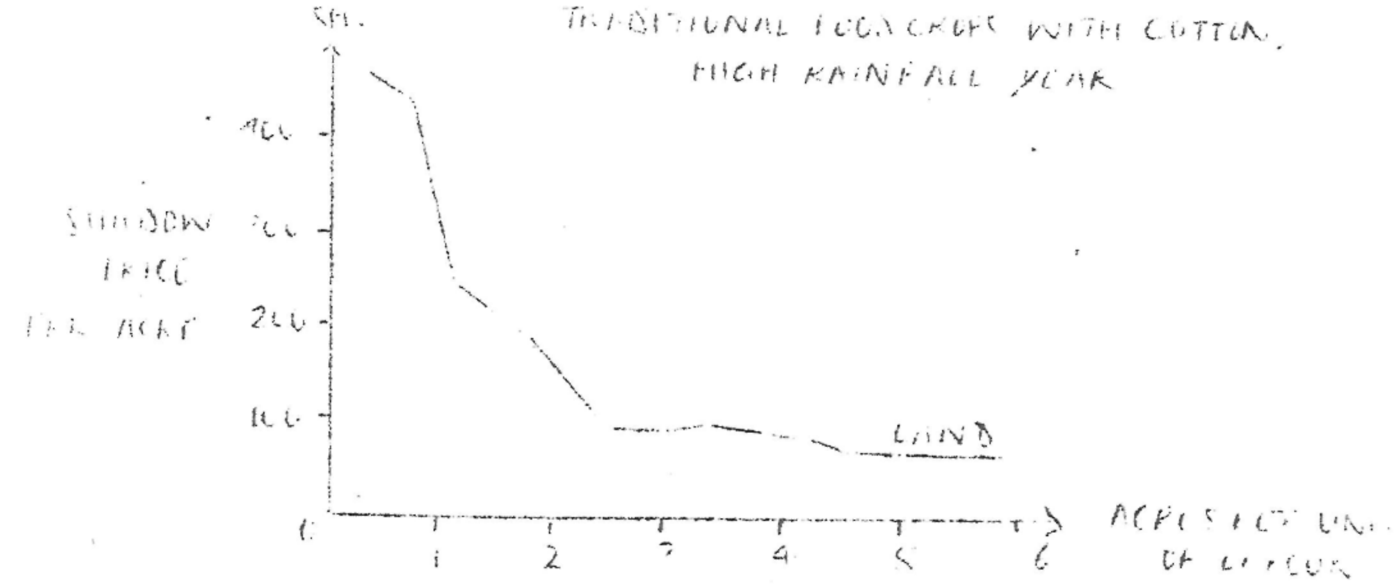
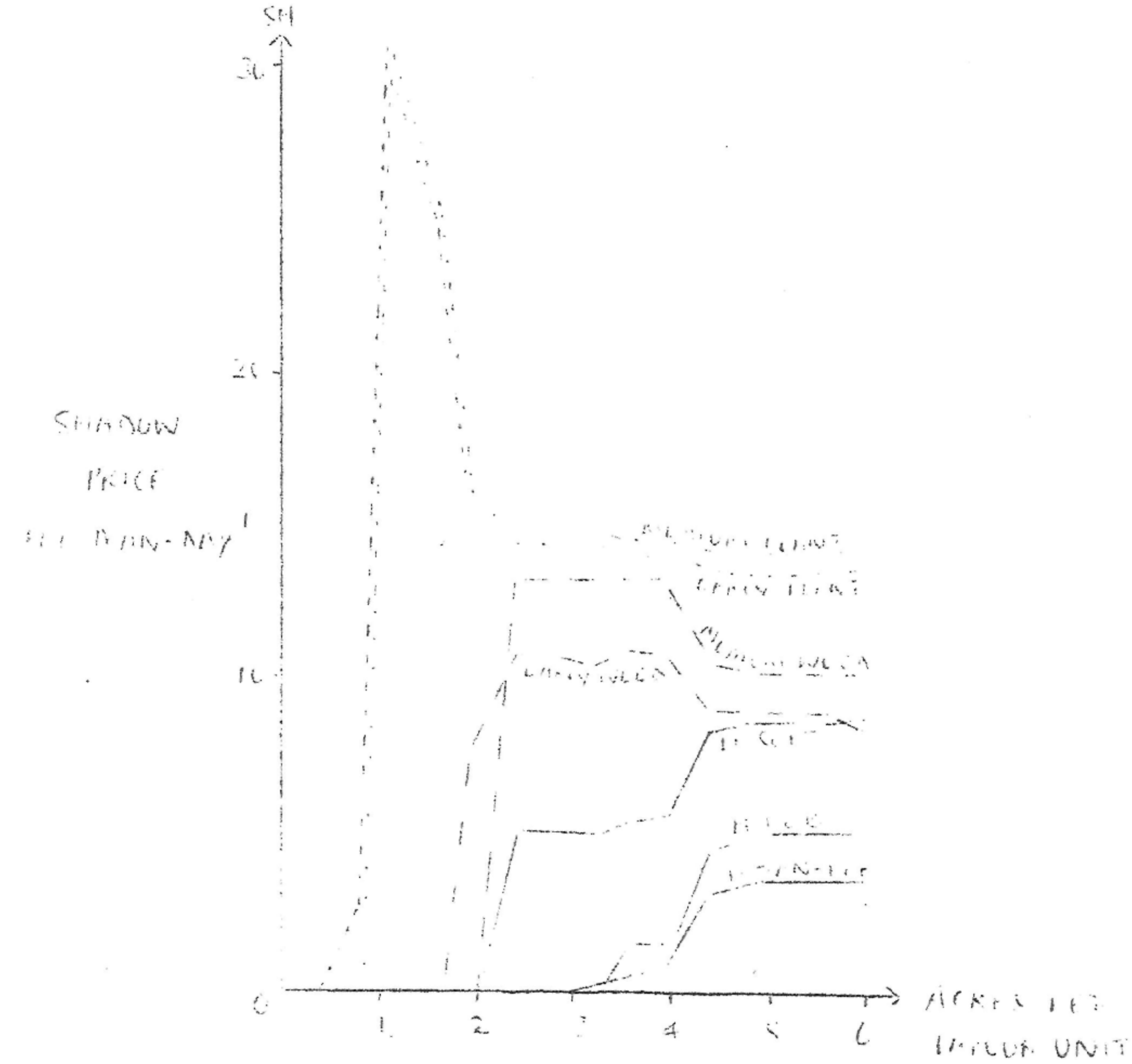


DIAGRAM 4. SHADOW PRICES OF LAND AND LABOUR CONSTRAINTS, AS LAND PER LABOUR UNIT RISES





1 A man day is 8 hours of an adult's work.