JUDITH HEYER*

A LINEAR PROGRAMMING ANALYSIS OF CONSTRAINTS ON PEASANT FARMS IN KENYA†

In this paper some of the results of a linear programming analysis of peasant farm production in Kenya are presented. The large body of literature that now exists on the use of linear programming in farm production analysis[1] includes remarkably little on small-scale farms in developing economies.[2] It is difficult to justify the use of linear programming for small-scale farms on an individual basis, but its value both as a basic research tool and in producing extension recommendations for groups of farms is unquestionable. The complexity of small-scale farm production is now recognized (*11*; *12*; *15*). The critical importance of timely operations, requiring careful allocations of labor at peak periods; the limited quantities of land and its lack of homogeneity requiring intricate sequencing of crop and livestock activities; the necessity for balancing a need for cash with a need for a sure and varied food supply which is not provided through the market: all contribute to complex decision-making processes and complex interactions in production on small-scale farms in developing areas. The need for sophisticated techniques to analyze small-scale farming systems has been underestimated in the past, but it is now becoming acknowledged.

The emphasis in the study presented here is on the dual solution to the linear programming problem. The central questions are: what are the major constraints on the farm systems; how do these constraints influence the farm systems; and what would be the result of reducing or removing some of the critical constraints. At the time of the study, solutions to the development problems of the area were being sought with remarkable disregard for constraints, particularly labor constraints.[3] It was decided, therefore, that an exploration of the potential for de-

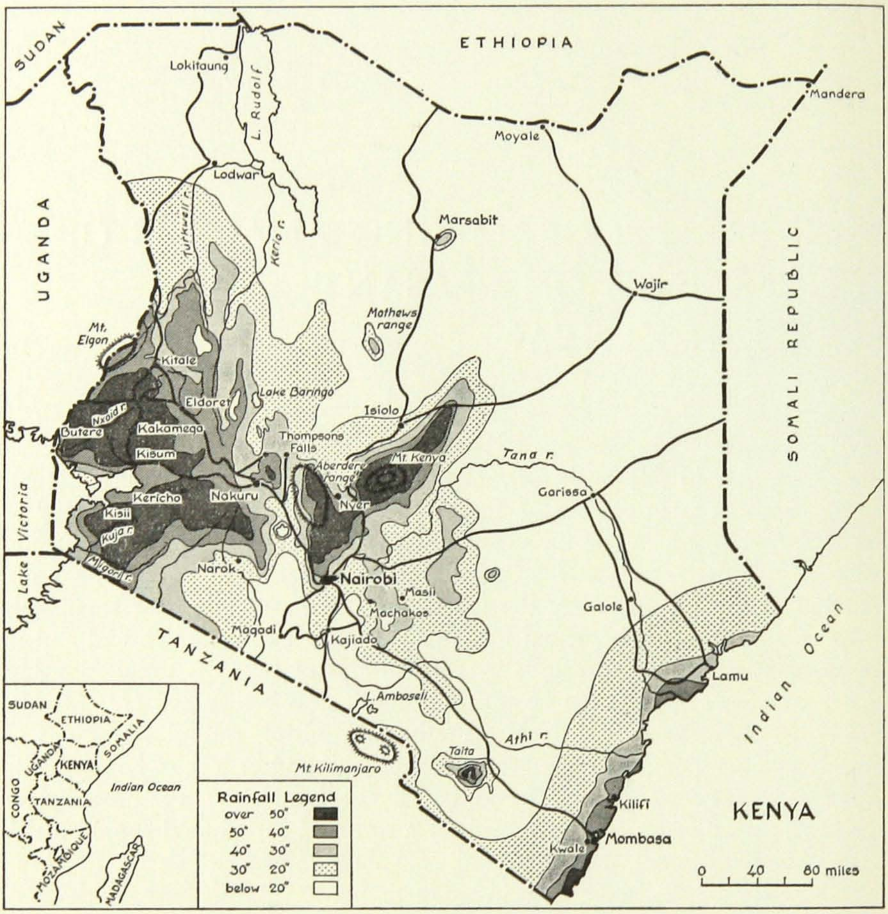
* Senior Lecturer, Department of Economics, University of Nairobi.

† This paper is based on my doctoral dissertation which was written at London University and at the University College Nairobi with financial support from the British Government under the Social Science Field Research Scheme, and the Institute for Development Studies, University College Nairobi. I am particularly indebted to J. L. Joy, who contributed substantially at all stages of the study. I am also grateful to B. F. Massell for helpful comments at its later stages.

[1] For a survey, see *6*.

[2] The only published linear programming studies of small-scale farms in Africa are *2*, *7*, and *9*. There have been some studies of small-scale farms in India, but these are less readily available.

[3] This point has been made in the Kenya context in *2*.



velopment through the removal of bottlenecks such as labor at critical times would be fruitful. An understanding of the way in which constraints operate on the farm systems would also be helpful in assessing the likely impact of innovations already being proposed. The impact of the introduction of cotton and a quick-maturing variety of maize, the examples considered here, is better understood in the context of critical constraints on the farm systems.

A microanalytic understanding of the farm level constraints in agriculture and the way in which they operate throws light on questions for macroanalysis. Issues such as the shadow-pricing of agricultural resources, employment policy, and future patterns of agricultural production are illuminated by more concrete analyses of constraints at the farm level.

A number of economists have used production function analysis to examine the nature of constraints on farm production systems (*1*; *5*; *10*; *16*). In production function analysis the contribution of different resources to production is measured, and conclusions are drawn from the relative values of the resources in current production. One of the questions that has been central to many production function studies has been the question of whether or not resources are allocated efficiently at any time. In the linear programming approach to the analysis of resource constraints, this question receives less attention, and the central question is what resources are critical in optimal solutions. Both kinds of analysis take the input-output relationships that occur in practice on the farms, without any assumption of technical efficiency. The question in the linear programming analysis presented here is, taking the activities available to farmers of average efficiency, what sort of production patterns are optimal and what are the most important constraints?

THE AREA OF THE STUDY

The paper is based on a study of farm production in Masii, a semi-arid area 60 miles southeast of Nairobi, Kenya. Masii has a relatively high population density, combined with a low and uncertain rainfall, resulting in periodic famines and low standards of living at all times. The most significant technical improvements of recent years, the successful development of quick-maturing varieties of maize and the introduction of cotton, still leave Masii with poor prospects for the future, as this study indicates.

Masii has an average annual rainfall of 25 inches, falling in two seasons of the year. The soils are sandy clay loams. Eighty to ninety per cent of the cultivated area is in maize, beans, and peas, and there are smaller acreages of millet, sorghum, sweet potatoes, cassava, gourds, castor, bananas, citrus, mangoes, and papaya. Cotton is a recent addition. Livestock, including poultry, supplement the crops as sources of income on the farms.

Ox-plows are used for land preparation, and the crops are planted behind the plow. *Pangas* (machetes) and *jembes* (hoes) are used for all other operations. There is little division of labor between the sexes and both men and women work hard at peak seasons, often more than 8 hours a day for 6 days of the week for weeks at a time.

THE MODEL

The linear programming model is well suited to an examination of constraints on production in a situation in which the objective function is unambiguous and risk considerations do not dominate production decisions. Neither of these conditions is easily fulfilled, however, in semi-subsistence peasant farming. The objective function is difficult to determine. Cultural and institutional factors such as an attachment to livestock or a taboo against planting maize before millet, can be viewed as further constraining the production environment and can be incorporated as constraints in the model. But there is still the difficulty of deciding what it is that subsistence farmers aim for, subject to the many constraints. Alternatives that can be considered include ensuring an adequate food supply in drought years, producing a suitably varied diet, maximizing the number of people fed, maximizing the market value of output, and so on. In this study it has been assumed that farmers simply maximize farm output valued at market prices, since Masii farmers engage in a good deal of market exchange and are aware of market prices at all times. Decisions not to sell are then viewed as determined by market prices that make it unattractive to do so. Alternative objective functions could be used without substantially modifying the basic model.

Uncertainties with respect to inputs and outputs are always present in agricultural production, and they are as important as anywhere in Masii. Lipton has argued that uncertainty dominates subsistence farming decisions to such a degree that it must be given the central role in any peasant farm production analysis (*8*). In this study it is assumed that farmers plan on the basis of maximum input requirements that occur in high rainfall years, and that there is sufficient flexibility to adjust to factors such as sickness in critical situations. To accommodate uncertainties with respect to output, the maximization of the value of output in high rainfall, low rainfall, and average rainfall situations was considered in the original study (*4*). In this paper the discussion is limited to the average rainfall results.

The crucial decisions for farmers in Masii concern not so much the crops and crop mixtures to plant as the way in which to allocate scarce labor at critical times.[4] There is a limited range of crop mixtures that can contribute substantially to the objective function, the important ones being maize/beans, maize/peas, maize/beans/peas, maize alone, and more recently cotton. These are the dominant mixtures in the optimal solutions of the analysis. They also dominate in practice in Masii. The difficult decisions concern the allocation of planting and weeding resources. The time of planting is critical because the rainy season is so short. For example, maize planted in the first week of the rains can be expected to give 10–15 per cent higher yields than maize planted in the second week, and planting later than the third week reduces expected maize yields by 30 per cent or more.[5] For farmers this means that the decision as to which crop mixtures to plant first is crucial. Similarly the timing and intensity of weeding operations are extremely important. To reflect the importance of these decisions on Masii farms, there is as much emphasis in the analysis on the timing of planting and the timing and intensity of weeding operations as on the choice of crop mixtures.

Farmers are constrained by climatic and ecological conditions, by the knowledge and techniques available, and by social and cultural factors mentioned above. In Masii, none of the social and cultural constraints is of sufficient importance in constraining production decisions to be included in the analysis. The natural environment, and the availability of knowledge and techniques, are taken as given. The constraints that play a central role in the analysis are labor and land. Capital is relatively unimportant in Masii farming and the capital stock is assumed to be given. Cotton is the only crop for which working capital requirements are substantial, and for these credit or local finance is usually available. For other crops, purchased inputs are of dubious value given the current state of knowledge. More research is needed to produce the crop varieties that will respond before purchased inputs can be seriously considered for crops other than cotton in Masii. The use of working capital to hire additional labor was considered in the original analysis, but it was treated as an extension of the discussion on labor constraints rather than as a general question of working capital.

[4] Most crops are interplanted in Masii. The term "crop mixture" is used in this paper to refer both to mixtures and to single stands.

[5] Research Officer, Machakos District 1966, private communication.

Fixed capital investments that are important include small implements, oxen, plows, and cotton dusting and spraying equipment. These were handled through a comparison of farms with and without critical items of capital equipment.

Land is treated as a homogeneous resource as it was not possible to collect sufficient data on the influence of different types of land on all the different activities in the model. The only distinction made is between land available at different times of the year.[6] Labor is treated as a homogeneous resource, using an arbitrary weighting system that discounts the labor of older adults and children.[7] It is also distinguished by time periods. The criterion for distinguishing one labor time period from another is whether the output would be affected if the labor input took place at one part of the time period rather than the other. If it would make no difference, the time period is treated as homogeneous. If the output would be affected, the time period is further broken down.[8] The labor constraints that were chosen and that proved constraining on at least some of the systems considered, were: 1–9 days after the start of the rains (early planting); 10–15 days after the start of the rains (medium planting); 4–7 weeks after the start of the rains (early weeding); 7–10 weeks after the start of the rains (medium weeding); fourth month after the start of the rains (January harvesting); fifth month after the start of the rains (February harvesting); eleventh month after the start of the rains (September harvesting). The "planting labor" constraints include an ox-team and plow and are thus not strictly labor constraints. Other labor constraints originally included in the model were not limiting in any solutions so they are not listed here.

The activities considered in the model reflect the important choices for Masii farmers: which crop mixtures to grow; when to plant each; and when and how much to weed each. Each activity is defined by the crop mixture, the time of planting, the time of weeding and the intensity of weeding. Cotton culture is further defined according to manure and insecticide application. Activities identical in every respect except one, intensity of weeding for example, allow for the relevant choice, in this case the intensity of weeding choice. Activities identical in every respect except time of planting allow for the time of planting choice.

All the common food crop mixtures that are grown in Masii were included as possible activities. Mixtures of local maize, beans, pigeon peas, bulrush millet, sorghum, and finger millet were included in all versions of the model, and cotton and quick-maturing maize were included in some versions. Crop rotations were not considered because no rotations are practiced and there was virtually no information on possible rotations for Masii. Livestock activities entered the analysis

[6] This distinction was made in the initial stages of the analysis, when the influence of second rains decisions on optimal production patterns for the first rains was being considered. In no case did second rains considerations have any impact, so second rains activities were ignored in subsequent stages of the analysis. In other parts of Kenya it would be more important.

[7] Men 20–60 years = 1; women 20–40 years = 1; women 40–60 years = 0.75; men and women over 60 years = 0.50; students and children 10–20 years = 0.50; children under 10 years = 0. As labor was measured in hours rather than days, there was no need to discount the labor of young women as has sometimes been done in other studies.

[8] What is involved in practice is a continuum, but for the linear programming model it is necessary to make the intervals discrete. In this analysis it is a matter of judgment where the breaks come, but what is important is that the time periods need to be of different lengths depending on how critical the timing of operations is.

as competitors for land, but as all farmers keep some livestock on nonarable land, and as the labor involved does not alter significantly when additional numbers of livestock are kept, livestock were assumed to involve no additional labor costs. It would be interesting to explore the relationships between livestock and crops through the use of manure, but, in addition to substantial data problems, the use of manure in Masii and the availability of land for livestock that provide manure are both so limited, that it was decided not to pursue this further.

Nonfarm activities such as casual labor, beer brewing, and others were discussed in relation to the value of labor in farming at different times of the year. They were not incorporated as activities in the model.

THE DATA[9]

The analysis is based on data collected in Masii during twice-weekly visits to farms through the year September–September 1962/63. Sixteen holdings were chosen to represent important production activities and input-output data were collected from these. The holdings studied had cultivated acreages ranging from 0.6 to 6.5, with an average of 2.8, available labor from 0.5 to 1.8 full time adult-equivalents, with an average of 1.0, and the ratio of land to labor varied from 0.8 to 5.0 acres per adult-equivalent, with an average of 3.0.

Suitably adjusted research station results and data from similar situations elsewhere in East Africa were used to supplement the input-output data collected on the farms. This was necessary to get input-output data for low rainfall and average rainfall years, 1962/63 being a high rainfall year. It is also necessary for innovations and any consideration of practices not in current use on the farms studied.

The precise way in which input-output relationships were estimated is as follows.[10] The areas under different crop mixtures on different plots were measured and these provided the basis for defining activities represented on the holdings. Labor inputs were recorded by crop mixture and according to who had performed them. Detailed land and labor inputs were thus available for each activity represented on the holdings in 1962/63. Outputs, on the other hand, were simply recorded for the holdings as a whole. The input-output relationships assumed in the analysis were estimated from adjusted figures available from experimental work in East Africa, and the case studies. The problem here is to isolate the effect of different inputs on output. In this analysis, crop mixture, time of planting, time of weeding, and intensity of weeding are all assumed to be critical. The *extent* to which output is influenced depends on the excluded inputs in the input-output relationship, most important of which (in this analysis) are quality of land and management. For the activities represented on the holdings studied, a range of input-output relationships was obtained. To get statistical averages for the effect of each separate input on output would require a comprehensive production function study. Even with far more substantial resources for this study it would have been difficult to contemplate this. Instead it was necessary to

[9] The data collection process and the way in which the data were used in the model are fully discussed in *4*.

[10] This is shown in detail in *4*.

fall back on a combination of good judgment and available information from elsewhere, in addition to the field data.

Price data were collected from local markets and traders. Information on year to year variations in price and yield was obtained from discussions with local farmers, local traders, and officials of the Agricultural Department.

The detailed input-output data required by the model pose substantial data problems, but they are essential to any analysis of the farm production situation. As with many farm production studies, the input-output data are of varying quality. The results of the analysis obviously rely on the assumptions made, and evaluation of the results would have to start with an examination of the technical assumptions that contributed to them.

THE RESULTS

The comparison that is presented in this paper is between a system in which only traditional food crops are included as possible activities, a system with quick-maturing maize, and a system with cotton, all in average rainfall conditions. Three different activity matrices were used to represent these alternatives.

A range of resources is available on different farms in Masii. Rather than choose a "typical farm" situation for analysis, it was decided to explore optimal solutions for a range of land/labor ratios, making the results applicable to a large number of farms in the area. Economies and diseconomies of scale are ignored by this procedure, but this was thought justifiable over the limited range of farm sizes covered in the study. Owing to limited programming facilities available for this work, land/labor ratios were varied discretely. The results presented below are for 1.25 units of labor and one to seven acres of land.

Labor and land are not the only critical resources likely to influence the solutions that are optimal. The most important omission in this analysis is undoubtedly management. Another that might be a significant source of variation in some situations is the quality of land. In the original study, there was some attempt to identify different levels of managerial ability, and to explore solutions for different managerial as well as land and labor resource endowments (*4*). But the data available were too limited to justify an extensive treatment of management

Table 1.—Attainable Value of Output in Different Systems
(*Shillings per year*)

Acres[a]	Land/labor ratio	Traditional system	Quick-maturing maize system	Cotton system
1.0	.8	244	263	327
2.0	1.6	465	516	503
3.0	2.4	591	692	635
4.0	3.2	671	818	708
5.0	4.0	746	937	775
6.0	4.8	818	1,052	836
7.0	5.6	879	1,165	892

[a] With 1.25 units of labor.

TABLE 2.—OPTIMAL PRODUCTION PATTERNS*
(*Acres*)

A: TRADITIONAL SYSTEM

	Early planted			Medium planted				Late planted			
Acres[a]	MP e3 (1)	M m3 (2)	MB e3 (3)	MP e3 (4)	MP m3 (5)	MB m3 (6)	M e3 (7)	MB l3 (8)	MP m3 (9)	MP l3 (10)	MBP m3 (11)
1.0	1.0	—	—	—	—	—	—	—	—	—	—
2.0	1.4	—	—	0.4	0.2	—	—	—	—	—	—
3.0	1.4	—	—	0.2	0.4	0.4	—	—	—	—	0.6
4.0	1.4	—	—	0.2	0.4	0.4	—	1.1	0.5	—	—
5.0	0.8	0.6	—	0.8	0.2	—	—	1.7	0.4	0.5	—
6.0	0.2	0.8	0.5	1.0	—	—	—	1.6	0.1	1.9	—
7.0	—	0.3	1.1	0.3	—	0.3	0.4	1.2	—	3.4	—

B: QUICK-MATURING MAIZE SYSTEM

	Early planted			Medium planted				Late planted		
Acres[a]	M_KP e3 (K1)	M_K e3 (K2)	M_KB e3 (K3)	M_KP e3 (K4)	M_KP m3 (K5)	M_K e2 (K12)	M_KB e3 (K13)	M_KP m3 (K9)	M_KP l3 (K10)	M_K m2 (K14)
1.0	1.0	—	—	—	—	—	—	—	—	—
2.0	1.4	—	—	0.4	0.2	—	—	—	—	—
3.0	1.2	—	0.2	—	0.9	—	0.1	0.6	—	—
4.0	0.9	0.5	—	—	0.4	0.6	—	1.0	0.6	—
5.0	0.5	0.9	—	—	0.1	0.8	—	1.1	1.5	—
6.0	0.3	1.1	—	—	—	1.0	—	0.8	2.4	0.5
7.0	0.4	1.1	—	—	—	1.0	—	—	3.2	1.4

C: COTTON SYSTEM

	Early planted				Medium planted			Late planted		
Acres[a]	C_{md} e3 (C1)	MP e3 (1)	MB e3 (3)	M m3 (2)	C_{md} e3 (C2)	C_{md} m3 (C3)	M e2 (12)	C_d m2 (C4)	MB l3 (8)	MP l3 (10)
1.0	0.6	—	—	—	0.4	—	—	—	—	—
2.0	0.1	1.3	—	—	0.4	—	—	0.2	—	—
3.0	0.1	0.8	0.3	—	—	0.4	—	1.3	—	—
4.0	—	1.0	0.3	—	—	0.4	—	1.1	1.1	—
5.0	—	0.5	0.8	—	—	0.4	—	0.9	1.2	1.2
6.0	—	0.2	1.1	0.1	—	0.3	0.2	0.6	1.2	2.3
7.0	—	—	1.1	0.3	—	0.1	0.6	0.3	1.2	3.2

* Crop mixtures are indicated by the following combinations of letters: M—traditional maize; P—pigeon peas; B—beans; M_K—quick-maturing maize; C—cotton. Planting time is indicated by grouping the activities into headed sections according to planting time. Weeding dates after the start of rains, except for cotton, are shown alphabetically: e—early (4–7 weeks); m—medium (7–10 weeks); l—late (over 10 weeks). For cotton it is assumed that there are two weedings, either early and medium indicated by "e," or medium and late indicated by "m." Intensity of weeding is shown numerically: 3—high; 2—medium; 1—low. For cotton, activities are also distinguished according to manuring and insecticide application, using subscripts to the "C" for cotton: m—manure applied at planting; d—full recommended insecticide treatment.

[a] With 1.25 units of labor.

as a third factor in the resource situation. The influence of management has been explored recently in other studies, in which the data were more suitable for an adequate treatment of the management factor (*10*; *14*). With recent progress in providing the theoretical and methodological framework for the treatment of management in farm production analysis, there is more likelihood that the relevant data will now be collected to allow its incorporation in production analyses (*13*). The current study would certainly have benefited from a fuller recognition of the importance of management at an early stage.

In Table 1, the total value of output attainable in the three different systems is shown. Cotton represents a considerable improvement over traditional crops at very low land/labor ratios, but this quickly changes as land becomes more plentiful. Cotton is a relatively labor intensive crop, which helps to explain this pattern. Its relative attractiveness even at low land/labor ratios has to be set against the appreciably greater effort required by the farm family when it is grown.

Quick-maturing maize has advantages that become more marked as land/labor ratios rise. This is because it is particularly valuable when medium and late planting have to be resorted to on the farms which quickly exhaust their early planting resources. Thus, quick-maturing maize is particularly attractive for farms with relatively plentiful land but scarce labor supplies.

The different patterns of farming that are optimal at different land/labor ratios are shown in Table 2. The implied values of the constraints are shown in Table 3.

The most limiting resource is early planting which becomes a constraint on the optimal solution at 1.4 acres with 1.25 units of labor in the traditional and quick-maturing maize systems, at a lower acreage when cotton is introduced. For cotton there is the possibility of manuring at planting time which draws heavily on the early planting resource. As the area cultivated increases, labor for early weeding, medium planting, September harvesting, and medium weeding successively constrain the farming systems when cotton is not grown. With cotton, medium planting constrains at a lower acreage, but otherwise the order is the same.

In all systems, maize, beans, and peas dominate other food crops. Sorghum, bulrush millet, finger millet, and root crops do not enter any optimal solutions at all. This accords with the situation in practice in Masii.

The patterns of farming that are optimal at different land/labor ratios are shown in Table 2A for traditional food crops alone. Taking this together with Table 3A, we can see how the constraints influence the production patterns.[11] Up to 1.4 acres with 1.25 units of labor, land is the only limiting resource, and the activity with the highest per acre return is chosen: the maize/peas mixture, which is early planted and early and intensively weeded. The early planting constraint begins to operate at 1.4 acres, and a medium planted maize/peas mixture is added, first early weeded, and then when early weeding labor is exhausted some medium weeded as well. At 3 acres, labor for harvesting pigeon peas in September constrains the solution. This necessitates a move from peas to beans.

[11] The number of activities should be the same as the number of binding constraints in all solutions. Rounding leads to some discrepancies in the result presented.

TABLE 3.—IMPLIED VALUES OF LAND AND LABOR

Acres[a]	Land (*shillings per acre*)	Labor (*shillings per man day*) Planting Early	Planting Medium	Weeding Early	Weeding Medium	Harvest Jan.	Harvest Feb.	Harvest Sept.
		A: TRADITIONAL SYSTEM						
1.0	244	—	—	—	—	—	—	—
2.0	163	7.7	—	—	—	—	—	—
3.0	101	14.4	8.0	5.5	—	—	—	4.4
4.0	77	14.4	8.0	7.8	2.4	—	—	4.7
5.0	74	14.1	8.0	7.8	2.5	—	4.1	4.8
6.0	71	14.7	8.8	7.4	2.5	—	7.2	5.1
7.0	63	15.8	7.8	7.3	2.7	1.8	2.0	6.2
		B: QUICK-MATURING MAIZE SYSTEM						
1.0	263	—	—	—	—	—	—	—
2.0	198	0.1	—	8.0	—	—	—	—
3.0	150	2.5	2.7	6.7	—	—	—	4.7
4.0	119	2.6	2.8	11.0	4.0	—	—	3.9
5.0	119	2.6	2.8	11.0	4.0	—	—	3.9
6.0	113	8.8	9.6	7.9	4.5	—	—	4.7
7.0	113	8.8	9.6	7.9	4.5	—	—	4.7
		C: COTTON SYSTEM						
1.0	316	2.1	—	—	—	—	—	—
2.0	163	19.6	18.2	1.5	—	—	—	—
3.0	91	11.5	10.2	6.5	3.3	—	—	5.0
4.0	72	10.7	9.6	8.6	5.2	—	—	5.2
5.0	66	10.6	9.5	9.1	5.4	—	0.9	5.2
6.0	56	12.8	9.1	7.1	4.7	1.3	2.4	6.6
7.0	56	12.8	9.1	7.1	4.7	1.3	2.4	6.6

[a] With 1.25 units of labor.

Medium planting has also become a constraint and some late planted mixtures are introduced. At 4 acres, late weeding is needed, as medium weeding is used up. At 5 acres, early planted maize replaces maize/peas, and at 6 and 7 acres adjustments are made to accommodate shortages of labor in January and February for harvesting beans.

Tables 2B and 3B show similar interactions between activities and constraints in the quick-maturing maize system in which all traditional food crop activities are included as possibilities in addition to a full range of possible activities with quick-maturing maize.

Table 2C shows the optimal production patterns for the system in which traditional food crops and cotton are included as possible activities, and Table 3C shows the operating constraints. Early planting resources constrain at very low land/labor ratios because cotton is planted with manure in each hole, a labor intensive planting process. (The alternative of planting without manure was only selected for late planted cotton, as can be seen in Table 2C.) At 2 and 3 acres, early planting resources are used for food crops, and cotton is planted later. Similarly, early weeding is transferred from cotton to food crops, with cotton weeded later, as land/labor ratios rise. At 4 and 5 acres, later planted food crops are added, and at 6 and 7 acres cotton appears to be on the way out, with food crops replacing it. In other parts of Kenya, agricultural extension officials have despaired of ever getting cotton planted early and having farmers give cotton priority over food crops. This analysis suggests that farmers are being rational in giving food crops priority at most land/labor ratios in Masii conditions.

The implied values of land and labor constraints are all shown in Tables 3A, 3B and 3C. One way of reducing acute labor bottlenecks and levelling out the demand for labor through the year is to introduce suitable new products. For example, the introduction of quick-maturing maize dramatically reduces the value of the critical planting constraints and shifts the major peak to weeding. The introduction of cotton does not have such a marked influence on the pattern of labor demands, although it makes the medium weeding constraints more important. In general, the value of land decreases as it becomes more abundant in relation to labor, as one would expect, and the decrease is most marked in the cotton system in which the land value is very high at low land/labor ratios. Values are high for planting resources which include the whole ox-and-plow team, but not very high for labor alone at other times.

The possibilities of hiring additional labor resources at times when their value is high needs to be considered in the context of high rainfall and low rainfall, as well as average rainfall situations. The prevailing rate for casual labor in Masii in 1962/63 was about Sh. 4/ per man-day with little seasonal variation. There were indications that a man-day of casual labor was not considered as productive as the family labor equivalent. Nearly all of the casual labor came from other farms. Taking the results presented here for average rainfall years alone, it would appear to be worthwhile for farmers with very low land/labor ratios to work for farmers with higher land/labor ratios at weeding and September harvesting times. Differences in managerial ability might make it worthwhile for labor from poorly managed farms to transfer to better managed farms as well, although this possibility was not investigated in the analysis. A considerable amount of labor is hired for weeding and September harvesting in Masii, and this supports the above conclusions even though they are incomplete without the high and low rainfall considerations.

The high shadow prices for planting resources suggest that it might be worthwhile to hire additional resources for early planting, although this becomes less attractive with the introduction of quick-maturing maize. But in practice it is almost impossible to get ox-teams early in the rains in Masii, when all available teams are very fully employed. It would be interesting to investigate this further to see whether the supply of oxen and plows needs to be augmented, or whether alternatively the extension of tractor cultivation would be worthwhile. There are one or two tractor hire services operating near Masii, but they have always had a limited market on the very large farms, and they have shown no signs of extending their market in the last ten years or so.

The liquidity constraint which is often thought to be a major factor limiting farmers' ability to hire resources did not appear to be serious in Masii. Pigeon peas and cotton are harvested just before the new season begins, and these provide a means for payment of casual labor on many farms. Except in years following severe droughts, it is only on the very poor farms that liquidity is likely to be a serious enough restraining factor to limit the hiring of additional resources at times when they would be valuable. These are often the farms from which the selling of labor services is worthwhile rather than hiring anyway.

SUMMARY AND CONCLUSIONS

In this paper, the use of a linear programming model for an analysis of peasant farm production in which the primary interest was the constraints has been demonstrated. The formulation of the model for the analysis of a peasant farm production system was discussed first. Among the central features of this analysis are the emphasis on alternative treatments of crop mixtures as much as on different crop mixtures themselves; the choice of varying lengths of labor time periods determined by the importance of timeliness of operations; the treatment of uncertainty through a consideration of solutions for both average and extreme natural conditions; and the parametric variation of resource endowments to achieve a measure of general applicability for the results of the analysis.

Three alternative production systems were compared: a traditional system, a system with quick-maturing maize, and a system with cotton. Cotton represented some improvement over traditional crops at very low land/labor ratios. At high land/labor ratios quick-maturing maize represented a more significant improvement. Neither of the improvements was substantial enough to render one optimistic about the future.

While it is argued that it is not worthwhile doing this type of analysis for individual farms, if done for a region, linear programming analysis can provide important guides to: (a) optimal product mixes and optimal production techniques; (b) the effect of innovations; (c) problems that need research and solution; (d) shadow prices of critical resources. Two of the more important questions relating to the development of an agricultural area are which products to encourage and what problems to emphasize in research. A linear programming analysis can show which products, existing and potential, are most promising. It can also show which constraints are most serious and most merit research. By way of illustration, the present analysis suggests that it would be particularly worthwhile to develop more efficient methods of weeding, harvesting pigeon peas and cotton, and performing the cultivating and planting operation. The possibilities of using more efficient hand tools, herbicides, small mechanical aids, and large-scale mechanization, could all be considered. There has been a tendency to disregard labor problems because of the general assumption that labor is not scarce. But if we are to employ more labor in farming, we need to consider increasing its productivity at peak periods by methods such as those listed.

On the product side, the analysis suggests that cotton and drought-resistant maize alone are not going to provide substantial increases in incomes, and that the optimism attached to new crop developments such as these can be ill-founded. More efforts will still have to be made to find solutions for semi-arid areas like Masii.

More generally, the analysis throws light on the nature of the labor problem in small-scale farming systems, the poor prospects for employment generation in agriculture in areas like Masii, and the potential value of this type of analysis for investigating employment and other resource problems in traditional agricultural areas in developing economies.

CITATIONS

1 Venkareddy Chennareddy, "Production Efficiency in South Indian Agriculture," *J. Farm Econ.*, 49, 4, Nov. 1967.

2 E. S. Clayton, "Economic and Technical Optima in Peasant Agriculture," *J. Agr. Econ.* (Edinburgh), 14, 3, May 1961.

3 Pierre de Schlippe, *Shifting Cultivation in Africa: The Zande System of Agriculture* (London, 1956).

4 Judith Heyer, "Agricultural Development and Peasant Farming in Kenya" (unpub. Ph.D. diss., London Univ., 1966).

5 W. D. Hopper, "Allocation Efficiency in Traditional Indian Agriculture," *J. Farm Econ.*, 47, 3, Aug. 1965.

6 R. F. Hutton, "Operations Research Techniques in Farm Management: Survey and Appraisal," *J. Farm Econ.*, 47, 5, Dec. 1965.

7 R. W. M. Johnson, "The African Village Economy: An Analytical Model," *Farm Economist* (Oxford), XI, 9, 1969.

8 Michael Lipton, "The Theory of the Optimising Peasant," *J. Dev. Studies* (London), 4, 3, Apr. 1968.

9 A. M. M. McFarquhar and A. Evans, "Linear Programming and the Combination of Enterprises in Tropical Agriculture," *J. Agr. Econ.* (Edinburgh), 12, 4, Dec. 1957.

10 B. F. Massell and R. W. M. Johnson, *Economics of Smallholder Farming in Rhodesia: A Cross-Section Analysis of Two Areas*, Supplement to *Food Res. Inst. Studies*, VIII, 1968.

11 J. W. Mellor, *The Economics of Agricultural Development* (New York, 1966).

12 T. W. Schultz, *Transforming Traditional Agriculture* (New Haven, 1964).

13 C. P. Timmer, "On Measuring Technical Efficiency," *Food Res. Inst. Studies*, IX, 2, 1970.

14 Martin Upton, "The Influence of Management of Farm Production on a Sample of Nigerian Farms," *Farm Economist* (Oxford), XI, 12, 1970.

15 C. R. Wharton, Jr., ed., *Subsistence Agriculture and Economic Development* (Chicago, 1969).

16 P. A. Yotopoulos, *Allocative Efficiency in Economic Development* (Athens, 1967).