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AN ECONOMETRIC ANALYSIS OF SMALLHOLDER TEA GROWING IN KENYA

A DISSERTATION

SUBMITTED TO THE FOOD RESEARCH INSTITUTE

AND THE COMMITTEE ON THE GRADUATE DIVISION

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

By

Dan Maxwell Etherington

December 1970

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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Approved for the University Committee on the Graduate Division:

Dean of the Graduate Division

ACKNOWLEDGMENTS

"Tea is a work of art and needs a master-hand to bring out its noblest qualities"

Okakura-Kakuzo

My chief debt of thanks is to the ninety-six farmers and their families who voluntarily and without payment gave so generously and willingly of their time during the course of the year-long survey to collect labour data. My chief regret is that they do not feature more prominently in a study that has turned out to be of a rather technical nature. I have a hunch that these farmers are indeed going to demonstrate a master hand.

The data collection phase of the study was made easier and more enjoyable by the cooperation and hard work of a good team of enumerators. I am particularly grateful to John arap Chepkwony and Stanley Njeru for their excellent supervisory work. I am also most grateful to the staff of the Kenya Tea Development Authority who gave willing assistance whenever it was requested.

Both the original survey and the subsequent analysis were financed by research grants from the Rockefeller Foundation, New York. The initial grant was made under the auspices of the Institute of Development Studies, University of Nairobi. The Rockefeller Foundation further extended themselves on my behalf by providing a full scholarship for the period of my stay at Stanford University. Both my family and I are extremely grateful for this assistance since it enabled us, as a family, to experience life on an American campus during a time of radical and significant change.

This study owes a substantial intellectual debt to the Faculty and graduate students at the Food Research Institute. They were the furnace in which poorly formulated hypotheses were refined and they showed remarkable forbearance when I continually brought the conversation around to my particular esoteric interest. Special thanks go to my thesis committee : Benton F. Massell, Pan A. Yotopoulos and C. Peter Timmer. Although not directly involved in the study, William O. Jones and Bruce F. Johnston were always a source of encouragement.

Fortunately I launched out on the research leading to this dissertation as a myopic optimist, underestimating the time and effort involved in the enterprise. Unfortunately I alone did not pay the price for my misjudgement : my family too have unwittingly had to bear this burden. I greatly regret the unread bed-time stories and the tears. But I am thankful that Maureen could read and reread the drafts and still give me the word and smile of encouragement without which this task would never have been completed. Richard (5) is particularly pleased that Daddy has finished his "feesis".

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CHAPTER I

INTRODUCTION

1. The Reasons for this Study

Exports of primary products are of vital importance to the economies of the less developed countries. Typically, agricultural products account for the largest share in export proceeds and form an important source of domestic cash income. Problems of employment, public finance, balance of payments, income distribution, price and income stabilization are thus directly related to the agricultural export sector. Consequently, the analysis of farmer response to changes in economic variables in this sector has important social and political ramifications.

While changes in relative factor and product prices can have extremely important effects on an economy, the economist studying the development of the export crops in a low income country is often faced with situations of extreme disequilibria in which any attempt to analyse farmer response in terms of carefully measured elasticities is either impossible or irrelevant. This is typically the case when a new crop is introduced into an economy. Here, the advent of a disease or the creation of structural bottlenecks elsewhere can lead to bursts of activity in the domestic export sector. Similarly, idle potential may await the building of an improved means of transport. When constraints are imposed on competitors, or domestic constraints removed, shifts - often radical shifts - can occur in product supply functions. The history of the development of any of the major export crops is rich with examples of dramatic increases in output in particular countries.[1] The Kenya tea industry provides a modern example of this.

Radical changes in supply functions call for economic analysis in which prices play a minor role. This is particularly true of the "small country" case where the producer is faced with a relatively elastic demand curve for his product. Concern in this case is primarily with the rate of increase in output and the resultant effects on income and employment. Increases in the output of perennial crops are, by the very nature of their poly-periodic production functions, determined by past inputs in planting, current maintenance (and harvesting) inputs, and the botanical characteristics of the crops. Where the planting takes place over a number of different seasons a cohort or vintage structure of production results.[2] Provided the relevant 'life cycles' are known, such structures greatly facilitate prediction. An obvious application of this is in the use of demographic data to estimate the future demand for goods or services.

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[1] For the case of rubber in Malaya see Knorr (19) p.11. For coffee and tea in Ceylon see Courtenay (6) pp.40-41 and also Wickizer (29) p.31.

[2] There are likely to be many constraints (e.g. capital, planting material, labour or land) preventing an immediate, single season adjustment to the new market situation. Thus, even if a farmer decides that planting X trees of a new crop will maximise the present discounted value of the net returns on his investment, it may take him a number of years to achieve the desired stock of trees.

Here younger age groups (i.e. cohorts) can be moved up a population pyramid and compared in size and composition to older age groups and the likely effects on demand gauged. Similarly, given the age distribution of an existing stock of trees and knowing the rate at which productivity increases as a tree matures (i.e. the yield or growth curve of the plant), then the output for the next few years can be reasonably well predicted (the vagaries of the weather being ignored).

Thus information on the rate of planting and the rate of maturation may be vital for efficient planning during the phase of rapid development of a new perennial crop. The information is also of some importance in estimating the supply elasticities when the industry is more nearly in equilibrium. It was the lack of data on the rate of maturation that forced Miss Peter Ady to adopt a nine year price lag in her estimation procedure for a long-run supply elasticity for cocoa (1). Thus she misspecified the output-planting relationship and ignored the contribution to total output of immature plants prior to their ninth year. Professor Stern in cocoa (24) and Francis Chan in rubber (5) employed the same lag technique. In the case of rubber the misspecification is not important, since the full latex flow is achieved soon after tapping is started. But with cocoa and other important perennial tree crops, such as coffee and tea, the move to maturity is more gradual and significant levels of production are achieved in the three to four years before maturity. In the face of such difficulties, Bateman (2) has sought to develop supply models which may be used to estimate elasticities when planting and age data are not available.

In the case of the smallholder tea industry in Kenya, which is the particular concern of this study, planting and output data are available but the crucial yield parameters are imprecisely known. In the present state of disequilibrium, while the industry is expanding very rapidly, predictions of future output are required for the optimal phasing of road and factory construction. Furthermore, the phasing of the repayment of the international loans which finance the industry depends mainly on the level of tea yields actually achieved. This study addresses itself primarily to the limited but important task of estimating these yield parameters by estimating the parameters of the production function for smallholder tea in Kenya. The estimation technique developed has general statistical and economic validity. The method presented here is relatively simple and it has wider applicability. The data required can become easily available for other perennial crops from samples of relatively small size.

2. Background

Tea is made from the young leaves and the unopened buds of the tea plant, Camellia sinensis (L.) O. Ktze, a species of plant which includes widely different varieties.[3] Of the three main varieties — the China, the Assam and the Cambodian - the Assama jat (Hind. —caste) is most suited to East African conditions. The tree of this jat will grow to heights of twenty to sixty feet but, when cultivated in a tea 'garden', it is maintained by pruning to a height of less

[3]For a good summary discussion of the plant, its cultivation and wide geographical dispersion, see Harler's small book (14). Greater detail is contained in (7).

than three feet. As bushes or 'stumps' are planted close together, the mature garden looks like a luxuriant, well kept lawn, raised three feet off the ground. The term 'garden' is singularly appropriate for a field of tea. The flat, raised, surface of the tea garden is referred to as the 'plucking table'. The act of harvesting tea is aptly called 'plucking'. This involves the selection by the 'plucker' of young leaves and unopened buds which are easily broken off between thumb and forefinger and placed in a basket usually carried on the plucker's back.[4] In this state the tea is described as 'green leaf'. After processing in a factory the tea is referred to as 'made tea'. About four and a half pounds of green leaf make one pound of made tea. This made tea, from the Assam jat, is the common 'black tea' of the world tea trade. 'Green tea' (not to be confused with green leaf) is produced by a different method of manufacture and usually utilizes the leaf of the China jat. This is the traditional tea of the East.

Tea was first planted in Kenya in 1903, but it was not until the early 1920's that planting on a commercial basis was undertaken. Expansion of production in the 1930's and 1940's was severely restricted under the International Tea Agreement to which East Africa adhered until 1947 when the Agreement was terminated. By 1947 the total acreage was only 16,239 acres but since then the industry has grown rapidly. The initial expansion was along the lines that had become accepted practice in the leading tea-producing countries,

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[4]Mechanical plucking has been undertaken for a number of years now in Russia and Japan but this does not produce high quality tea.

India and Ceylon (Table 1): large estates of 500 to 2,000 acres each were cleared from forest land and planted with tea by companies that usually had extensive tea interests in Asia. Africans were at this time legally prohibited from growing tea. By 1957, estate acreage in Kenya had increased nearly 100 per cent to 30,500 acres. The growth of the estates continues at a steady pace (Table 2) while Kenya's overall 8.2 per cent per annum increase in output between 1958 and 1965 is considerably ahead of the 2 per cent per annum increase in world supply over the same period. Not only the absolute but also the relative importance of tea in the Kenya economy has increased. In 1957 tea exports accounted for 10.8 per cent of the value of the country's agricultural exports of £K26.4 million; by 1968 the figure was 22 per cent of £K47.7 million.

Table 1 - Comparative Statistics on Tea Acreage, Production and Exports of India, Ceylon and East Africa 1965, 1966*

Country	1965 area (thousand acres)	1966 production (million lbs.)	1966 exports (million lbs.)
India	853	825	395
Ceylon	594	490	441
East Africa	144	130	120
of which Kenya	61	56	50

* Source: Tea Board of India, Tea Statistics, 1966/67 pp.147-150.

Table 2 - Estate and Smallholder Tea Acreages and Production. Kenya 1959-1968.*

Year	Area (thousand acres)			Production (million pounds)		
	Estate	Smallholder	Total	Estate	Smallholder	Total
1959	36.1	1.6	37.7	27.9	...[a]	27.9
1960	37.0	2.3	39.3	30.4	...[a]	30.4
1961	39.6	3.4	43.0	27.7	0.2	27.9
1962	42.8	6.2	49.0	35.7	0.5	36.2
1963	44.4	8.4	58.8	39.2	0.7	39.9
1964	45.8	10.7	56.5	43.3	1.3	44.6
1965	47.8	12.7	60.5	41.1	2.6	43.7
1966	51.1	16.0	67.1	52.1	3.9	56.0
1967	54.0[b]	20.8	74.8[b]	46.7	3.6	50.3
1968	56.0[b]	27.0	83.0[b]	57.0	8.6	65.6

*Data from East African Tea Boards, Tea, January 1968; Kenya Tea Development Authority (KTDA) 1965-1968/8; and Kenya Ministry of Economic Planning and Development, Stats. Division, Statistical Abstract, 1967, pp.74,79. Production data are for "made tea" — dry, manufactured tea, excluding waste.

[a]Negligible.

[b]Provisional estimates.

However, it has been neither the estate sectors' growth nor the total growth of Kenya's tea industry that has been particularly rapid in recent years. Rather, it is the smallholder sector that has shown dramatic growth since 1960 (Table 2). This sector is adjusting to the disequilibrium caused by the removal of the technical, legal, financial, and administrative constraints that formerly prevented Africans from growing tea for the international market.

As the tea estates expanded, the Department of Agriculture became interested in the possibility of African smallholders[5] growing tea as a cash crop[6] although it was well aware of the failure of similar schemes in other countries.[7] Ecologically many African farming areas provided good tea land.[8] A recent survey (4) has suggested that these areas contain a total of some 1.5 million acres of suitable land. The Department then proceeded to experiment in

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[5] Kenya African smallholdings are typically 4 to 10 acres in size and may have ½ to 1½ acres under tea.

[6] It is worthy of note, however, that a certain initiative came from the African growers themselves. Thus the Agricultural Officer most concerned with initial developments in the Central Province wrote: "In the years directly after the last war, there was a demand from the people for the introduction of Cash Crops .... There were numerous (suitable) areas in the Central Province where tea would grow. This had been proved by the go-ahead African, some of whom had, in fact, brought home seedlings from their employers (on the Tea Estates), planted them in their back gardens and were producing a tea of a sort". (10, p.2)

[7] It was for this reason that Mr. Gamble visited a number of Asian countries early in 1950. His report contains numerous observations and recommendations which appear to have formed the basis for the subsequent approach to developing smallholder tea in Kenya. (19 pp.43-44 and pp.74-76). However, the general problems of smallholder tea producers in the older producing countries are not well documented. (But see 30, 21, 8, 11, and 15).

[8] A pH of between 4.5 and 5.5 (i.e. a fairly acid soil), and a rainfall within the 50" isohyet, and at altitudes of between 6,000 and 7,300 feet.

the early 1950's with both "block"[9] and individual gardens of tea. The individual gardens were more popular and produced a surprisingly high quantity and quality of tea.[10]

Slow initial progress was dictated not only by necessary caution but also by the growth characteristics of tea: tea seedlings (stumps) take two years to produce in nurseries; a further two years pass in the field before any tea is produced; commercially significant yields start in the sixth year; and maturity is probably achieved in the tenth year in the field. In addition, the early 1950's were marked by the severe administrative difficulties and political pressures arising from the Mau Mau rebellion (1952-1956). However, the Swynnerton Plan (1954) (25), with its requirements of viable cash crops for the African farmer, gave impetus to smallholder tea and encouraged the relaxing of the legal prohibitions against African growers. The first factory built especially for smallholders was

[9] A "block" was a unified stand of 5 to 20 acres of tea in which the surrounding farmers had shares.

[10] By 1958, yields of 1,400 lbs. of made tea per acre were being achieved by African growers (letter from Mr. Gamble to Director of Agriculture, 5th September 1958). For comparison, the highest yield I know of is that of 4,000 lbs. per acre from vegetatively propagated (VP) stumps on experimental plantings in Ceylon (13, p.42). The best Assam yields for seven year old tea are in the order of 2,400 lbs. (15, p.452). More generally, yields in India range from 102 to 926 to 1,200 in Bihar, Assam and Madras respectively (23, p.11). In the 1950's, the average yield of Ceylon estates was in the region of 650 lbs. per acre, while most smallholdings produced less than 250 lbs. of poor quality tea per acre (21, p.2). The fine plucking recommended by Gamble (9, p.75) culminated in the excellent reception of the first sample of smallholder tea taken to London (see footnote 11 below). The standards have remained high (see 27, p.35).

completed in 1957 at Ragati in Nyeri District.[11] The initial developments were the responsibilities of two marketing boards: the Central Province African Grown Tea Marketing Board and the Nyanza and Rift Valley Provinces Tea Marketing Board.

There is much evidence to suggest that the success of Kenya's smallholder tea scheme derives from the careful manner in which the industry was nurtured. Aside from answering the important question as to the willingness of African smallholders to be bound to a technically demanding crop, the early work in the Central Province evolved the technology needed for the long distance haulage of tea leaf from field to factory. It is essential that the leaves are well aired, are in the factory within six hours after plucking, and are not bruised on the journey since this results in pre-fermentation and the consequent loss of quality of made tea. It was shown that successful production of tea by peasant growers necessitated complementary organizational inputs of a large scale nature. This was true of nursery management, extension services, transportation, processing and provision of credit. There is little doubt that had the development been in the form of back yard plantings, the industry would be suffering from the same problems that have plagued smallholders in

[11] The first news of the quality of Ragati tea was contained in a letter from Sir Frank Engledow to the Director of Agriculture (A.R. Melville) dated 5th February 1960: 'I now have the opinions of tasters on the Ragati tea sample ... They are very favourable: The colour of the infusion is satisfactory and the liquor bright, lively, with a considerable briskness and pungency. These strange terms are used by tasters and all of them are, in this case, favourable. What it comes to is that they approve Ragati - the sample I brought home - as a very good tea.'

Ceylon.[12]

Because of the need for a central organization (22) to handle the international financing required for an expansion programme, a Special Crops Development Authority (SCDA) was established in 1960 and it took over the responsibilities of the marketing boards in 1962.

The first task of the Authority was to obtain finance from the International Development Association (IDA) and the Commonwealth Development Corporation (CDC) for two Development Plans. The First Plan (1960 to 1967) aimed to bring smallholder tea acreage up from 1,500 acres to 10,500 acres in 1965. The Second Plan (1964 to 1970) sought to raise the total to 25,000 acres by 1969. In fact these plans were completed ahead of schedule (see Table 2).

Since the SCDA dealt only with tea, its name was subsequently altered to the Kenya Tea Development Authority (KTDA). (For historical and organizational details see 16, 17, 26, 27, 22). At the same time its constitution was made more democratic by including elected growers' representatives on its Board of Directors. However, the Authority remains an all powerful autocratic organization; it is both monopolist and monopsonist. It has been the only legal source of planting material and the major source of credit. This position is further reinforced by the fact that the KTDA operates the entire extension system for smallholder tea farmers. It is a strict monopsony, being the only avenue through which farmers can sell their produce. Such a bi-lateral monopoly, dealing with some 40,000 debtors and creditors, could not have functioned with its present

[12] If evidence is needed, I refer the diligent researcher to the lengthy correspondence in Ministry of Agriculture files on the problem of persuading nine growers of an inferior China hybrid jat in Fort Hall District to uproot their bushes and plant high yielding Assam tea.

efficiency and moderate costs prior to the advent of computers. It has individual records for each farmer on the number of tea stumps bought in each year, the price paid for them, the credit advanced, monthly production figures, the amount paid to the farmer and his outstanding debt. There is indeed a mine of information here.

Fortunately the KTDA has remained faithful to its stated objective of promoting and fostering the growing of tea by Africans in Kenya. The rapid expansion of acreage since the Authority started operations is a measure of its success. Its raison d'être has been partly technical and partly financial: the field sector of its operations is financed partly by loans raised on commercial terms, and partly (and increasingly) from self-generating revenues received by cesses levied on growers - the cess income also provides revenue for the redemption of loans. Factories established for processing leaf grown by smallholders are separately financed (in part by the Authority) and are self-contained units. Apart from road construction and improvements and certain capital items required for Government-employed field staff, for which the Kenya Government provides grant finance,[13] the whole complex of tea development under the Authority's auspices is designed to be a self-contained financial entity (17).

By 1969, the administration of the KTDA had been completely Africanised with the exception of professional accountants. With the completion of its first two planting programmes well ahead of

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[13] This is a grant as far as the Authority is concerned, but the Kenya Government has financed these roads with IDA funds. (See (18)).

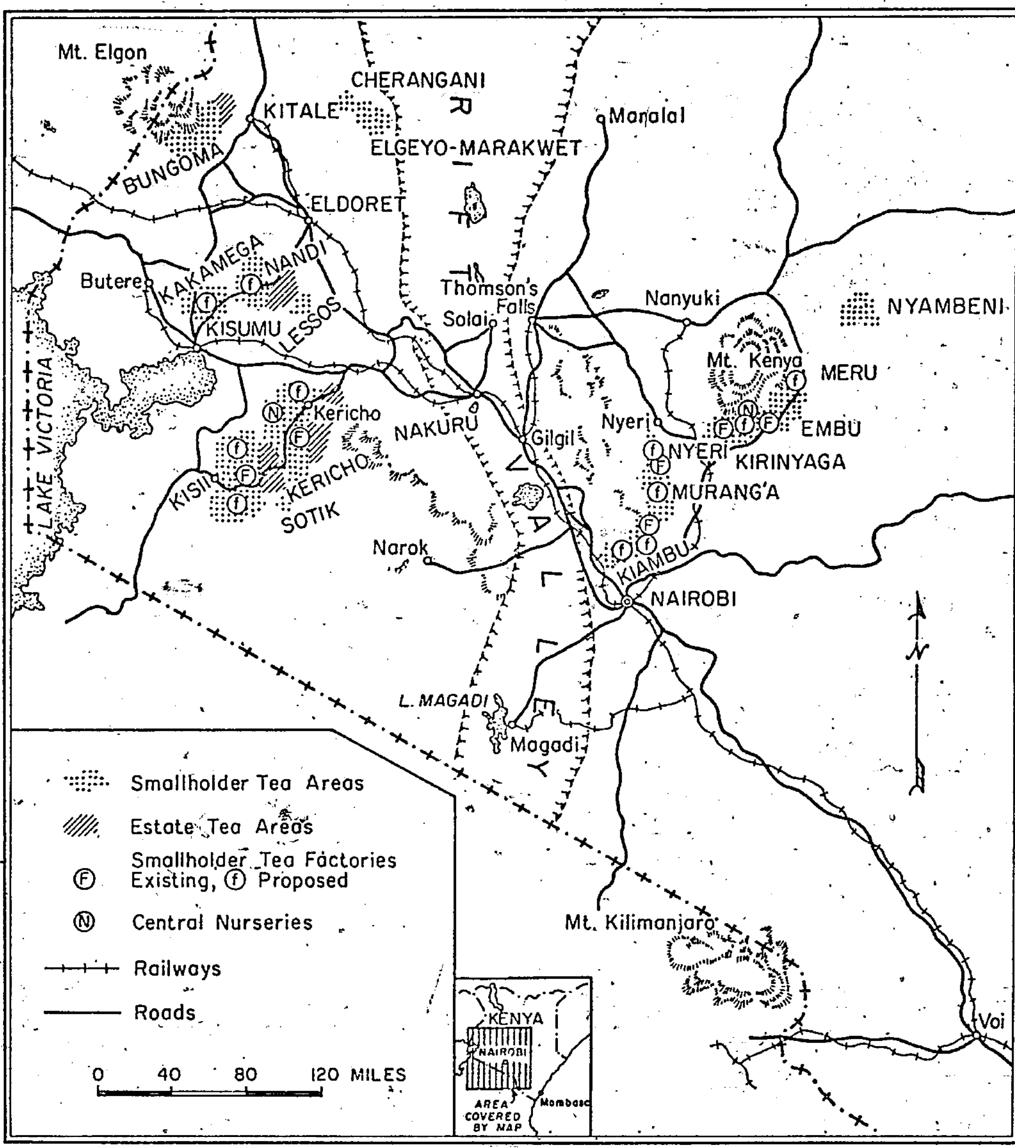
the 1970 season, the "Third Plan" has been started and calls for the planting of an additional 30,000 acres by 1973. This will bring the smallholder acreage to about 57,000 acres - a truly remarkable organizational achievement.

The accompanying map shows the main tea producing areas of Kenya together with important geographical features of the country. A distinction is made between estate and smallholder producing areas. The positions of the administrative Districts which feature most prominently in this study are also indicated.

3. The Field Operations

Since it is of considerable relevance to an understanding of later chapters, this chapter concludes with a very brief description of the field operations for tea (28). Tea seedlings are produced in central nurseries and at two years of age are pulled up, pruned to a four inch stock and are distributed to growers in time for the March-April planting season. The seedlings or "stumps", as they are called, have traditionally been produced from seed but as superior parent clones are discovered increasing emphasis is being placed on vegetative propagation. The stumps are planted in holes about two feet deep and 9 to 12 inches wide. The spacing adopted in the areas west of the Rift Valley has been 5' by 3' giving 2,904 stumps to the acre. East of the Rift, the spacing is 5' by 2½' giving 3,485 stumps to the acre. The time period between holing and planting should be kept as short as possible. Hence, planting is a period of intensive labour activity and unless the reasons underlying the recommended planting practices are clearly understood it may be tempting to do

ESTATE AND SMALLHOLDER TEA GROWING AREAS IN KENYA



a less than thorough job.

Once smallholder tea was seen to be a success the demand for plants rapidly outpaced the supply forthcoming from the nurseries. The situation has been difficult to rectify since there is at least a three year lag between the preparation of the nursery and the production of stumps from seed. In spite of having the largest tea nurseries in the world the KTDA has always found itself underestimating demand and, consequently, measures have had to be taken to ration the limited supply among growers. It is only now, with the recent isolation and testing of particularly good clones that can be vegetatively propagated (V.P.), that an end to this bottleneck is in sight.[14] The limited availability of stumps and the high labour requirements for planting mean that farmers seldom plant much more than a third of an acre (i.e. about 1,000 stumps) each year.

The fertilizer recommendations of the KTDA have been confusing and have not been pushed with much vigour by their extension staff.[15] Very little had been used up to 1966. Because stumps are pruned before distribution, it is necessary to shade each stump after planting in the field - this is usually achieved with three or

[14] The fact that some African farmers are now successfully producing V.P. stumps speaks well of the increasing sophistication of their agricultural practices. It was only a few years ago that the Chief Agricultural Research Officer wrote in a memorandum: "Much of the effort of the Tea Research Institute is being put into the development of V.P. techniques which are expensive and difficult and, in my view, beyond the reach of the indigenous cultivator for many years to come". (Memorandum from E. Hainsworth, C.A.R.O. 15th July 1960)

[15] This is hardly surprising as it is only in the last couple of years that the East Africa Tea Research Institute has really been able to show the economic advantages of fertilizer application. The KTDA stresses the need for further research. (16, p.18)

four bracken fronds. Since the ground has to be well cultivated and clean of all tree roots, the soil is usually lightly mulched until the plants themselves provide sufficient leaf cover - usually by the fourth year. As indicated earlier, tea takes a relatively long time to reach maturity. Although output commences in the third year in the field full maturity is only achieved by the tenth year.

High yields throughout the life of the bush, which may be 50 years or more, depend largely on the formation of a strong spreading 'frame' of lower branches, which must be developed during the early years after planting. Broadly speaking, the object of frame formation during the early development is to suppress the natural upward growth of the primary branches and to encourage the maximum possible sideways spread.[16] In addition, mature branches are periodically pruned to stimulate new growth and maximise yields (see 28,p.42); to remove unproductive or diseased wood; to bring the plucking table down to a manageable height; and to allow correction to an uneven plucking table by giving a fresh start. Pruning is supplemented by 'tipping in' which is essentially a form of light prune designed to give a plucking table parallel to the slope of the ground. Table 3 gives the KTDA's standard pruning procedure.[17]

[16] This is a technically demanding task and incorrect pruning in the early years is difficult to rectify. This was a major cause of concern during the "First Plan". See for example E. Hainsworth's 1962 Safari Diary (12). For the results of pruning experiments see (3). My own survey data indicate that there is a greater degree of specialization, and hence hiring of labour, in pruning than in the other tasks.

[17] Since the data for this study were collected, the procedure has been changed by the introduction of 'pegging' - a time-consuming task but one which produces excellent lateral coverage.

Table 3 - Standard Pruning Procedure of the KTDA*

Years after Planting	Height of Prune (inches)	Height of Tipping (inches)
1	6	-
2	11	-
3	-	30
4	16	30
5	-	-
6	20	30
7	-	-
8	-	-
9	22	30
10[a]	-	-

*Source: KTDA, Standard Procedure: Technical 2/66

[a]Thereafter raising the height by 2 inches at each subsequent prune, every three years.

Between prunes is the period of commercial production during which tea is harvested or plucked.

Plucking itself is a skilled task in which only two fresh leaves and a bud are taken as the saleable product. The correct shoots must be recognised and plucked while dormant shoots (technically called 'banjhi') are broken off and rejected, necessitating considerable manual dexterity. Mismanagement is common in plucking, which is not surprising given the newness of the crop and the skill required. In order that the many different ways in which mismanagement can occur might be appreciated, the KTDA's instructions on tipping and plucking are given as Appendix I.

In Kenya, plucking continues throughout the year with between 6 and 12 per cent of the annual crop coming in in any one month. During flush periods, 'plucking rounds' may be five days apart, decreasing to 10 days or longer at other times. A 'plucking round' is defined as the action of plucking all one's tea. The time between rounds is then the time between successive pluckings of any given bush.

Tea 'buying centres' are located along the roads in the tea-growing areas. Generally, a farmer will be within a mile of the nearest buying centre. The KTDA, through its Leaf Officers, arranges a regular collection schedule. Thus the farmer's responsibilities for the crop end with his delivery of the green leaf to the centre where it is checked for quality and weighed before being sent on to the factory for processing. The farmer receives a receipt for his leaf and is paid monthly, with about a two month lag between deliveries and payment.

4. Summary and the Plan of the Study

The agricultural sectors of many less developed countries have a vital role to play in the process of development and any rapid changes in the sector are of interest to the economist. Smallholder tea production in Kenya was really launched in 1960 and, in a manner carefully controlled by the Kenya Tea Development Authority (KTDA), is adjusting rapidly to a disequilibrium situation caused by the removal of legal and technical constraints. Tea is a crop requiring considerable care and skill during the establishment phase and the early years of the ten year maturation period. Prediction of future output is important for the efficient phasing of road and factory construction and international loan repayments. However, while planting and age data are available from KTDA records, tea yields are only imprecisely known. Although the particular case studied is of smallholder tea in Kenya, it is the prime task of this study to develop a general technique for estimating the yield parameters of perennial crops through a production function approach.

Following this introductory chapter, the study contains three main sections: the first (Chapters II and III) is concerned with the specification of functional form needed to estimate the output parameters for tea. The second section (Chapters IV and V) tests the various models and uses the results to predict output for different producing areas in Kenya. The last section (Chapters VI, VII, and VIII) discusses the role of management and labour in the function, and states the conclusions of the study.

CITATIONS

1 Ady, Peter, "Trends in Cocoa Production" Oxford University Institute of Statistics Bulletin, Vol.11 (1949)

2 Bateman, Merrill J., "Supply Relations for Perennial Crops in the Less Developed Areas" in Wharton, Clifford, (Ed.) Subsistence Agriculture and Economic Development (Chicago: Aldine, 1969)

3 Brandam-Jones, R. et al, "Bringing Young Tea into Bearing" Tea - Journal of the Tea Boards of East Africa (VI, No.3 1965)

4 Brown, Leslie H., A Report on the Tea Growing Potential of Kenya (Nairobi: Ministry of Agriculture, January 1966)

5 Chan, Francis, 1962, "A Preliminary Study of the Supply Response of Malayan Rubber Estates Between 1948 and 1959" Malayan Economic Review, Vol. 7 No.2 (October 1962) pp. 77-94

6 Courtenay, P.Q. Plantation Agriculture (New York: Praeger, 1965)

7 Eden, T., Tea, Second Edition (London: Longmans, 1965)

8 Gadd, C.E., "Small-holdings in Tea" The Tea Quarterly Journal of the Tea Research Institute of Ceylon V Part 3, 1932

9 Gamble, G., Report on Visits to India, Malaya, and Ceylon with some Notes for the Guidance of Tea Planters in Kenya, (Nairobi: Government Printer, 1951)

10 Gamble, G., Expansion of Tea Planting in the Central Province (Nyeri: Department of Agriculture, August 7 1958) Mimeographed report.

11 Hall, C.J.J. van, "Bevolkingsthee", DeLandbomo in de Indische Archipel, Vol.IIB, Hall, C.J.J. van and Kappell, C. van de, Eds. (Amsterdam, 1949)

12 Hainsworth, E., Safari Diary: Chief Research Officer Visits to the African Tea-Growing Areas in South Nyanza, 20-24 August 1962, (Department of Agriculture files).

13 Hainsworth, E., "Tea in Ceylon and Assam", TEA - Journal of the Tea Boards of East Africa (VIII, No. 3, 1967)

14 Harler, C.R., Tea Growing, (London: Oxford University Press, 1966)

15 Harler, C.R., "The Smallholder as Tea Cultivator", Investors Guardian - Tea and Rubber Mail (Feb. 19, 1965)

16 Kenya Tea Development Authority, Annual Report and Accounts 1966/67, (Nairobi: KTDA, December 1967)

17 Kenya Tea Development Authority, The Operations and Development Plans of the Kenya Tea Development Authority (Nairobi: KTDA, December 31, 1964)

18 King, John A. Jr., "Kenya Tea Roads", Economic Development Projects and Their Appraisal: Cases and Principles from the Experience of the World Bank, (Maryland: Johns Hopkins Press, 1967), Case 19.

19 Knorr, K.E., World Rubber and Its Regulations (California: Stanford University Press, 1945)

20 McWilliam, M.W., "The Kenya Tea Industry", East African Economics Review, VI No. 1 (1959)

21 Report of an Interdepartmental Committee on the Manufacture and Sale of Smallholder Tea, (Colombo, 1958), Mimeograph copy.

22 Reports of the Working Party Set up to Consider the Establishment of an Authority to Promote the Development of Cash Crops for Smallholders and of the Working Party Set up to Consider the Financial Implications of the Proposed Authority, (Nairobi: Colony and Protectorate of Kenya, 1960)

23 Report, The Finance Committee, (New Delhi: Government of India, 1964)

24 Stern, Robert M. "The Determinants of Cocoa Supply in West Africa", in African Primary Products and International Trade, I.G. Stewart and H.W. Ord, Eds. (Edinburgh: Edinburgh University Press, 1965)

25 Swynnerton, R.J.M., A Plan to Intensify the Development of African Agriculture in Kenya, (Kenya: Department of Agriculture, Nairobi, 1954)

26 Tea in Kenya, (Nairobi: Tea Board of Kenya, 1966)

27 Tea - The Journal of the Tea Boards of Kenya, Vol.VIII No.3, 1967

28 Tea Research Institute of East Africa, Tea Estate Practice 1966 (Nairobi: Tea Boards of Kenya, Tanganyika and Uganda, 1966)

29 Wickizer, V.D., Tea Under International Regulation, 2nd printing. (California: Stanford University Press, 1951)

30 "The Smallholder in Tropical Export Production", Food Research Institute Studies, (Vol.I, No.1)

CHAPTER II

THE PRODUCTION FUNCTION I

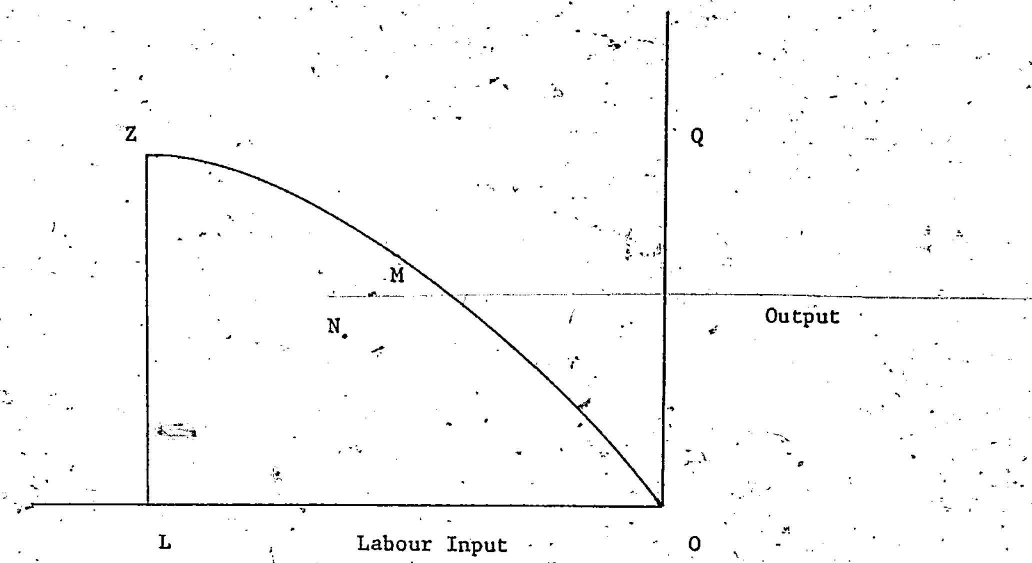
1. Its Logical Existence

A production function is a mathematical expression showing the transformation of a given set of inputs into a set of outputs. In the traditional theory of the firm, technical efficiency is assumed so that the production function shows the maximum output obtainable from every possible input combination. In terms of sets, we say that the production function traces out the subset of points on the boundary of the production possibility set. This is illustrated in Figure 1 where units of labour input are given negative values. The set represents the possible realizations of output of a commodity in response to labour inputs. The set is closed and bounded so that the concave curve OMZ of the boundary, or "frontier", represents the traditional production function of micro-economic theory. (17).

"The best utilization of any particular input combination is a technical, not an economic problem. The selection of the best input combination for the production of a particular output level depends upon input and output prices and is the subject of economic analysis". (7, p.44).

Since economists make some claim that their discipline is a positive science, the estimation of production functions is an important aspect of their attempt to explain "what is". In agriculture, it is often possible to design experiments to generate the

Figure 1 - A Production Possibility Set for One Variable Input



necessary data (6). In these circumstances, the major analytical problem revolves around the appropriate choice of function. With nonexperimental data, such as are used in this study, the problems are more complex. We are faced with the initial, philosophical question as to the existence of the production function and, if it exists, what specifically our observations and variables mean. For, "without specifying explicitly what produces the observed data it is impossible to draw any 'structural' conclusions from nonexperimental data". (5, p.283)

Ideally, from time series data on a given firm with constant technology but with a set of changing factor prices and product prices, we should be able to trace out a production surface. The changing factor prices trace out the isoquants while, at constant factor prices, the changing product prices reveal the expansion paths. Rarely are we in a position to have these data — either because relative prices do not change significantly or because technology changes and hence the production function itself changes. For permanent crop agriculture, the long maturation periods between planting and harvesting mean that observations must cover a number of years - a period often too long for one to assume constant technology.[1] In these circumstances, any straightforward relationship between price and output (or planting) may be tenuous. In general, with any time series data (for a firm, an industry or a country) technological change must be explicitly catered for.

However, it is not only with regard to the constancy of technology that the maturation period is important; it also implies a poly-periodic production function. As will be discussed in the next section, the crucial inputs are those undertaken at and around the time of planting. Here the number of tea stumps planted and the care with which they are planted affect the future stream of output critically. In the circumstances, a model incorporating "point input" and "multipoint output" is appropriate. Assuming that the farmer is only concerned with his tea (this is, of course, a gross over-simplification),

[1] Thus improved varieties and cultural practices have, in recent years, led to very substantial yield increases in cocoa, rubber, palm oil and tea (a matter to which we shall return).

then clearly, if economically rational, he will wish to maximise the present value of net profits subject to the technical constraints imposed by his production function. What are his decision rules? Let:

$$\pi^* = \sum_{t=o}^{T} p_t \; q_t \; (1+r)^{-t} - \sum_{j=1}^{n} w_j \; x_j + \lambda F(q_o,..,q_T;x_1,..,x_n) \qquad \text{(II - 1)}$$

be the farmer's constrained profit function,

where

q_t = expected output of green tea leaf in year t (t = o,...T)

p_t = expected price of green leaf in year t

r = rate of interest (0<r<1)

w_j = price of input j (j = 1,...,n)

x_j = input j (j = 1,...,n)

Then the first order conditions for a maximum are:[2]

$$\frac{\partial \pi^*}{\partial q_t} = p_t \; (1+r)^{-t} + \lambda F_t = 0 \qquad \text{(II - 2)}$$

$$\left(\text{where } F_t = \frac{\partial F}{\partial q_t}\right)$$

$$\frac{\partial \pi^*}{\partial x_j} = w_j + \lambda F_j = 0 \qquad \text{(II - 3)}$$

$$\left(\text{where } F_j = \frac{\partial F}{\partial x_j}\right)$$

$$\frac{\partial \pi^*}{\partial \lambda} = F\,(q_o,..,q_T;\, x_1,..., x_n) = 0 \qquad \text{(II - 4)}$$

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[2] The second order conditions for the maximization of this function are that the relevant bordered Hessian determinants alternate in sign.

Being particularly interested in the input-output relationship, we divide (II - 2) by (II - 3) to get

$$p_t(1 + r)^{-t} w_j^{-1} = -F_t F_j^{-1}$$

which, by the implicit function rule (where $F_t F_j^{-1} = -\frac{\partial x_j}{\partial q_t}$) means that

$$w_j = p_t (1 + r)^{-t} \frac{\partial q_t}{\partial x_j} \qquad \text{(II - 5)}$$

Equation (II - 5) simply states that the farmer should increase the amount of input x_j until the discounted value of the marginal product equals the input price (w_j). But for the time element and the discount factor (r) this is the standard input optimization rule. There are two particular points of interest: in the first place, q_t was defined in terms of expected output since tea is a new crop to the farmer and he may not fully appreciate the impact on future output of the complicated planting and pruning instructions passed on to him through the KTDA extension service. In most of the producing regions in which tea grows well in Kenya it is the first perennial crop with a long life span.[3] It is, therefore, not unlikely that the farmer has a hazy view of the future output stream and how it might be influenced by those labour inputs that are highly complementary with the number of stumps planted. This theme is taken up again later.

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[3] Pyrethrum is an alternative in some areas but the life cycle is only four years. Tea, on the other hand, has a life span of fifty years or more.

The second point of interest in equation (II - 5) is that there is a readily available discount rate which is the same for all farmers. The farmers can obtain credit from the KTDA for stump purchases up to sixty per cent of the cost of planting one acre of tea.[4] The interest rate on this loan is 6½ per cent per annum.[5] After a farmer has planted one acre, credit is no longer available from the KTDA for this purpose, but very often commercial bank loans (at 9 per cent) are available owing to the regular, monthly nature of the receipts which the KTDA often pays directly into a farmer's bank account. If the investment is worthwhile on loan capital at 9 per cent then it will certainly be worthwhile at 6½ per cent with funds limited to this purpose. Conversely, farmers may well cease to plant tea after reaching the one acre limit. Having these discount rates sidesteps the possibility of every farmer using his own rate of positive time preference and hence preventing any meaningful interpretation of the relative performance of different tea farmers.

The foregoing discussion suggests some of the reasons why there will be a scatter of observations from cross section data such as are used in this study. Theoretically, if one works from the assumptions of technical and price efficiency and of a perfect market for the factors of production, then all firms should be located on the same expansion path. Add to this an assumption of a perfect

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[4]The full price of a stump is 30 cents and there are, on average, about 3,000 stumps per acre. Thus the capital cost for material for planting an acre of tea is about 900 shillings.

[5]This is considerably below the open market rate but somewhat above the rate at which KTDA itself was paying the international lending agencies.

product market and then all input/output observations should be located at a single point at any one time. It is indeed a basic hypothesis of this study that in any given homogeneous geographical location there is a basic underlying, technically determined production surface. However, there are at least four reasons for supposing that there should be a scatter of observations on the production surface. First, individual assessments of the market may differ. Given the multiple time periods with which the farmers are dealing, the expectation of future prices (p_t in equation II - 1) is likely to vary among individuals. Secondly, the individual credit worthiness of farmers will vary. Some farmers may not have the initial deposit (of forty per cent) required for stump purchases. Such farmers are unlikely to have acceptable collateral for bank loans and the rural money market is not geared to long term loans. Thirdly, farmers may be price inefficient in input space. Thus they may be operating on the frontier production possibility set but using an input combination which does not reflect the relative factor prices. Lastly, as was indicated in Chapter I, there has been an inadequate supply of planting material. The limited supplies are rationed out at set prices to those farmers with the desire to plant and with sufficient cash to pay the deposit for the tea stumps. The rationing at the local level is done by elected representatives of the growers and has tended to be fairly egalitarian. No trading is permitted among recipients of the stumps. Thus while optimization in input/output space (equation II - 5) may indicate one level of production, the limitation on a factor's supply restricts the domain and, if the restriction is binding, that input becomes a fixed factor of production. But for each farmer it may be fixed at a different, arbitrary level, i.e. it is dependent on the allocation committee's decision.

This explanation as to why, with a given set of factor prices, we obtain observations along a segment of the production function, conforms basically with the classical approach of Marschak and Andrews. However, our fixed factors include not only entrepreneurship[6] but also the constraint on the supply of planting material.

Next, the scatter about the function must be noted. Provided the production function is indeed correctly specified and all relevant variables are included, then there remains the "noise" of minor stochastic errors which should conform with an a priori defined probability distribution. However, because of the lack of knowledge about the production process, or for lack of adequate data, the economist is rarely able to specify the full set of conditional probability distributions in a stochastic relationship but rather must specify the parameters of the most important subset. In these circumstances, the omission of variables or the misspecification of included variables will increase the residual errors and bias the coefficients of the included variables.[7]

The discussion thus far has been traditional in assuming that

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[6] See, in particular, A.A. Walters discussion of the Marschak and Andrews model and the exogenous variable (16, p.14-16)

[7] Yotopoulos gives one of the good formal presentations of the logic of this section (18, Chapter 3).

technical efficiency exists.[8] That is to say, the traditional production function describes only the efficient techniques whereby maximum output of a desired commodity is produced for given inputs. For many years divergence from technical efficiency was deemed to be a management problem and so outside the range of economics. This is no longer the case (see, for example, 1, 3, 10, 13, 15, and 17). "Everybody" knows that in any industry there are firms who are less efficient than the best. Thus firms are not all producing along the efficient frontier of the production possibility set but also at inefficient interior points, such as point N in Figure 1. Once this has been admitted, then the stochastic error term contains more than just random "noise". One is no longer estimating a purely statistical average of a scatter of points along the frontier, but some interior "average".

> Some firms could therefore produce more than the average; some less. But the meaning of such an "average" function is not necessarily clear. Average in the sense of what? A conditional median? a mean? or a mode? More importantly, average about what? about some input? about technology? or about something else? Some economists refer to it as the function for a "firm of average size". This interpretation cannot be correct unless it is assumed that the parameters of the function are random variables and have their expectations equal to those of the firm of "average size". Others seem to refer to the average function as reflecting some sort of "average technology". (1, pp.829-830)

The problem can be illustrated by a modification of Figure 1. Instead of a production possibility set with a single efficient frontier production function, it is suggested that there exist a

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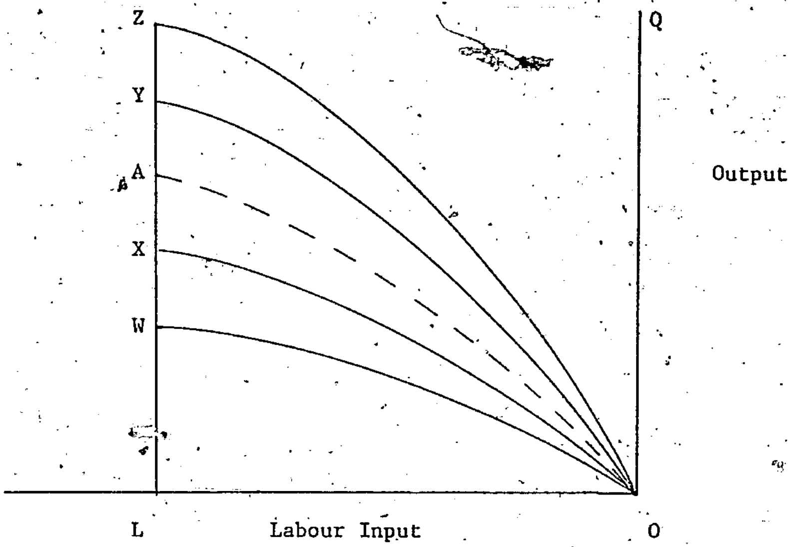
[8]The following discussion owes a heavy intellectual debt to Peter Timmer and, in particular, to his lengthy discussion paper 15.

Figure 2 - Differing Efficiency Levels in a Production Possibility Set



family of production functions depicting various efficiency levels. For example, four levels of efficiency are depicted in Figure 2.

OZ is still the efficient frontier. OY, OX and OW are progressively lower efficiency levels, while OA is the function "reflecting some sort of 'average' technology' ".

The conclusion is that in situations of rapid technological change or where there are other reasons for believing that technical efficiency on the part of firms is an unacceptable hypothesis, explicit account must be taken of this in the specification of the production function. Clearly, a hypothesis of technical efficiency must be unacceptable in the case of the smallholder tea production in Kenya since this is a new crop with the whole range of unfamiliar production techniques, or cultural practices, noted at the end of Chapter I. This is not a case where there is some constant rate of technical progress with the progress embodied in the relevant vintage. Neither is there merely a single technical innovation being accepted along the usual logistic adoption curve for new practices. Rather it is a situation where a single new product, with a technology radically different from that used on the common annual food crops, is incorporated into the multi-product farm. Consequently, even among the farmers who "accept" tea (i.e. plant tea stumps) there will be a wide range in the degree to which the total package of innovations is accepted. It will become important for this study to be able to distinguish between "better" farms (which have adopted in full the new technology), "average" farms, and those performing worse than average.

This concern with "technical efficiency" is nothing new. Within the less developed countries the variability in efficiency between farmers has for long found explicit expression in such descriptive phrases as "Progressive Farmer", "Master Farmer" or "Better Farmer". The mounting literature on the subject is evidence of the growing interest of economists in explaining the wide range in efficiency found in cross-section studies of firms (3, 9, 10, 11, 13, 15). Agricultural extension services and economic theory recognise that the ultimate responsibility for the degree of efficiency on a given farm must lie with the farmer himself and his managerial ability. It is thus an essential requirement of this study that adequate attention be paid to the problem of "technical efficiency".

2. The Production Variables

A basic rule for choosing the appropriate algebraic form for a production function refers to the "logic, or the basic mechanics of the production process" (18, p.48). It was for this reason that the mechanics of tea production were discussed in some detail in Chapter I and why it is now necessary to elaborate further on the production variables before discussing the functional form in the next chapter.

The full set of production variables for smallholder tea can be represented as follows:

$$Q_{it} = F(X_{kit}, L_{it}, S_i, D_i, C_{it}, M_{it}, M_{it-1} \ldots\ldots M_{it-5}) \qquad (II - 6)$$

where

Q_{it} is the output of green leaf of farm i in year t.

X_{kit} is the number of tea "stumps" (i.e. bushes) of age k on farm i in year t.

L_{it} is the number of man equivalent hours spent in plucking tea.

D_i is an index of marketing difficulty constructed by measuring the distance of any farm i from the nearest tea "buying centre".

S_i is the land input of farm i.

C_{it} is the micro climate on farm i in year t.

M_{it}, $M_{it-1} \ldots M_{it-5}$ represents the present and past cultural practices of the farmer in terms of the optimum preparation of the land before planting; the correct spacing of plants; provision of adequate shade and mulch for young stumps; and, finally, correct pruning procedures and fertilizer application.

Output (Q_{it}) is measured in pounds of green leaf delivered by the farmer to his local "tea buying centre". It is here that the leaf is inspected for quality and that the farmer receives his receipt. Consequently, this is the logical point at which to measure farm output.

The first and most important of the input categories is the actual number of tea stumps planted in each year (X_{kit}).[9] At any one time, the farmer's stock of tea bushes consists of an amalgam of bushes of different vintages. In terms of its contribution to the total output of green leaf, each vintage is located somewhere along a logistic growth curve such as that depicted in Figure 3.

The structural parameters of this curve are unknown for any specific tea growing area in Kenya. All that is really known is that it takes nine to ten years for a tea plant to achieve maturity. Since this process of maturation is continuous (but for interruptions caused by pruning), the approximate shape of the curve is fairly obvious. Some intelligent guesses as to the position of the curve can also be made. This is essentially all that the KTDA has been able to do to date.[10]

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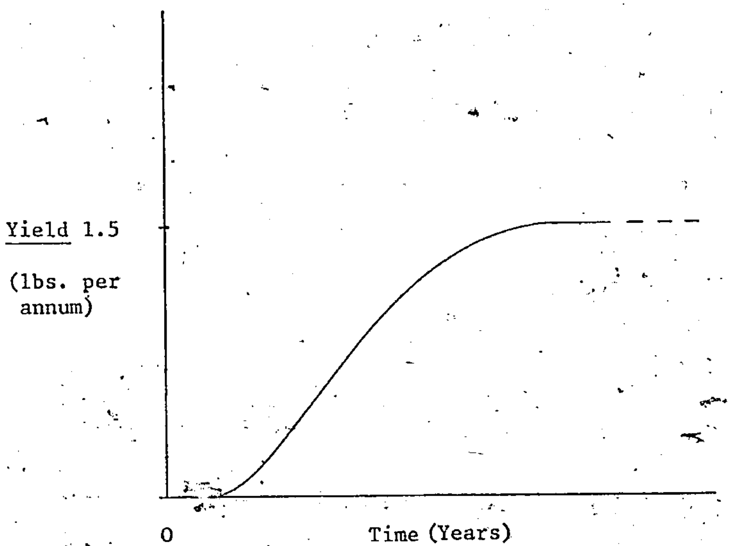
[9] Its primacy relates not merely to the fact that this is where the product grows but also to the farmer's decision making. The farmer's major economic decision is whether or not to plant tea. Once the stumps are planted, the farmer has a severely constrained set of decision parameters.

[10] The latest official communication on the subject is a 1968 article in the Journal of Tea Boards of East Africa by the Authority's chief technical officers, Mr. Gacoka and Mr. Green. (4).

Figure 3 - Hypothetical Yield Curve for a Tea Bush



The Authority arrives at its estimates by using recorded data from its tea training farm at Kagochi to draw a "bench mark" growth curve. Then, since this data refers to only the one specific area,[11] rule of thumb additions and subtractions are made to this curve to produce a family of curves similar to those depicted in Figure 2. The yield curve chosen for any particular area is that which appears to "fit" best with actual production obtained so far. Each curve is given a name or rating. The yield ratings currently in use are shown in Table 4 and range from Extra High to Extra Low.

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[11] Not only one area but one farm in the area. Their technique could be widened by examining the performance of all those farmers who planted tea in only one year. Although this is unlikely to be a representative sample, Brown appears to have received yield estimates from the KTDA obtained in this manner (2,p.7)

Table 4 - Kenya Tea Development Authority's Tea Yield Ratings*
(Pounds of made tea per acre by rating)

Year of maturity	Extra high	Very high	High[a]	Medium	Low	Very low	Extra low
3	300	250	200	150	100	50	25
4	600	500	450	350	250	150	100
5	850	700	650	500	400	250	150
6	1,100	900	850	650	500	350	200
7	1,250	1,050	950	750	600	400	250
8	1,400	1,200	1,050	850	650	450	300
9	1,500	1,300	1,100	900	700	500	300

*Data received directly from the KTDA, December, 1965.

[a]Actual yields obtained on Kagochi Tea Training Farm.

Normalised versions of these figures could be used to convert stumps of different ages to a "mature stump equivalent" and, hence, the total stock of bushes could be summed up to a "mature acre equivalent"[12] for any given farm, or group of farms. However, if data on plantings were available for many farms, it would be an unnecessarily crude procedure to build on the rather uncertain foundations of these yield ratings.

Given the planting data, how are the various vintages related to one another and to total output? Since there is unlikely to be any interaction between one vintage and the next, the relationship will be a linear one:

$$Q_t = \beta_3 X_{3t} + \beta_4 X_{4t} + \ldots\ldots \qquad \text{(II - 7)}$$

where Q_t is the output of tea in year t

β_3 is the yield of 3 year old tea stumps

X_{3t} is the number of year old tea stumps in year t
.....etc.

The linear function (II - 7), which, by itself, necessarily assumes that none of the other variables in (II - 6) is a binding constraint, is not only simple but intuitively appealing. All tea stumps sown from seed will not be identical, but differences will be random in most samples of seed (such as those of the KTDA), and,

[12] This is analogous to the procedure for calculating "man equivalent" units for labour and, indeed, when any vector of inputs is aggregated.

consequently, there is no reason to assume that there is any systematic divergence from a linear relationship between output and the number of stumps planted.

The next input category in the list of variables in equation (II - 6) of labour. L_{it} is the number of man equivalent hours[13] spent in plucking tea. Now labour is considered to be a prime factor of production in classical micro-economics and in this case it is certainly a necessary input: without labour there can be no output (in the sense in which it has been defined). But what is the line of causation? Does labour input determine output, or does the number of "two leaves and a bud" call forth a certain labour input? We have been careful to note the uniform and strict plucking instructions issued by the KTDA (see Appendix I). The KTDA, being the complete monopsonist, is in a position to ensure that its orders (?!) are complied with. It is interesting to note that the KTDA relates poor plucking to management[14] and not to the labour input per se which is technically determined by the length of time it takes the eye to seek out and the hand to pluck "two leaves and a bud".[15] If this is the relationship between output and labour then it is incorrect to include labour as an input in the production

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[13]We are immediately making as assumption that we know the appropriate weights by which we can "add up" male, female and juvenile labour. We don't know these weights. Here we are merely using the unit for convenience of exposition.

[14]See Appendix I, paragraph 2.(4).

[15]This is not to deny that there is a wide range in the skills of individual pluckers.

function. In other words, if our other inputs perfectly explain output, they would also perfectly explain the labour input. In statistical terms, this is a case of complete multicolinearity of inputs. In economic terminology, we have perfectly complementary inputs.

There is a possible objection to the above argument. No account is taken of relative product prices which may affect the labour input in any one crop at any one time. But this implies that labour is a binding constraint in the production process. Two technical aspects of tea production should be recalled: first, plucking "rounds" are spaced between five and ten days apart and any one buying centre is in operation two to three days a week. Secondly, tea in Kenya is harvested throughout the year without the peak labour demands usually associated with agriculture. In spite of the high labour demands of the crop, these two factors allow a distinct range of flexibility in timing which minimises the competition between tea and other crops for labour services. Furthermore, in these rural areas hired labour is available at costs substantially below the legal minimum (or union) wages forced upon the large scale estates.[16]

There is the additional problem of the labour inputs other than plucking. These are "clearing and digging", "planting", "mulching", "weeding", "pruning" and "delivery to buying centre".

[16] Thus the rural wage rate in tea growing areas is about sixty shillings per month while estate wages are nearly double this figure and the estates provide superior accommodation and social services. Against these higher wages should be set the stricter discipline insisted upon by the estates.

The first three are related to the initial life of the stumps. Improper planting procedures are probably more important in determining the vigour of the bushes than is the actual time spent on the operations. Consequently these inputs are better classified as managerial than labour. The same is true of the last item, pruning. Unlike many other perennial tree crops, the weeding requirements are minimal after the fourth year in the field. The close spacing of the bushes, the wide lateral growth of the branches and the dense foliage block out light from the ground and consequently inhibit the growth of weeds. The last category, "delivery to buying centre", is considered below.

There are two aspects to the input of land (S_i) on a given farm - quantity and quality. The smallholder producer has not had much choice regarding the spacing of his plants - the same recommendations go to all growers. Consequently, there is a fixed relationship between the quantity of land and the number of stumps planted. We therefore regard a planted stump as composed of the stump per se plus its associated land. As far as quality is concerned, soil fertility will undoubtedly vary somewhat between farms and between fields on a given farm. Furthermore, the variability is likely to increase as the size of any given sample area increases.

The analysis of the effects of varying climatic conditions on the growth and productivity of the tea bush has been the subject of many scientific articles (see, for example, 12 and 17). The important variables for the micro-climate (C_{it} in equation II - 6) relate to both meteorological and plant conditions. A list of the variables would include at least the following:[17]

(1)	Meteorological:	Radiation or sunshine hours Mean air temperature Mean temperature of dew point Mean run of wind Rainfall
(2)	Plant/Soil:	Depth of tea root zone Water content at field capacity Water content at wilting point

We are interested in two dimensions of the micro-climate: the inter-farm variability ($C_{i \cdot}$) and the inter-year variability ($C_{\cdot t}$). Inter-farm differences in climate, as with soil, are likely to increase with the size of the sample area. Climatic conditions on neighbouring farms are likely to be nearly identical since each farm is only about ten acres in size. A given tea buying centre will have tea delivered to it from farms within a radius of about one mile and here again, but for a minor exception noted below, climatic conditions can be considered to be uniform. The size of area which can, for our purposes, be considered to be homogeneous regarding land and climate will be the subject of later statistical analysis.

The data demands for intertemporal climatic changes are, as the above list indicates, considerable. Were the data available it would be possible to calculate a water deficit for each month and hence some annual index of climatic influences. However, as is so often the case, the only variable on which information is readily available is rainfall. While rainfall is obviously important, the tea areas of Kenya generally receive rainfall every month and it is the rare year (e.g. 1967) when moisture is a limiting factor (see 12, p.390).

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[17] For details see (17).

Some of the tea growing areas of Kenya face an additional problem which impinges on both dimensions of the micro-climate. The problem is that of hail damage (14). Hail storms tend to be so highly localised as to affect individual farms rather than groups of farms. The width of a hail storm may be only a couple of hundred yards across and its path random. A severe hail storm will rip off most of the leaves from the bushes and has the same effect on immediate production as pruning but, unlike pruning, gives no long run benefits. It may take three months for the plants to recover. Hail introduces some very genuine exogenous "noise" into the data set. The rogue elephant which caused similar damage in days of old was usually shot. Rocket technology has introduced a similar approach to solving the hail problem! (see 8).

It is possible that the distance that a given farmer has to carry his produce to the market might be a limiting factor on output. That is to say this transportation factor (D_i) might impose a maximum quantity that the farmer is able or willing to carry. It is with this consideration in mind that the KTDA has tried to keep growers within a mile of a buying centre. Given this type of grouping, the problem of transporting leaf from the garden to the centres is not likely to be serious.

We turn, finally, to the managerial input (M_{it}, M_{it-1}, $\ldots M_{it-5}$), both in the current year and previous years. While management is of importance throughout the life of the plant, it is the careful nurture of the young tea plant that is particularly critical and justifies our describing the multiperiod production function as a point-input - multipoint-output process. There are, however, many phases in the cultivation of tea during which it is possible for the smallholder not to achieve technical efficiency. The potential for inefficiency starts in the pre-planting phase and continues right through the plucking phase. Thus it is possible for a good farmer to turn to bad practices at any stage in the life of the plant with a resultant adverse effect on yield. The converse is, however, more likely. It is more usual for less efficient farmers to try to raise their level of management. The problem here is that poor planting and pruning practices in the early years affect the frame and formation of the bush in a manner that cannot be reversed. It is therefore reasonable to consider there to be a single management variable on each farm that does not change over time. Hence, in the next chapter, we shall consider M_i as a management variable and exclude the time subscripts shown in equation (II - 6). Thus the ultimate responsibility for inefficiency is placed on the managerial abilities of the farmer. The problem with placing so much weight on this factor is that, unlike the other inputs, "... there is no generally accepted cardinal measure of entrepreneurship". (16,p.5) "Since it is a non-observable, non-measurable input, management is judged by the results of its decisions, i.e. by the degree of efficiency achieved in production". (15,p.8)

3. Summary

This chapter has been concerned with a discussion of the nature of the production function for smallholder tea from both theoretical and practical points of view. The theoretical implications of the poly-periodic production process were examined and reasons were advanced as to why it is likely that there will be a scatter of input and output data points for these farmers. The practical importance of a set of six production variables was then discussed in detail.

The next chapter will discuss the specification of a statistical production function that is consistent with the hypotheses that have been advanced as to the nature of the production process. For this specification to be correct, the variables that have been discussed must be included, if not explicitly, then, at least, implicitly.

CITATIONS

1 Aigner, D.I. and Chu, S.F., "On Estimating the Industry Production Function", American Economic Review, LVIII, No.4 (September 1968) pp. 826-839.

2 Brown, Leslie H., A Report on The Tea Growing Potential of Kenya (Nairobi: Ministry of Agriculture, January 1966).

3 Farrell, J.J., "The Measurement of Productive Efficiency", Journal of the Royal Statistical Society, Series A (General) Vol.120, part 3 (1957).

4 Gacoka, P. and Green, T.R.M., "Yield Performance of KTDA Smallholdings and Method of Estimating Future Production", Tea - The Journal of the Tea Boards of East Africa IX, No.3 (October 1968) pp.26-27.

5 Griliches, Z., "Agricultural Production Functions by Earl O. Heads and John L. Dillon". Review. The American Economic Review, LII (March 1962) pp.281-283.

6 Heads, Earl O. and Dillon, John L., Agricultural Production Functions, (Ames: Iowa State University Press, 1961) pp.1-667.

7 Henderson, James M. and Quandt, Richard E., Microeconomic Theory, (New York: McGraw-Hill, 1958) pp.1-291.

8 Henderson, T.J., "Hail Suppression Project Utilizing Anti-Hail Rockets", TEA - Journal of the Tea Boards of East Africa, (VI. No.2, 1966).

9 Kilby, Peter, "Organization and Productivity in Backward Economies", Quarterly Journal of Economics (LXXVI No.2, May 1962).

10 Lau, L.J. and Yotopoulos, P.A., "A New Test for Relative Efficiency and an Application to Indian Agriculture", (Unpublished manuscript: Stanford 1970) pp.1-33.

11 Leibenstein, H., "Allocative Efficiency vs. 'X-Efficiency'" American Economic Review, Vol. LVI, No.3 (June 1966).

12 McCulloch, J.S.G., et al, "The Effect of Shade Trees on Tea Yields", Agricultural Meteorology (No.2, 1965) pp.385-399.

13 Nerlove, Marc, Estimation and Identification of Cobb-Douglas Production Functions, (Chicago: Rand McNally & Co., 1965) pp.86-100.

14 Sansom, H.W., "The Occurrence of Hailstorms in East Africa", Nubila (VI, 1961) pp.34-51.

15 Timmer, C. Peter, On Measuring Technical Efficiency. Food Research Institute Discussion Paper No.69-5 (June 1969) pp.1-120.

16 Walters, A.A., "Production and Cost Functions: An Econometric Survey", Econometrica (XXXI, No.1-2, 1963) pp.1-66.

17 Wilson, K.C., "The Design and Control of Irrigation Systems" TEA - The Journal of the Tea Boards of East Africa, (VI No.3, 1965) pp.28-29.

18 Yotopoulos, Pan A., Allocative Efficiency in Economic Development, (Athens: Center of Planning and Economic Research, Research Monograph Series No.18, 1967).

CHAPTER III

THE PRODUCTION FUNCTION II

1. The Data Set

From its inception, the Kenya Tea Development Authority has kept individual records for all smallholder tea farms. These records include planting data for each year, output data for each month and the debt standing of each grower. The data for this study were assembled in 1966 at which time there were more than 20,000 registered smallholder tea growers - each with his individual records being maintained by the Authority.[1] Tea is grown in twelve Districts of the country.[2] In each District, there are one or more "factory areas" - the local unit of control of the Authority - where detailed accounts of weekly tea deliveries by growers and monthly payments to growers are kept. This is also the operating unit of KTDA extension service, which has recently started to keep records on the cultural standards of individual farmers. Three of the Districts dominate the industry: in the first two "Plans", Kericho, Kiambu and Kisii Districts were to plant 10,350 acres out of the total of 25,500 acres. In addition, the amount of suitable tea land in these Districts was estimated by Brown (1) to be 714,000 acres, or half the total

[1]By 1969 there were close to 40,000 growers.

[2]The national administrative units are, in decreasing order of size: the Provinces (of which there are seven), Districts, Divisions, Locations and Sub-locations.

potential acreage in the non-scheduled areas.[3] Kericho and Kisii are "West of the Rift Valley" and are located in the Rift Valley and Nyanza Provinces respectively. Kiambu is "East of the Rift" in Central Province. (The Districts are shown on the map on page 14.)

During the period June 1965 to July 1966, the author, with a team of eight enumerators supervised by two senior enumerators, undertook the collection of detailed input and output data from a sample of 96 farms in these Districts. A two stage random sampling procedure was adopted. As a first step, all the Tea Buying Centres in each District were grouped into clusters so that each cluster contained 60 to 150 farms. Two clusters were randomly picked in both Kericho and Kisii and four in Kiambu. The breakdown of the sample by stages from the District, through the Divisional level, to the local market places is shown in Table 5. The tea buying centres were generally located at or near the market places (but see footnote to Table 5).

Following an intensive public relations effort with the elected growers-representatives on the District and Divisional Tea Committees, twelve farms were randomly selected at public barazas (Swahili - public meeting) in each of the sample areas. These farms were visited twice weekly for the period of one year in order to collect data on all inputs (particularly labour) and output (particularly sales).

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[3]The phrase "non-scheduled" was the legal term used in Kenya for those areas not scheduled for European settlement, i.e. areas of African farming. The phrase is still used for descriptive purposes.

Table 5 - Tea Buying Centres Selected for Farm Survey 1965-1966

District	Total No. Growers [a]	Total No. of Buying Centres	Clusters Selected [b]: No. and Division	No. of Growers	Nearest Market Place
Kericho	1627	60	1 in Buret	115	Litein & Cheborge
			1 in Konoin	106	Kaptabengwet
Kisii	2372	43	1 in Kitutu	123	Magombo
			1 in Nyamira	126	Kenyenya
Kiambu	1523	15	2 in Githunguri	60	Gitiha
				113	Kagaa
			2 in Gatundu	82	Mundoro
				149	Mataara

[a] These were the growers who actually delivered green leaf and hence had bushes aged two years and over.

[b] In Kericho and Kisii there tend to be many small Buying Centres while Kiambu has fewer larger ones. Thus the Kiambu "clusters" are single buying centres. Magombo was also a single Buying Centre. At the other extreme Kaptabengwet was made up of four centres.

Thus the data set consists of two parts: the first is composed of the planting and output records of the farmers in the primary sample for the period 1959 to 1966. This provides a cross-section, time-series data matrix of 874 farms and five years. The second part consists of the detailed records of 96 farms. The first stage sample will be used for the major portion of the analysis in this study. Use will be made of the labour input data from 48 of the 96 farms to check on certain of the hypotheses regarding labour inputs noted in the previous chapter.

2. Statistical and Economic Specification

Of the six types of variables listed in Equation (II - 6) and discussed in Chapter II, it was suggested that the number of bushes and the age of those bushes was the most important vector of variables in the input set. It was further suggested that vintages of tea bushes do not interact with one another, so that their contributions to output are additive. Taking merely these "mechanics of production" into account and assuming for the moment that the other variables are redundant, we can write the production function:

$$Q_{it} = \beta_o + \sum_{k=3}^{7} \beta_k X_{kit} + \varepsilon_{it} \qquad \text{(III - 1)}$$

where Q_{it} is the output of green leaf from farm i in year t (i = 1,..., N and t = 1,..,T)

X_{kit} is the number of stumps of age k on farm i in year t (k = 3,...,7)

β_k is the yield of green tea for stumps k years old

β_o is the intercept

ε_{it} is the stochastic error term

In order to use the least squares estimator to estimate the coefficients of this equation, it is assumed that the error terms are normally distributed with constant variance and zero covariance both between farms and between years on a given farm. Independence between the regressors and the error terms is also assumed. This last assumption, however, is doubtful. There are ample reasons for expecting inputs to be measured with error. The planting data refer specifically to the recorded sales of tea stumps by the KTDA to the farmers - not to the number of stumps actually growing in the field. Thus no account is taken of divergences between recorded sales and actual sales, of the mortality of the stumps, or of illegal plantings. The purely accounting error is likely to be random and very minor. but there is undoubtedly a mortality error in the data, tending to bias the estimates downwards. Furthermore, contrary to intuitive expectation, to the extent that illegal planting has taken place (usually with stumps stolen from the large tea estates), the estimated co-efficients will again be biased downward. (6, p. 148-150). In practice, this last error is the only one of real significance since the coefficients can be interpreted as being recorded stump purchases rather than for actual healthy plants. For our purposes then, the least-squares estimator is appropriate, although it would not be valid as a technique for obtaining unbiased estimates of the strictly biological parameters, (4).

The second input category discussed in Chapter II was labour (L_{it} in equation II - 6). Tea growing is a labour intensive occupation but during the first couple of years it is the adherence to the complex set of recommended planting and pruning practices that is crucial rather than the time spent with each bush. Hence, it is hypothesised, the absence from the data set of detailed information on the labour input in planting and pruning young tea bushes is not a serious disadvantage provided a management variable can be introduced into the equation that is to be estimated. Furthermore, the labour input in plucking was hypothesised to be jointly determined, with output, by the other inputs. This hypothesis is tested in Chapter VII. In the meantime it is an assumption that conveniently allows us to ignore labour inputs.

The omission of this variable means that, where it is not perfectly complementary with included inputs, its effects will be included in the error term (ε_{it}) in equation (III - 1). There is no reason to believe that this will invalidate our least squares assumptions.

~~Climatic~~ and soil ~~difference between~~ farms (C_i and S_i) were thought to be important. The difference in the physical environment tends to be greater the larger the area in which the farms are located. Micro-climatic differences can therefore be minimised by dividing the data set into areas that can be considered homogeneous. The Tea Buying Centres (or clusters) are convenient for this purpose since the radius within which farms are located is only about one mile. Such a grouping may be too cautious since all these buying centres are located in the "Kikuyu-grass" ecological zone, are between 6,000' and 7,000' in elevation, and have an annual rainfall of between 1,300 and 2,000 millimetres (say, 50 to 70 inches). There are differences however. Kiambu has a more distinct bimodal rainfall pattern; cloudy, misty conditions tend to persist into the late mornings (incidentally, this makes tea plucking a rather wet and cold job); and, finally, unlike Kericho but like Kisii, many of the farms are on steep slopes. The climatic differences are illustrated in Figures 4 and 5.

Whether the division of the data set into these sub-groups is valid can be tested by examining the estimated coefficients. For example, the hypothesis that individual Divisions within Kiambu District are ecologically homogeneous can be tested by comparing the yield and year effect coefficients of samples drawn from within each Division. The following procedure is adapted from that set out by Johnston (6, pp.136-139) and Chow (2).

Write the matrix equations

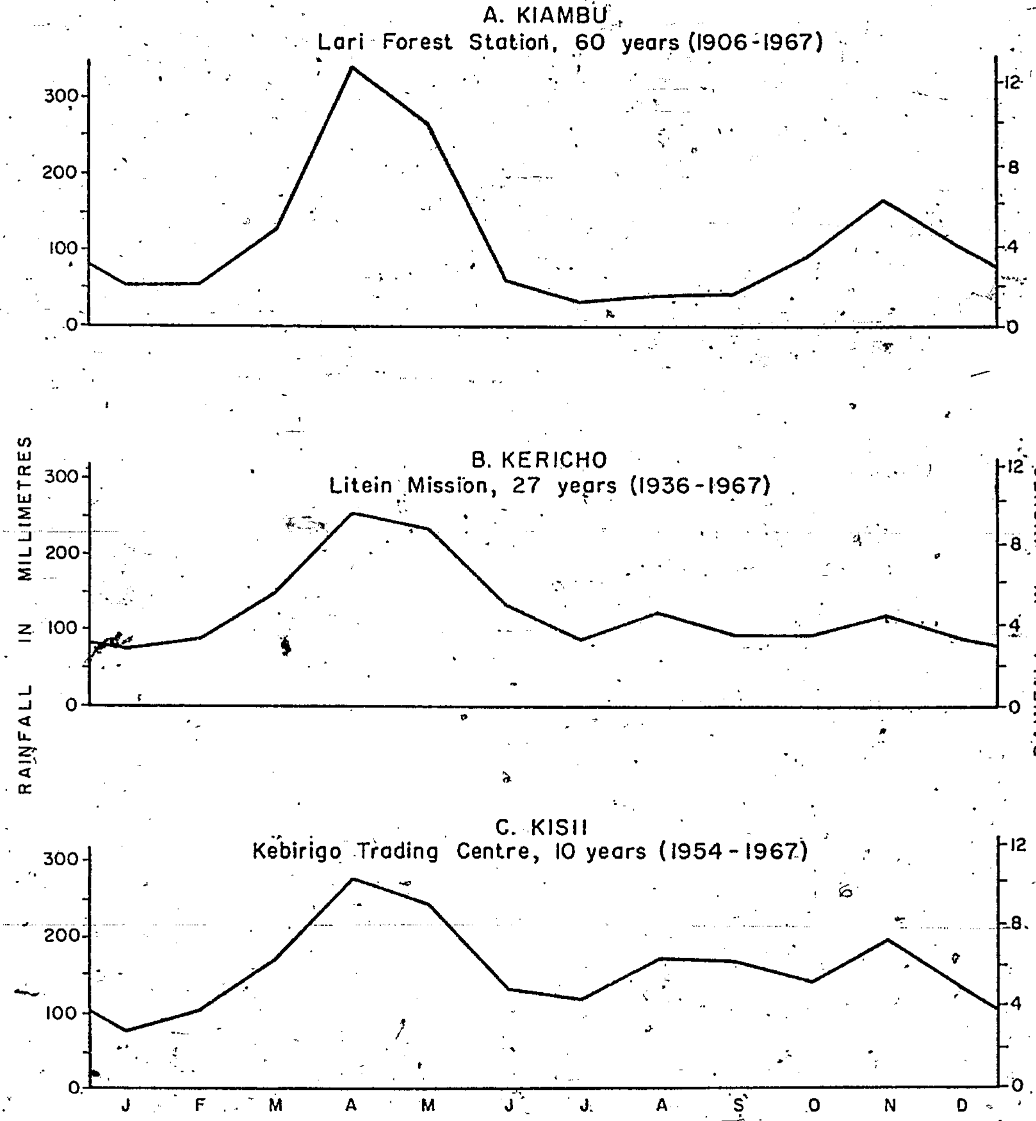
$$Y_1 = X_1 \beta_1 + Z_1 \gamma_1 + \upsilon_1 \qquad (III - 2)$$

$$Y_2 = X_2 \beta_2 + Z_2 \gamma_2 + \upsilon_2 \qquad (III - 3)$$

where subscripts 1 and 2 are the first and second samples from a Division. Let X_1 and X_2 be the matrices from equation (III - 1) augmented by the inclusion of a dummy variable for each year included in the time series, while Z_1 and Z_2 are matrices of farm effect dummy variables.[4] Then X_1 is of order $M_1 \times K_1 + T_1$ and X_2 is $M_2 \times K_2 + T_2$, Z_1 is $M_1 \times N_1$ and Z_2 is of $M_x \times N_2$ where N is the number of farms; M is the number of cases (i.e. the total number of observations); K is the number of yield variables and T the number of year variables.[4]

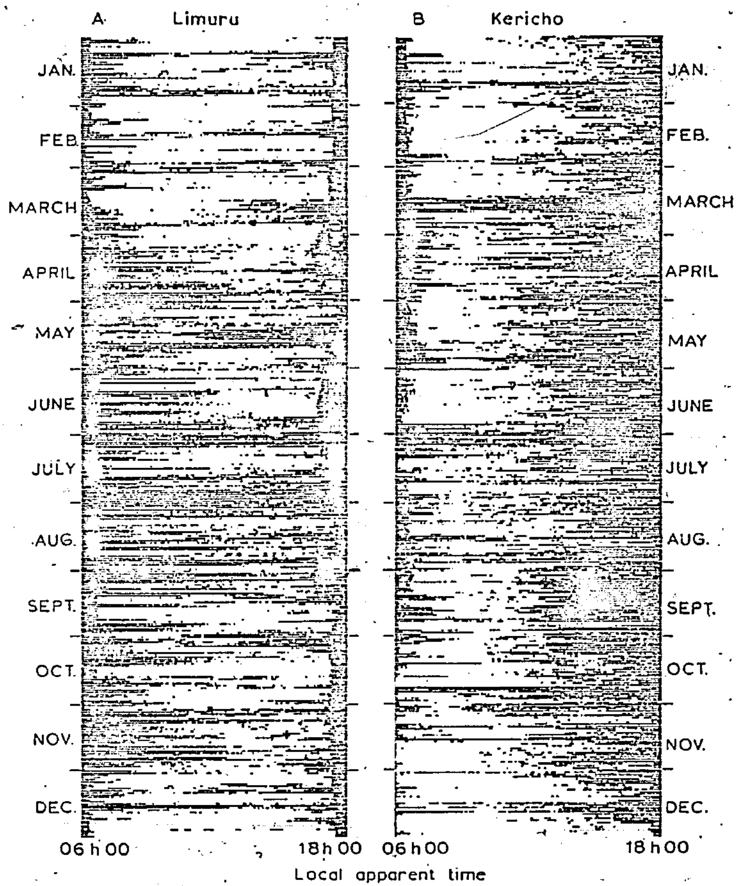
[4]The dummy variables for year effect and farm effect variables are discussed below. It will be observed that the procedure adopted here is to partition a larger data matrix in each area (call it W_1 in area 1) into two matrices (i.e. X_1 and Z_1) to make it clear that we are only testing the null hypothesis regarding a subset (i.e. $K_1 + T_1$) of the full set of variables (e.g. $K_1 + T_1 + N_1$). See Goldberger (3) pp.174-175.

Fig. 4. Long-Run Average Monthly Rainfall*



*Private communication from East African Meteorological Department.

Figure 5 – Daily Pattern of Sunshine for One Year at Limuru (A)[a] and Kericho (B)*



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* From (11, p.391)

[a] Limuru is contiguous to Kiambu and their tea growing areas, to which this data refers, have similar climates.

In this problem $K_1 = K_2$ and $T_1 = T_2$. If we set up the hypothesis that $\beta_1 = \beta_2 = \beta$, the model becomes:

$$\begin{pmatrix} Y_1 \\ \\ Y_2 \end{pmatrix} = \begin{pmatrix} X_1 \\ \\ X_2 \end{pmatrix} \beta + \begin{pmatrix} Z_1 \\ \\ Z_2 \end{pmatrix} \begin{pmatrix} 1 \\ \\ 2 \end{pmatrix} + \begin{pmatrix} \upsilon_1 \\ \\ \upsilon_1 \end{pmatrix} \qquad \text{(III - 4)}$$

Take the sum of squared residuals in (III - 2) and (III - 3), and add them; call this Q_2. Then take the sum of squared residuals in equation (III - 4) and call this Q_1. Now use the F ratio:

$$F = \frac{(Q_1 - Q_2) / (K + T)}{Q_2 / (M_1 - N_1) + (M_2 - N_2) - 2(K + T)} \qquad \text{(III - 5)}$$

with $K + T$ and $(M_1 - N_1) + (M_2 - N_2) - 2(K + T)$ degrees of freedom. We would reject the hypothesis that any two areas, be they locations, Divisions or Districts, are ecologically homogeneous if $E > F_\alpha$, where $1 - \alpha$ is the desired confidence level.

It is necessary next to take account of inter-year differences in climate. In all areas there were substantial differences in the rainfall over the period of study (1961/62 to 1965/66), as is shown in Table 6.

It was noted in the previous chapter that there are many more parameters to a moisture balance equation than mere rainfall. The information is not available to construct the necessary index for the explicit inclusion of weather. The variable can, however, be included in an implicit fashion by use of a dummy variable to take account of

Table 6 - Annual Rainfall in Kericho, Kiambu and Kisii

1961-1966* (mm)

Period[a]	Kericho[b]	Kiambu[c]	Kisii[d]
1961/62	2,010.7	2,118.8	2,226.8
1962/63	1,800.5	2,103.0	2,609.3
1963/64	1,723.7	1,867.9	1,969.2
1964/65	1,177.7	1,153.1	1,545.4
1965/66	1,647.5	1,787.2	3,780.4[e]
Long term Average	1,548.2	1,414.9	1,800.6

*Private communication from the East African Meteorological Department.

[a]The annual figures refer to the period May through April since this is probably the relevant period for the KTDA July-June financial year to which all tea production figures refer.

[b]Litein Mission. Long-Run average is based on 27 years (1936-1967).

[c]Lari Forest Station: 10 years (1954-1967).

[d]Kisii District Office: 36 years (1931-1967). The series for Kibirigo Trading Centre (used in Figure 1) was, unfortunately, incomplete.

[e]This figure has been checked. It is not representative of the District. (One wonders who was pouring what into the raingauge!!)

the total "year effect". Consequently, we have the function:

$$Q_{it} = \beta_o + \beta_{oot} + \Sigma\beta_k X_{kit} + \varepsilon_{it} \qquad \text{(III - 6)}$$

where β_{oot} is the year effect coefficient for year t.

It must be recognised, however, that weather phenomena need not be the most significant influence on the year effect. Changes in cultural practices could equally well be included in the β_{oot}. Given the newness of the crop, it would be reasonable to expect some learning process to be taking place - both because of the efforts of the agricultural extension personnel and through "learning by doing". In the period after the data for this study were collected, there have been three distinct changes in cultural practices or technology. The first relates to the practice of "pegging" out the branches of young bushes to improve their lateral spread which started in the 1966 planting season. Secondly, in some districts there is limited planting taking place in the short rains (October-November). Finally, up to the 1968 planting season all the planting material had come from seed and could reasonably be considered to be homogeneous from one year to the next. However, by the 1970 planting season, it is expected that all planting material will be in the form of Vegetatively Propagated stumps from specially selected, high-yielding, clones.[5]

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[5]There are distinct advantages to the KTDA in using the model developed in this study in order to check on the impact that improved cultural practices or improved planting materials have on yields.

If there are substantial increases in yields each year then the model is incorrectly specified. Whether the inclusion of the year effect provides the correct model is the subject of statistical test in the next chapter.

The importance of management in smallholder tea operations has been consistently stressed. Consequently its exclusion from the function involves misspecification and the introduction of "management bias". The problem of management bias (5, 9, 10, 11) arises if both inputs and output are functionally related to a farmer's managerial ability. If there exists a positive relation between inputs and managerial ability (the usual case in agriculture) then the coefficients of included variables will be biased upward and vice versa.[6] The classic illustration of the effect of management bias is shown in Figure 6. Given a series of observations on two farms, the one

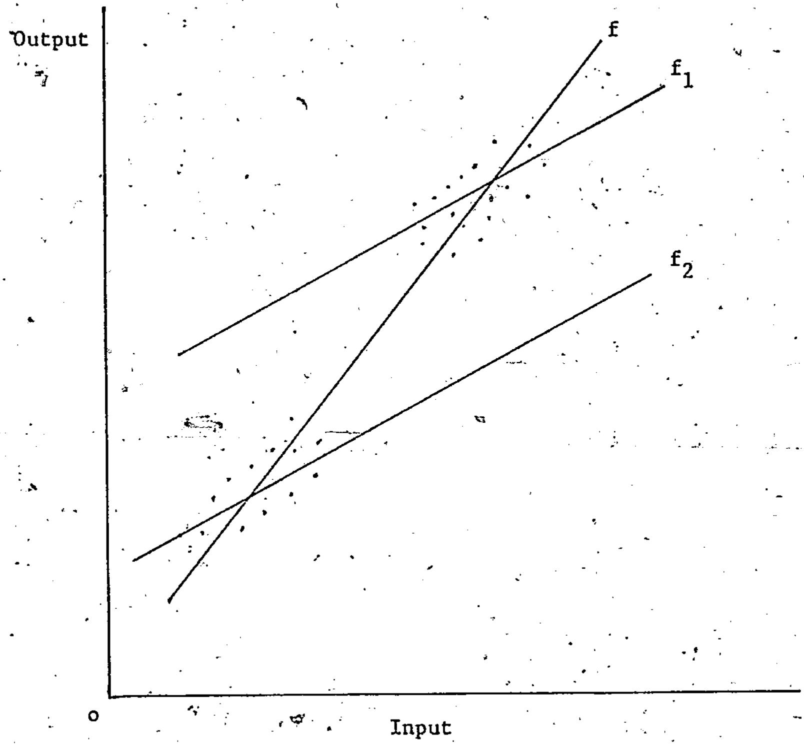
[6] It is easy to hypothesise the positive relationship in many agricultural situations but it is rare that ex ante evidence is forthcoming on this. In general, complete reliance is placed on the statistical tests of the significance of including the farm effect variables. In the case of smallholder tea in Kenya, there is one set of ex ante data which tends to confirm the hypothesis.

Acreage and Incomes of Progressive and Neighbourhood Farmers Growing Tea in East Kitutu Division, Kisii District*

Category	Acreage	Income	Income per acre
		(Shillings)	
Progressive Farmers (1)	1.22	968.1	794
Neighbourhood Farmers (2)	.81	618.1	745
Ratio (1)/(2)	1.47	1.57	1.07

*From the field notes of Victor C. Uchendu and Kenneth R.M. Anthony, gathered for the Rood Research Institute's study: Economic, Cultural and Technical Determinants of Agricultural Change in Tropical Africa.

Figure 6 - The Effect of Management Bias



with good management, the other with poor, and given that the good farmer uses more inputs, then, in the absence of this information, the pooled function would be f rather than the two separate functions f_1 and f_2 which do discriminate between classes of management.

If one has data on a cross section of farms, the series of observations needed on any given farm (or class of farms) for the estimation of both the farm effect and the production functions can be either on time series (5, 12) or on separate enterprises in the multiproduct farm (9). The statistical technique for the estimation procedure is that of analysis of covariance or, which is exactly equivalent, the inclusion of a separate dummy variable for each farm. The case for the least squares estimator becomes stronger in an analysis of covariance framework since farm effect and time effect can be hypothesised to take up much of the disturbance transmitted by errors in input measurement - such as that encountered with illegal planting (see 13). The production function is now written as:

$$Q_{it} = \beta_o + \beta_{oi} + \beta_{oot} + \Sigma\beta_k X_{kit} + \varepsilon_{it} \qquad \text{(III - 7)}$$

where β_{oi} is the farm effect coefficient of farm i. Given that the statistical tests confirm the importance of the farm effect coefficients, then an index of managerial ability can be constructed. One possible index would be:

$$\hat{M}_i = \frac{\beta_{oi}}{\tilde{\beta}_{oi}} \times 100 \qquad \text{(III - 8)}$$

where $\tilde{\beta}_{oi}$ is the farmer with the highest farm effect.

As with the year effect, it is obvious that the farm effect can take under its wing more than purely management factors - in particular, micro differences in ecology (soils and climate) and such features as the distance of the farm from the buying centre, and the existence on particular farms of illegally planted bushes. If one had secondary data on factors likely to affect management then they should be regressed on the index to obtain a weighting system for a new index of management M_i which can be inserted as a new variable in the production function. The β_{oi} remain in the function as a means of correcting for the physical environment.[7] This procedure is not adopted in this study but indices of management are examined in detail in Chapter VI.

The model that has been presented in equation (III - 7) might be formally correct in its inclusion of farm effect and year effect variables but it is misspecified in its economic logic. It should be recalled that the classic discussions of management bias by Mundlak (12), Hoch (5) and Massell (9) are all concerned with the Cobb-Douglas production function which is linear in the logarithms. For example:

$$q_{it} = a_o + a_{oi} + a_{oot} + \sum_j \alpha_j X_{jit} + e_{it} \qquad \text{(III - 9)}$$

which is written in natural numbers as:

$$Q_{it} = A_o A_{oi} A_{oot} \prod_j X_{jit}^{\alpha_j} E_{it} \qquad \text{(III - 10)}$$

---

[7] This iterative procedure is that adopted by Timmer (14, pp.60-61) where he considered each of 48 states of the United States as a separate farm firm. It would be expected that the bias introduced into the original management index by the differences in the physical environment between States would be relatively more extreme than between the almost contiguous farms of this study.

where A_o = overall intercept

A_{oi} = firm intercept and

A_{oot} = time intercept

The assumption made in such a model is that the elasticity of output with respect to input J (α_j) is constant across firms. Management only enters the function in the form of the firm intercept A_{oi}. In equation (III - 10) this intercept (as with the time intercept) has a neutral multiplicative effect on the production function. The larger the inputs the greater the impact on total output that a good (or bad) manager (or agricultural season) will have. That is to say, management pivots the production function in a perfectly neutral manner. While one can argue with the assumption of constancy of elasticity,[8] the manner in which the management and year effects enter is certainly a great deal more satisfactory than in equation (III - 7) where these effects are purely additive and unrelated to the size of the inputs. Thus, since equation (III - 7) is linear in natural numbers, a good farmer with a high β_{oi} merely has this amount added to the output which is explained by his stock of trees and the yield parameters (β_k). The amount added is quite independent of the amount of tea planted (X_k). As an extreme case, the equation

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[8]As does Timmer (14) p.37-38, where he discusses a reformulation with variable elasticities:

$$Q_i = A_o A_{oi} \Pi X_{ji}^{\alpha_j + \alpha_{oi}} e_i$$

states that farms can achieve some output of tea (if $\beta_o + \beta_{oi} + \beta_{oot} > 0$) without any tea bushes. This is patently nonsensical. The problem arises because of the linear nature of the production process. However, the model must be reformulated to allow for the multiplicative effect of management.

Rewriting equation (III - 7) in terms of yield as the dependent variable, instead of output, gives:

$$\frac{Q_{it}}{\sum_{k=3}^{7} X_{kit}} \equiv Y_{it} = \beta'_{oi} + \beta'_{oot} + \sum_{k=4}^{7} \beta'_k P_{kit} + u_{it} \qquad \text{(III - 11)}$$

where Y_{it} is the total yield achieved by farm i in year t

β'_{oi} and β'_{oot} are the farm and year effects respectively

P_{kit} is the proportion of total stumps in any age group k

β'_k is the "ratio coefficient" and shows the contribution to total yield derived from the proportion of stumps age k

u_{it} is the stochastic error term.

To obtain the equivalent yield coefficients of equation (III - 7) multiply through in (III - 11) by the denominator on the left hand side. Then, ignoring the year effect coefficient and error term for convenience, we get:

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[9] The overall intercept is omitted from this and subsequent equations for convenience and because it has to be omitted in the estimation procedure to avoid a singular moment matrix.

$$Q_{it} = \beta'_{oi} \sum_{k=3}^{7} X_{kit} + \sum_{k=4}^{7} \beta'_{k} X_{kit} \qquad \text{(III - 12)}$$

$$= \sum_{k=3}^{7} (\beta'_{oi} + \beta'_{k}) X_{kit}$$

$$= \sum_{k=3}^{7} \beta_{ki} X_{kit} \qquad \text{(III - 13)}$$

Let us be clear as to the meaning of these alternative formulations of the impact of the farm (and year) effect. Referring to the unit of the dependent variable, the farm effect in equation (III - 7) shifts output by the amount of the farm effect intercept; there is no impact in terms of yield although a yield change is necessarily implied. Equation (III - 11) shifts yield by the amount of the farm effect intercept and, as is shown in (III - 13), has a multiplicative effect on output.

Comparison of the two models also raises the statistical question of the manner in which the error term enters the equations. A basic assumption of the least squares estimator is that the error variance is constant over the range of the observations. With combined time-series and cross-section data, this assumption is often open to question. In the present case, the farmers are expanding their tea gardens rapidly over the five year period. It might be reasonable to assume that the smaller tea gardens are subject to smaller absolute shocks than the larger gardens. This leads to the conclusion that heteroscedasticity of the residuals would be more likely in equation (III - 7) than equation (III - 10). If this is the case then the regression on the deflated variables of (III - 10) gives the more efficient unbiased regression estimate (see 8, pp. 406-408).

It is questionable whether even this improved formulation is correct since it is unlikely that better management on farm i will add β'_{oi} pounds of green leaf to the output of three year old tea and add the same poundage to older tea. It would be more reasonable to expect a multiplicative effect on yields, not merely on output. Given the additive nature of the output of bushes of differing ages, the fully multiplicative farm effect can be introduced as follows:

$$Q_{it} = \beta^{*}_{oi} \left(\sum_{k=3}^{7} \beta_k X_{kit} \right) + \varepsilon_{it} \qquad \text{(III - 14)}$$

where the notation is perfectly consistent with previous models and β^{*}_{oi} is a multiplicative management effect. (The year effect is omitted merely for convenience of exposition).

The difference between equations (III - 10) and (III - 14) is made clearer in Figures 7 and 8. Three different levels of management are shown in each Figure (curves a,b,c and a′, b′, c′) illustrating the different impact on the production function of the alternative specifications of management effect.

Call curves b and b′ average yield curves; then note that in Figure 7 the good farmer, represented by curve "a", raises the yield curve by the same absolute amount (and hence declining relative amount) over curve b whether or not the bush is mature. This Figure portrays the effect of the management effect coefficients

Figure 7 -- Management Effect Affecting Yields Additively

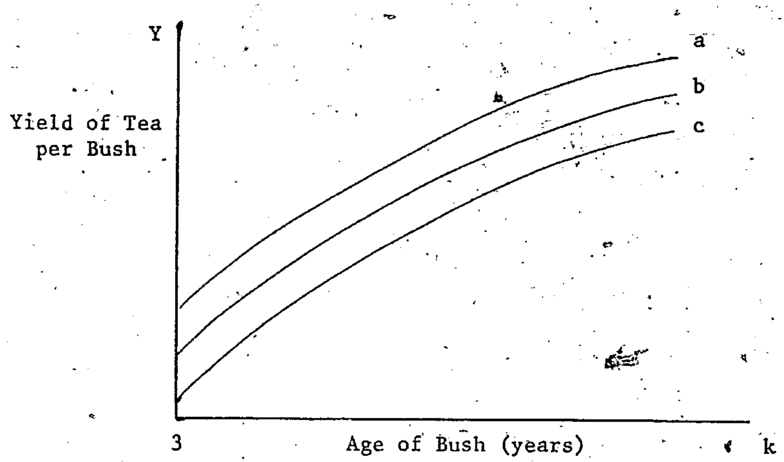
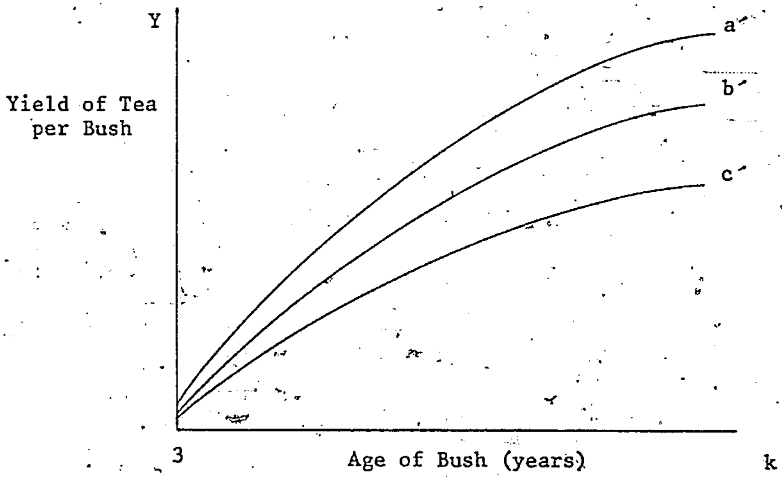


Figure 8 - Management Effect Affecting Yields Multiplicatively



in equation (III - 10) which are additive in terms of yields.

In Figure 8 the curve a′ raises the yield over the 'average' curve b′ by an increasing absolute amount (but a constant relative amount) as the bush increases in maturity (k>3). This situation shows the multiplicative effect on yields of the management coefficients in equation (III - 14). The manner in which the curves are pivoted by the management effect here is similar to its impact in the logarithmically linear function of equation (III - 8).

Equation (III - 14) presents major problems of statistical estimation since it cannot be written as linear in the parameters without using an iterative estimation technique.[10] Such a technique can be adopted, but the β^*_{oi} and β_k coefficients cannot be uniquely determined. Their product, however, can be. Consider the following procedure:

Let $$\hat{Q}_{it} = \beta^*_{oi} \left(\sum_{k=3}^{7} \beta^o_k X_{kit} \right) \qquad \text{(III - 15)}$$

be our starting point where β^o_k is any initial vector of yield coefficients (say from equation III - 11).

Let $$\sum_k \beta^o_k X_{kit} \equiv K^o_{it}$$

and $$\frac{Q_{it}}{K^o_{it}} \equiv Y^o_{it} \qquad \text{(III - 16)}$$

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[10] An alternative could be to use a Taylor's expansion of the independent variables to approximate $\text{Log}_e(\Sigma\beta_k X_{kit})$. Given the slow convergence of the linear approximation, such an approach creates more problems than it solves.

Then we can estimate the farm effect coefficients (with the asterisk omitted for convenience) using the equation:

$$\hat{Y}^{o}_{it} = \beta^{1}_{oi} D_{i} \qquad \text{(III - 17)}$$

where the dummy variables are given explicitly by an identity matrix D_i. This provides us with the first round vector of farm effect coefficients β^{1}_{oi}.

This vector is now used to deflate output

$$\frac{Q_{it}}{\beta^{1}_{oi}} \equiv R^{1}_{it} \qquad \text{(III - 18)}$$

and a new vector of yield coefficients is estimated by OLS

$$\hat{R}^{1}_{it} = \sum_{k} \beta^{1}_{k} X_{kit} \qquad \text{(III - 19)}$$

but $\sum_{k} \beta^{1}_{k} X_{kit} \equiv K^{1}_{it}$

We can now move back to equation (III - 16) and repeat the procedure with all the superscripts increasing by one. This iterative procedure can be continued until some predetermined set of criteria are fulfilled. For example, on the assumption that the product of the management and yield coefficients actually converges, then we can stop the iterations when the difference between two rounds is less than some arbitrary value of epsilon.

Thus, given [11]

$$\beta^r_{o.} \equiv \sum_i^N \beta^r_{oi} \Big/ N$$

$$\text{test} \quad \left| \left(\beta^{r-1}_{o.} \;\cdot\cdot\; \beta^{r-1}_k \right) - \left(\beta^r_{o.} \;\cdot\; \beta^r_k \right) \right| < \delta \qquad \text{(III - 20)}$$

for all k (k = 1, ...,5).

There are both practical and theoretical difficulties with this model. In the first place, a computer programme that allows this iterative regression analysis to be undertaken within the computer itself has to be specially written for the problem. Alternatively, the time-consuming method of having the output of each successive regression fed onto disk storage prior to calculating the deflated dependent variables (Y^r_{it} and R^r_{it}) can be adopted.[12] This technique has the advantage of using a standard regression programme and uses the computer to calculate the deflated variables and make the test at each iteration. However, it is rather slow and consequently expensive. Secondly, the statistical properties of the model are unclear since the separate estimates of β_{oi} and β_k are not consistent from one iteration to the next although their product is consistent.

Because of the difficulties of operating with the model based on equation (III - 14), most of the empirical results will refer to

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[11] It seemed unnecessarily ambitious to test for each farm effect separately; hence the use of the mean farm effect.

[12] This procedure was, in fact, used in a test case and the results are given in the next chapter.

the models in which yield is the dependent variable. These results form the basis of the next three chapters.

CITATIONS

1 Brown, Leslie H., A Report on the Tea Growing Potential of Kenya (Nairobi: Ministry of Agriculture, January 1966).

2 Chow, G.C., "Tests of Equality between Sets of Coefficients in two Linear Regressions", Econometrica 28, No. 3 (July 1960).

3 Goldberger, A.S., Econometric Theory (New York; John Wiley and Sons, 1964).

4 Griliches, Zvi, "Specification Bias in Estimates of Production Functions", Journal of Farm Economics, XXXIX, No. 1 (February 1957) pp. 8-20.

5 Hoch, I., "Estimation of Production Function Parameters Combining Time-Series and Cross-Section Data", Econometrica, XXX, No. 1 (January 1962), pp.34-53.

6 Johnston, J., Econometric Methods (New York: McGraw Hill Book Co. Inc., 1963).

7 Kuh, Edwin, "The Validity of Cross-Sectionally Estimated Behavior Equations in Time-Series Applications", Econometrica, 27, No. 2 (April 1959).

8 ———, and Meyer, John R., "Correlation and Regression Estimates when the Data are Ratios", Econometrica, XIII, No. 4 (October 1955) pp. 400-413.

9 Massell, Benton F., "Elimination of Management Bias from Production Functions Fitted to Cross-Section Data: A Model and an Application to African Agriculture", Econometrica, XXXV, No. 3-4 (July-October 1967), pp.495-508.

10 ———, "Farm Management in Peasant Agriculture: An Empirical Study", Food Research Institute Studies VII, No. 2 (1967).

11 McCulloch, J.S.G., Pereira, H.C., Kerfoot O., and Goodchild, N.A., "Effect of Shade Trees on Tea Yields", Agricultural Meteorology, 2 (1965) pp.385-399.

12. Mundlak, Yair, "Empirical Production Function Free of Management Bias", Journal of Farm Economics, XLIII, No. 1 (February 1961) pp.44-56.

13 ———, and Hoch, Irving, "Consequences of Alternative Specifications in Estimation of Cobb-Douglas Production Functions", Econometrica, XXXIII, No. 4 (October 1965) pp.814-828.

14 Timmer, C. Peter, On Measuring Technical Efficiency, Food Research Institute Discussion Paper No.69-5 (June 1969) pp.1-120.

CHAPTER IV

THE EMPIRICAL RESULTS

1. Summary of the Models

The exposition of the empirical results will be facilitated by summarizing and naming the models discussed in the previous chapter.

(a) Models with ADDITIVE year and farm effects

Model I $$Q_{it} = \beta_o + \beta_{oi} + \beta_{oot} + \sum_{k=3}^{7} \beta_k X_{kit} + \varepsilon_{it}$$

Model II $$Q_{it} = \beta_o + \beta_{oi} + \sum_{k=3}^{7} \beta_k X_{kit} + \varepsilon_{it}$$

(b) Models with MULTIPLICATIVE year and farm effects

Model III $$\frac{Q_{it}}{\sum_{k=3}^{7} X_{kit}} \equiv Y_{it} = \beta'_{oi} + \beta'_{oot} + \sum_{k=4}^{7} \beta'_k P_{kit} + u_{it}$$

Model IV $$Y_{it} = \beta'_{oi} + \sum_{k=4}^{7} \beta'_k P_{kit} + u_{it}$$

Model V $$Q_{it} = \beta_{oi}\left(\sum_{k=3}^{7} \beta_k X_{kit}\right) + \varepsilon_{it}$$

Notation

Q_{it} is the output of green leaf from farm i in year t

X_{kit} is the number of stumps of age k on farm i in year t

β_k is the yield coefficient of stumps of age k years, that is, it gives the number of pounds of green tea obtained from a stump k years old. (k = 3 to 7)

β_o is an overall intercept

β_{oi} and β'_{oi} are the "farm effects" for their respective models

β_{oot} and β'_{oot} are the "year effects" for their respective models

$P_{kit} = \frac{X_{kit}}{\sum_k X_{kit}}$ is the proportion of total stumps in any group k. (k = 4 to 7.)

$Y_{it} = \frac{Q_{it}}{\sum_k X_{kit}}$ is the yield achieved by farm i in year t.

β'_k is the contribution to the overall yield derived from the proportion of stumps of age k. (k = 4 to 7.)

ε_{it} and u_{it} are the error terms for their respective models.

It should be noted that the only difference between Models I and II is the inclusion and exclusion of the year effect variables. There is the same distinction between Models III and IV. It has been shown that the Additive models represent an incorrect specification of the production function. Consequently, only the results obtained from the Multiplicative models are presented in the body of this study. However, results for the Additive models are given in Appendix II.

The statistical analysis of these models is composed of two sections. The first, in this chapter, is concerned with the estimation of the parameters of the models by means of ordinary least squares. The validity of the models is tested for each area and the year effects are examined.

The second section, in Chapter V, is concerned with using the models to derive yield coefficients and to predict output. Given the dual objectives, the data matrix for each area was divided into two parts. Randomly selected subsamples of one third of the farms were used in the estimation process; the remaining two thirds of the data were kept to test the predictive powers of the models.

2. Tests for Pooling Sample Areas

Ecological differences between areas are important in their effect on tea yields. Such differences between farms can be minimised by drawing samples from small geographical areas. Tea buying centres provide convenient groupings since it is a reasonable assumption that all farms within a one mile radius of a buying centre have the same ecology or micro-climate. However, such groupings may be unnecessarily restrictive. In many instances whole administrative Divisions may be ecologically homogeneous.

This hypothesis is tested in the two Divisions of Kiambu District for each of which there are two samples - Githunguri and Gatundu. The regressions were run on each sample and then on the pooled samples at both the Divisional and District level. The statistical test given in the last chapter was conclusive. The results are presented in Table 7. The hypothesis that each Division is homogeneous was accepted at the 90 per cent level.[1] The hypothesis that

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[1] The 90 per cent confidence level was selected since this decreases the Type II error. Given the fact that the test for homogeneity is $F < F_{\alpha}$ if the hypothesis is accepted with $\alpha = .10$ it will certainly be accepted with $\alpha = 0.01$ since $F_{.10} < F_{.01}$.

Table 7 - Results of F-Tests of the Hypothesis of Homogeneity within Divisions - Kiambu District *

Tea Buying Centre	Division	Degrees of Freedom	F Ratio[a] $F_{0.10}$	Hypothesis
Kagaa Gitiha	Githunguri	4,119	1.78 < 1.99	Yes
Mundoro Mataara	Gatundu	4,182	1.217 < 1.96	Yes
	Githunguri Gatundu	4,309	7.26 > 1.94	No

* The tests are on Model IV which is appropriate for these areas (see Table 8).

[a] The F Ratio used is $F = \dfrac{(Q_1 - Q_2)/K}{Q_2/\{(M_1 - N_1) + (M_2 - N_2) - 2K\}}$ where

$Q_1 = e'e$ in the pooled data set; $Q_2 = e_1'e_1 + e_2'e_2$ with the subscripts indicating the two samples. N is the number of farms; M the number of observations (in areas 1 and 2) and K is the number of output coefficients. Since this test is conducted using Model IV the degrees of freedom differ from those given in the theoretical discussion in Chapter III. There the year effect variables are also included with the yield variables in testing the hypothesis of ecological homogeneity.

the Divisions together could be considered to be homogeneous was rejected. Following this outcome all the statistical results are given at the Divisional level.

3. Tests of Significance of Covariance Models

Model III is completely specified in the sense that, in addition to the farm effect variables, it includes year effect variables. It needs to be shown that this is the correct specification for any particular area - in other words, that all these variables are necessary. In Table 8 F-tests are used to compare a model with neither farm nor year effect variables to Model IV, and again to compare Models III and IV. The hypothesis that the models including more variables represent significant improvements over those excluding these variables would be accepted if $F > F_{\alpha}$. The hypothesis that the farm effect variables should be included in the model is accepted for all areas at the 99 per cent level of confidence. The hypothesis that, in addition, the year effect variables should be included, is rejected only in Kiambu District. In the other areas it is accepted at the 99 per cent level.[2]

On the strength of these results Tables 9 and 10 present only the results of estimating the coefficients of the relevant models for each area - that is, Model III for Kericho/Kisii and Model IV for Kiambu. In these tables the "Ratio Coefficients" (β_k') represent the contribution to total yield obtained from the proportion of total plantings in a given age group. Necessarily, in

[2] In Nyamira the acceptance is at a level a shade below 99 per cent.

Table 8 - Results of F-Tests for the Inclusion of Farm Effect and Year Effect Variables - By Divisions

District	Division	Farm Effect[a] Degrees of Freedom	Farm Effect[a] F-Ratio	Farm Effect[a] $F_{0.01}$	Farm and Year Effects[b] Degrees of Freedom	Farm and Year Effects[b] F-Ratio	Farm and Year Effects[b] $F_{0.01}$
Kericho	Buret	33,80	5.50	1.94	4,76	7.25	3.57
Kiambu	Githunguri	42,123	4.63	1.75	4,119	1.58	3.48
	Gatundu	56,186	5.61	1.60	4,182	0.54	3.40
Kisii	Kitutu	38,96	3.06	1.80	4,94	13.83	3.52
	Nyamira	31,96	7.12	1.88	4,94	4.26	3.52

[a]The F-Ratio used is $F = \frac{(Q_1 - Q_2)/N}{Q_2/(M - N - K)}$ where Q_1 = e´e in a model with neither farm nor year effect variables. Q_2 = e´e in Model IV. M is the number of observations, N the number of farms and K the number of output coefficients. See (2) p.177.

[b]The F-Ratio used is $F = \frac{(Q_1 - Q_2)/T}{Q_2/\{M - N - (K + T)\}}$ where Q_1 = e´e in Model IV and Q_2 = e´e in Model III. T is the number of year effect coefficients which is one less than the number of years of data in the time series.

Table 9 - Ratio Coefficients and Mean Farm Effect Coefficient of Model IV: Kiambu District*

Item	Coefficient	Specified tea buying centres: Githunguri Division	Specified tea buying centres: Gatundu Division
Year of Maturity		Ratio Coefficients	
4	β'_4	0.2135 (5.7534)	0.2767 (8.7123)
5	β'_5	0.4087 (8.6515)	0.4273 (11.7767)
6	β'_6	0.5580 (8.7047)	0.7178 (14.5275)
7	β'_7	1.0221 (13.7349)	0.9365 (12.4860)
		Other information	
Mean farm effect	$\beta'^{a}_{o.}$	0.0803	0.1452
$\bar{R}^2$		.745	.717
Number of:			
Farms		42	56
Observations		169	246

*Ratio coefficients computed from Model IV are all significant at the 1 per cent level. The ratio of the Ratio Coefficients to their standard errors are shown in parentheses.

a $\beta'_o = \sum_i^N \beta'_{oi}/N$

Table 10 - Ratio Coefficients, Mean Farm Effect and Mean Year Effect Coefficients of Model III: Kericho and Kisii Districts*

		Specified tea buying centres		
		Kericho District	Kisii District	
Item	Coefficient	Buret Division	Kitutu Division	Nyamira Division
Year of Maturity		Ratio Coefficients		
4	β'_4	.4293 (3.2495)	.7378 (3.1963)	1.0282 (4.1353)
5	β'_5	.7437 (3.5812)	1.0818 (2.6964)	1.5302 (3.5920)
6	β'_6	1.1111 (3.7374)	1.5618 (2.5896)	1.1870 (2.2653)
7	β'_7	1.8038 (4.7414)	1.0045[a] (1.2123)	1.6253 (2.3210)
		Other information		
Mean farm effect	$\beta'_{o.}$ [b]	.0926	.5553	-.4739
Mean year effect	$\beta'_{oo.}$ [c]	.3691	.191[illegible]	.5399
$\bar{R}^2$		.784	.807	.681
Number of: Farms (N)		33	38	31
Observations		117	140	133

* Ratio Coefficients computed from Model III are significant at the 1 per cent level except as noted by a. The ratio of Ratio Coefficients to their standard errors are shown in parentheses.

[a] Not significant [b] $\beta'_{o.} = \sum_{i}^{N} \beta'_{oi.} / N$ [c] $\beta'_{oo.} = \sum_{t}^{T} \beta'_{oot.} / T$

order to avoid a singular matrix, only ratio coefficients for four of the five age groups are estimated and presented. With one exception, the coefficients are highly significant. Additional information includes the mean farm effect (both tables) and the mean year effect (Table 10).

The Ratio Coefficients arise out of the manner in which the farm effects are incorporated into Models III and IV. These coefficients are essentially stepping stones to the calculation of yield coefficients. There are a number of alternative ways in which this transformation can be done and the discussion of these is postponed until the next chapter.[3]

4. Year Effect Coefficients and Weather

The positive manner in which Model IV was accepted for Kericho/Kisii but rejected for Kiambu is most encouraging since it meets one's expectations based on the relative weather patterns of the areas. Although Kiambu has the more pronounced bimodal rainfall distribution, the persistence of misty conditions and low stratus clouds for many weeks of the year tends to lessen the importance of rain as a source of moisture. The clear days and afternoon thunderstorm activity in Kericho/Kisii heightens the reliance of these areas on rainfall. This proposition receives further confirmation in the year effect and rainfall indices presented in Table 11. Since the year effect coefficients of Model IV are scaled in an arbitrary

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[3]The general form of the transformation from Ratio Coefficients to yield coefficients has already been shown in equations (III - 11) to (III - 13) in Chapter III.

Table 11 – Indices and Rankings of Year Effect Coefficients and Rainfall – Kericho and Kisii Districts 1961/62 to 1965/66*

	Kericho District		Kisii District		
	Buret Division		Nyamira Division		Kitutu Division
Year	Year Effect	Rainfall	Year Effect	Rainfall	Year Effect
	Indices (Rank)				
1961/62	157(1)	121(1)	211(1)	92(3)	94(3)
1962/63	121(2)	108(2)	122(2)	107(2)	102(2)
1963/64	50(5)	103(3)	0(5)	81(4)	44(5)
1964/65	91(3)	70(5)	105(3)	64(5)	89(4)
1965/66	79(4)	99(4)	75(4)	156(1)	170(1)

*See text for calculation of indices. The rainfall indices are based on Table 6 in Chapter III.

manner according to which dummy variables are omitted to avoid a singular moment matrix,[4] the choice of indices is also arbitrary. It seems logical, however, to have the indices for rainfall and year effects operating in approximately the same range. The base chosen was the sum of the mean farm and mean year effects. Thus:

$$W_t = \frac{\beta'_{o.} + \beta'_{oot}}{\beta'_{o..}}$$

where W_t is the year effect index and the periods (.) in the year effect or farm effect coefficients denote averages.[5] The rainfall index is based on the mean rainfall for the five year period. Given the arbitrary nature of the indices, no reliance can be placed on the numbers themselves, but the indices do facilitate comparisons. What is important is the ranking within each index and the comparison of rankings between indices.

In general, the rankings of the Buret and Kitutu year effects coincide closely with their respective rainfall rankings. Nyamira has an identical ranking to Buret and, consequently, conforms well with its rainfall pattern. This is not a matter of pure chance since the Nyamira sample buying centres are located exactly equidistant between the two sites of the rainfall recording stations (at Litein and Kisii town).

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[4]This issue is further discussed in Chapter V.

[5]Thus $\beta'_{o.} \equiv \sum_i^N \beta'_{oi}/N$ and $\beta'_{oo.} \equiv \sum_t^T \beta'_{oot}/T$ and then $\beta'_{o..} \equiv \beta'_{o.} + \beta'_{oo.}$

For Nyamira, rather than adding β'_o to numerator and denominator, the wide range of the year effects and negative mean farm effect necessitated an unweighted index based on β'_{oo}.

The year 1963/64 is interesting in that it is ranked lowest in each of the year effect rankings. The year's output was in fact poor in all smallholder tea areas in the country. The reasons for this are attributed (by the KTDA in its Annual Report) to a relatively high percentage of vacancies in some areas,[6] partly to the contribution of the 'sun-dried' tea industry,[7] and partly to substandard cultivation and underplucking in some areas (4). This is more a list of symptoms than of actual reasons. It may be more relevant to note that this was the year of Kenya's independence. It was a year of unusual pressures and uncertainties in almost every administrative department of government. It is not unlikely that the root cause for the poor level of tea production lay in the realm of politics.

Overall, the results of the systematic analysis of weather effects by means of analysis of covariance has been revealing. The rejection of Model III for Kiambu and its acceptance for Kericho/Kisii was important. The hypothesis that year to year shifts in the production function for smallholder tea are mainly caused by climatic conditions would appear to be confirmed.

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[6] By "vacancies" the Authority means absentee landlords.

[7] This was not a problem in the areas with which we are dealing.

CITATIONS

1 Chow, G.C., "Tests of Equality between Sets of Coefficients in two Linear Regressions", Econometrica 28, No. 3 (July 1960)

2 Goldberger, A.S., Econometric Theory (New York; John Wiley and Sons, 1964) XI, pp.1-399

3 Johnston, J., Econometric Methods (New York: McGraw Hill Book Co. Inc., 1963) pp.3-299

4 Kenya Tea Development Authority Annual Report and Accounts 1963/64 (Nairobi; KTDA, 1964)

CHAPTER V

SMALLHOLDER TEA YIELDS

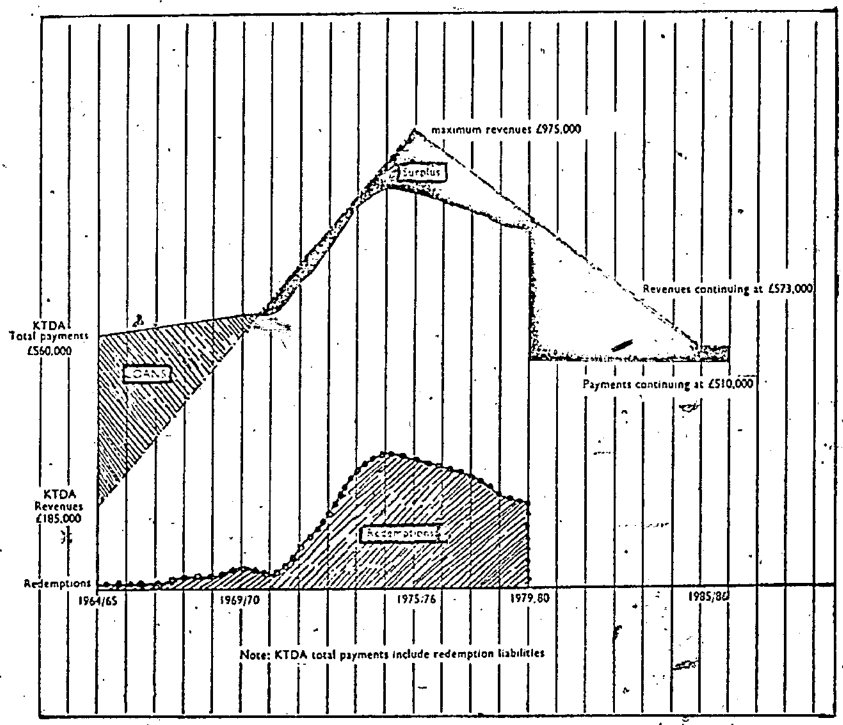
1. The Importance of Tea Yield Estimates

An important outcome of the manner in which the production function for smallholder tea has been specified is the statistical estimation of tea yield curves for each farm. This provides some exciting information with interesting and useful applications.

Tea yield estimates are of considerable importance both in the planning phase for the expansion of the smallholder tea scheme and also as a potential tool in extension work. At the national level, the importance relates to the applications for international development finance. In submissions for international loan funds for its three "Plans", the KTDA has produced elaborate planting and production schedules. These schedules form the backbone of the whole loan repayment structure. Figure 9 reproduces the expenditure/receipt schedules of the First Plan in diagrammatic form. The calculations were all based on an assumed yield of 200, 400, 800, and 1000 pounds of made tea per acre in the third to sixth years after planting.

The impact of the yield assumptions is not only felt in national planning but works its way right down to the farm level. Initial gross payments to the grower are fixed at 40 Kenya cents per pound. Recurrent costs of the KTDA are covered by a cess of 10 cents

Figure 9 - Time Path of KTDA Payments, Receipts and Loan Redemptions. First Development Plan.



Source (1, p.18)

per pound of green leaf.[1] The capital repayments of the farmer to the Authority, and therefore of the Authority to the lending agencies[2] are covered by a similar 7 cents cess. The net return to the farmer from the KTDA is therefore 23 cents per pound.[3] Since the capital cess also covers some of the KTDA's fixed costs, all growers, whether or not they have made use of credit facilities, pay this cess. A grower who has taken maximum credit on the initial purchase of stumps (18 cents on stumps costing 30 cents) would take fifteen years to repay his loan and pay for his share of the Authority's own capital expenditure. At the end of this period his stumps will have effectively cost him 1.35 shillings each. A grower who has taken no initial credit still pays the cess for eleven years by which time his payments will have amounted to 1.06 shillings per stump planted (1, p.18).

The role of yield estimates is crucial in these calculations. If leaf yields proved to be lower than estimated, the period of repayment would be longer and the cost per stump higher. It is interesting to note, therefore, that for the Second Plan the KTDA radically

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[1] The currency referred to in this study is the Kenya shilling. It is divided into 100 cents. Prior to the British devaluation in November 1967, 20 Kenya shillings equalled £1 sterling. Thus one Kenya shilling continues to equal about 14 American cents.

[2] These include: The International Development Association, the Commonwealth Development Corporation and the Kreditanstalt für Wiederaufbau.

[3] There is generally a "second payment" made from the profits of each tea factory to the growers in its area. This payment used to amount to about 10 cents per pound of green leaf but it has not been possible to maintain this level in the wake of the devaluation of the British pound. Since Britain (the main market), India and Ceylon (the major suppliers) all devalued their currencies while Kenya did not, the price of tea in Kenya shillings fell. Second payments now average 3 to 4 cents per pound.

reduced its yield estimates from those given above to 100, 300, 600, and 900 pounds of made tea per acre in the third to sixth years of planting (1, p.16).

In addition to its own specific finances, the KTDA also arranges for the establishment of the tea factories which process smallholder tea.[4] Each factory costs about £200,000 and is designed to process up to 1 million pounds of made tea per year. The KTDA's production schedules form the basis for the timing of factory construction and the provision of collection facilities. For this reason the Authority makes annual predictions of output for each "factory area". The failure of a factory to achieve its designed throughput can have serious implications for its profitability. The difference in yields between areas is likely to be an important parameter in cost-benefit comparisons and, consequently, national investment decisions.

2. Statistical Yield Curves

The radical revision of the KTDA's yield estimates makes it obvious that for international loan applications the KTDA requires some form of national yield curve. For factory construction, yield curves are required for each potential "factory area". For extension purposes, yield curves for individual farms or groups of farms (e.g. those farms delivering to any particular buying centre) may be

[4]The share capital for the factories is obtained in equal proportions from the commercial tea companies, the KTDA and the Commonwealth Development Corporation. The commercial tea companies act as the managing agents. Provision is made for smallholders to purchase shares in the factory companies.

desirable. The method by which the KTDA derives its tea yield curves was discussed in Chapter II. The coefficients of the production functions given as Models III and IV provide a more objective basis for constructing tea yield curves. We now turn to the derivation of these yield curves from the ratio coefficients presented in the previous chapter.

The equation for Model III is:

$$\frac{Q_{it}}{\sum_k X_{kit}} \equiv Y_{it} = \beta'_{oi} + \beta'_{oot} + \sum_k \beta'_k P_{kit} + e_{it} \qquad (V-1)$$ [5]

where Q_{it} is the output of green leaf on farm i in year t

X_{kit} is the number of tea bushes of age k on farm i in year t. (k = 3 to 7)

Y_{it} is the overall yield of tea of farm i in year t

β'_{oi} is the farm effect coefficient for farm i

β'_{oot} is the year effect coefficient for year t

$P_{kit} \equiv \frac{X_{kit}}{\sum_k X_{kit}}$ is the proportion of farm i's total stock of tea bushes at is of age k in year t. (k = 4 to 7)

β'_k is the "ratio coefficient" giving the contribution to total yield of the proportion of bushes aged k years. (k = 4 to 7)

It should be noted that while there are five years of planting (X_k, k = 3 to 7) only four proportions (P_k; k = 4 to 7) enter the equation since the fifth proportion is simply a linear

[5] The overall intercept β'_o is omitted. This is a matter of convenience since two intercept variables have to be omitted to avoid a singular moment matrix. In practice, the overall intercept and the last farm effect variable were omitted in the statistical computations. The choice of which variables to omit is perfectly arbitrary - the effect is to scale the resultant coefficients with respect to the omitted variables.

combination of the other four and its inclusion would result in a singular matrix. This means that the omitted ratio coefficient equals zero. In this case $\beta_3' = 0$.

Multiplying through both sides of equation (V - 1) by $\sum_{k=3}^{7} X_{kit}$ we get:

$$Q_{it} = \beta_{oi}' \sum_k X_{kit} + \beta_{oot}' \sum_k X_{kit} + \sum_{k=4}^{7} \beta_k' P_k \sum_k X_{kit} + U_{it} \qquad (V - 2)$$

In the penultimate term of this equation, the P_k variables cancel out since, by definition,

$$P_k \equiv \frac{X_{kit}}{\sum_k X_{kit}}$$

Hence the equation simplifies to:

$$Q_{it} = \sum_{k=3}^{7} (\beta_k' + \beta_{oi}' + \beta_{oot}') X_{kit} + U_{it} \qquad (V - 3)$$

and, by adding the terms in parentheses, the notation can be further simplified to:

$$Q_{it} = \sum_{k=3}^{7} \beta_{kit} X_{kit} + U_{it} \qquad (V - 4)$$ [6]

where β_{kit} is the yield of green leaf from bushes of age k on farm i in year t. In other words, for every farm for every year

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[6] In other words, since $\beta_3' = 0$, $\beta_{3it} = \beta_{oi} + \beta_{oot}$ while $\beta_{4it} = \beta_4' + \beta_{oi} + \beta_{oot}$, etc.

we have a separate yield curve. This degree of detail is likely to be of interest to the extension personnel but is of little interest at the regional and national planning level.

There are a number of alternative ways in which an average yield curve can be obtained for any given area. From equation (V - 3) we have:

$$\beta_{kit} = \beta'_k + \beta'_{oi} + \beta'_{oot} \qquad (V - 5)$$

An average yield curve ($\beta_{k..}$) can then be defined by using the average farm effects and the average year effects:

$$\beta_{k..} = \beta'_k + \beta'_{o.} + \beta'_{oo.} \qquad (V - 6)$$

where $\beta'_{o.} = \sum_i^N \beta_{oi} / N$ and $\beta'_{oo.} = \sum_t^T \beta_{oot} / T$

with there being N farms and T years of observations. Alternatively, since an average year effect is not particularly meaningful, and since year effects have no systematic relationship with the plantings,[7] the year effect may be omitted in the estimation procedure as is done in Model IV. This model implicitly assigns a different average year effect and changes the estimated coefficients. Thus we have:

$$\beta_{k.} = \beta'_k + \beta'_{o.} \qquad (V - 7)$$

[7] The amount to be planted in any year is determined by the nursery manager's decisions of two years earlier - not by the weather (although rainfall may have some influence on the mortality rate among stumps).

However, in both (V - 6) and (V - 7), averaging the farm effects across all farms may be an over-simplification for some purposes since one can hypothesise reasons why different groups of farmers may perform with differing efficiency. The first farmers to plant tea might be the best (either because they were informally selected by the extension personnel or because they were genuinely 'progressive', innovative farmers). Alternatively, farmers who plant later might be better because they learn from the innovator's mistakes. Drawing distinctions between successive groups of farmers is likely to be most important in using the model to predict output during the early years of development. In these circumstances, the average yield coefficients can be written as

$$\hat{\beta}_{kj} = \hat{\beta}'_k + \hat{\beta}'_{oj} \qquad (j = 1,\ldots,5) \qquad (V - 8)$$

where $\hat{\beta}'_{oj} = \sum_i^{N_j} \hat{\beta}'_{oi}/N_j$ and N_j refers to the number of farmers who planted in vintage j or earlier. That is to say, N_j is a cumulative total of the farmers planting tea. Thus, for example, N_1 will be the number of farmers who planted tea in 1959 and had their first output in 1961/62. N_2 is composed of those farmers who planted in 1960 and those who planted in 1959. This procedure continues until N_5 which includes all the farmers in the sample. The rationale for the successive accumulation is that few farmers plant tea in only one year. Thus most of the farmers who planted in 1959 also planted in 1960 and 1961. Many of the first group have planted in four out of five years. Equation (V - 8) implies the following matrix of yield coefficients:

$$\beta_{kj} \equiv \begin{bmatrix} \beta_{31} & & & & \\ \beta_{32} & \beta_{41} & & & \\ \beta_{33} & \beta_{42} & \beta_{51} & & \\ \beta_{34} & \beta_{43} & \beta_{52} & \beta_{61} & \\ \beta_{35} & \beta_{44} & \beta_{53} & \beta_{62} & \beta_{71} \end{bmatrix} \qquad (V - 9)$$

Since the subscripts are not in the usual order in the rows and columns, a word of explanation is due. The third row reads β_{33} β_{42} β_{51}. The first subscript refers to the age of the tea bushes which have these yield coefficients. The second subscript refers to the group of farmers who could have planted tea with these yields. Thus when the appropriate stock of bushes is multiplied by these coefficients we get:

$$Q_5 = \beta_{33}X_{35} + \beta_{42}X_{45} + \beta_{51}X_{55} \qquad (V - 10)$$

This equation states that the output of tea in year 5 (Q_5) is the result of the number of bushes that are five years old in that year (X_{55}) times the yield coefficient (for five year old tea) obtained by the first group of farmers who planted tea (β_{51}); plus the four year old tea times the yield coefficient of that tea as obtained by the second (cumulative) group of farmers who planted tea; plus the three year old tea times its yield coefficient. The importance of the matrix lies in the fact that only the farm effects of those farmers who could have contributed to the yield of a particular vintage of bushes are included in the calculation of t e average farm effect and hence in the calculation of the yield coefficient for that vintage. On the other hand, the yield coefficients given in equations (V - 6) and (V - 7) are vectors which are calculated on the assumption that there are no differences between those farmers who planted tea in the initial years of its introduction and those who planted in the later years.

The matrix (V - 9) can be amplified to incorporate Model III by including the year effects in the form of a third subscript (t):

$$\beta_{kjt} = \begin{bmatrix} \beta_{313} & & & & \\ \beta_{324} & \beta_{414} & & & \\ \beta_{335} & \beta_{425} & \beta_{515} & & \\ \beta_{346} & \beta_{436} & \beta_{526} & \beta_{616} & \\ \beta_{357} & \beta_{447} & \beta_{537} & \beta_{627} & \beta_{717} \end{bmatrix} \qquad (V - 11)$$

β_{kjt} is the yield coefficient in year t for tea bushes of age k grown by farmers in group j. (k,t = 3 to 7. j = 1 to 5)

This matrix of yield coefficients represents the fullest and most reasonable set of averages that can be obtained from Model III. The matrix (V - 9) is the comparative set of coefficients for Model IV. The vectors of coefficients in equations (V - 6) and (V - 7) represent the overall averages for the same models.

3. Prediction

The data set available for this study was divided into two sections. A random sample of one third of the data for each of the five administrative Divisions was used to estimate the parameters of the production functions. The remaining two thirds of the data is used in this section to test the predictive powers of the different models and the different average yield curves. The standard for comparison is the set of yield curves used by the KTDA. These yield curves were set out in Table 4 (Chapter II). In that table, the units are "pounds of made-tea per acre per year". In order that they might be compared to the statistically derived yield curves, the KTDA yields are converted to "pounds of green leaf per bush per year".[8]

The predictions of this study are all of an *ex post* nature. For each of the five years for which planting and output data are available the yield coefficients are applied to the total plantings in the relevant vintage. Thus

$$\hat{Q}_t = \sum_k \beta_{kt} X_{kt} \quad (k = 3,..7) \qquad (V - 12)$$

is the general form of the prediction equation,

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[8]West of the Rift, plant spacing gives 2,904 bushes to the acre. East of the Rift, the figure is 3,485 bushes to the acre. 4.5 pounds of green leaf make one pound of made-tea. Thus the conversion factors to obtain pounds of green leaf per bush are:

$$\frac{4.5}{2,904} = .00155 \text{ for areas West of the Rift; and}$$

$$\frac{4.5}{3,485} = .00129 \text{ for areas East of the Rift.}$$

where

$\hat{Q}_t$ is the predicted output in year t.

X_{kt} is the total number of tea bushes of vintage k in year t.

β_{kt} is the vector of yield coefficients used for year t.

The results of testing the various models are summarized in Tables 12 and 13. Table 12 gives the weighted mean errors for all five years while Table 13 gives similar information for the last two years.

Following the preceding discussion, the average yield coefficients used in the predictions on which these tables are based vary in their degree of detail. They can be summarized as follows: for Model III, β_{kjt} is the full matrix of coefficients given in the identity (V - 11) where it is assumed that the different groups of farmers (j) are important and each year effect (β'_{oot}) is taken into account; $\beta_{k \cdot t}$ pools <u>all</u> farm effects but maintains the distinction of year effects; $\beta_{k..}$ uses both the average of the farm effects and the average of the year effects (see equation (V - 6)). For Model IV, which excludes the year effect, β_{kj} is the yield coefficient of bushes of age k grown by farmers in group j (see the matrix (V-9)); β^*_{kj} is the last row vector of matrix (V-9) while $\beta_{k.}$ averages the farm effects across all farms.

The major reason for presenting Tables 12 and 13 separately is that the size of the output in the years 1964/65 and 1965/66 was <u>very much greater than in the three earlier years</u>. The higher output is of more interest considering the rapid expansion of the industry. The detailed results on which these tables are based are given in the set of tables in Appendix III. Their actual output, predicted output and error are given by year for each model. The units are in terms of the per cent of the weighted mean errors of the predictions. Percentage errors are based upon the actual output and are calculated as follows:

$$E_t = \frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100 \qquad (V - 13)$$

where E_t is the percentage error in year t.

Q_t is the actual output.

and $\hat{Q}_t$ is the predicted output.

The weighted mean errors are then simple calculations:

$$\bar{E} = \frac{\sum_t \left| \hat{Q}_t - Q_t \right|}{\sum_t Q_t} \cdot 100 \qquad (V - 14)$$

The results of the analysis indicate that the statistical models represent substantial improvements over the method currently in use by the KTDA.

In Table 12, which covers all five years, the overall average error in prediction, using the KTDA's yield rating, is 21.25 per cent while the range in the error is between 11.70 (for Buret) and 26.51 (for Nyamira). As expected, the average yield coefficients based on Model III and using the maximum information available regarding the farm effects and the year effects (i.e. β_{kjt}) produce the best predictive model when all years are considered. Here the overall mean error is only 7.43 per cent while the range is between 4.40 and 11.47 (for Githunguri and Nyamira

Table 12 – Weighted Mean Errors of Predictions of Output, by Divisions for the Period 1961/62 to 1965/66.

Division	Model III			Model IV			KTDA
	Average Yield Coefficients[a]						Yield Rating
	β_{kjt}	$\beta_{k.t}$	$\beta_{k..}$	β_{kj}	β^*_{kj}	$\beta_{k.}$	
	1	2	3	4	5	6	7
	Weighted Mean Errors (per cent)						
Githunguri	4.40	5.13	9.03	6.70	6.81	7.14	17.10
Gatundu	6.56	6.58	13.27	8.83	9.33	8.99	25.14
Buret	5.05	5.34	14.19	6.12	7.18	7.15	11.70
Kitutu	9.48	12.01	20.31	10.78	14.49	16.02	25.82
Nyamira	11.47	14.31	23.99	15.45	15.76	14.94	26.51
All Areas	7.43	8.67	16.16	9.58	10.71	10.85	21.25
(Rank)	(1)	(2)	(6)	(3)	(4)	(5)	(7)

[a] β_{kjt} is the yield coefficient obtained by farmers of group j in year t for stumps of age k. $\beta_{k.t}$ keeps the distinction between years but averages in all farm effects. $\beta_{k..}$ uses the average farm effect and the average year effect. Models IV ignores the year effect. β_{kj} distinguishes farm groups. β^*_{kj} is a vector of coefficients formed by the last row of matrix β_{kj}. $\beta_{k.}$ uses the average farm effect. More detailed information on these coefficients is presented in the text.

Table 13 - Weighted Mean Errors of Predictions of Output for Various Models by Divisions for the Period 1964/65 to 1965/66.

Division	Model III			Model IV			KTDA
	Average Yield Coefficients[a]						
	β_{kjt}	$\beta_{k.t}$	$\beta_{k..}$	β_{kj}	β^*_{kj}	$\beta_{k.}$	Yield Rating
	1	2	3	4	5	6	7
	Weighted Mean Errors (per cent)						
Githunguri	2.34	3.05	4.91	3.09	3.17	3.38	13.83
Gatundu	7.20	6.92	13.66	10.27	9.82	9.25	28.38
Buret	2.63	2.34	9.66	1.72	2.00	2.29	6.74
Kitutu	8.19	9.96	12.28	5.58	6.91	8.38	29.65
Nyamira	12.45	4.58	2.35	12.66	10.80	9.94	20.75
All Areas	6.56	5.37	8.57	6.67	6.94	6.65	19.87
(Rank)	(2)	(1)	(6)	(4)	(5)	(3)	(7)

[a] See footnote to Table 12

respectively).[9] More important than the average or the range is the fact that this predictor is consistently better than the others in all Divisions.

When just the last two years are considered (in Table 13), the models including the year effect still turn out to be best in the rankings. On the other hand, the predictor using coefficients based on the average farm and the average year effects ($\beta_{k..}$) remains at the bottom of the ranking of the statistical measures. The average error using the KTDA's rating is still the largest and, more importantly, the statistical measures are relatively even better than in Table 12. Thus the KTDA's error only reduces from 21.25 to 19.87 per cent while the average errors of the statistical models decline from about 10 per cent to around 7 per cent.

Certain of the other changes in the rankings between Tables 12 and 13 are interesting. The importance of distinguishing between the groups of farmers loses its significance when dealing with only the last two years. Thus the rankings of columns 1 and 2 ($\beta_{kj.t}$ and $\beta_{k.t}$) change over as do the rankings of columns 4 and 6 ($\beta_{kj.}$ and $\beta_{k..}$).[10] The reason for these changes is probably the simple fact that the ratio coefficients for later years (β_6' and β_7') are already estimated from only those farmers who planted in 1959 and 1960. These farmers'

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[9] The improvement in prediction using yield coefficients including the year effect over those not doing so is somewhat surprising in the case of Githunguri and Gatundu since the statistical analysis of the previous chapter rejected the null hypothesis regarding the significance of the year effect variables in these two areas.

[10] One hastens to add that the actual difference between the average errors in the latter case is negligible.

plantings are the only ones to enter (with inputs greater than zero) the data matrix at this point. Hence, the inclusion of the average farm effects, for these groups alone, in the calculation of the yield coefficients, amounts to a form of "double counting". Furthermore, while the number of stumps planted in the first two years is generally less than two-fifths of the total planting in the five year period (see Appendix III), the very much higher yields of the more mature bushes suggest that it is particularly important not to double count the effect of these particular groups of farmers. The farm effects are the subject of more detailed analysis in the next chapter.

For actual ex ante prediction or for long run forecasting purposes, the prior calculation of a measure for the year effect is not possible. It is of interest therefore that the models excluding the year effect hold up well and still represent substantial improvements over the KTDA's technique. It is particularly useful that the farm effects model using a simple mean farm effect (the model in column 6 using $\beta_{k.}$) is ranked third in the predictions in Table 13. However, an obvious question immediately poses itself: if a model using an explicit average of farm effects is of sufficient accuracy for prediction purposes, would a model which implicitly averages farm effects - by ignoring them - also be acceptable? Consider the equation:

$$Y_{it} = \beta_o' + \sum_k \beta_k' P_{kit} + u_{it} \qquad (V - 15)$$

where the notation is identical with that already in use. Model VI, so let it be called, keeps yields (Y_{it}) as the dependent variable[11] but both year effect and farm effect variables are omitted. If management bias is a problem, (which is a question to which we return in Chapter VI), then the coefficients in Model VI will be biased. However, for prediction purposes, statistically biased coefficients may be preferred. Thus, if better farmers do indeed plant more tea, then we should want to take this into account in prediction, and hence the upward bias imparted to the coefficients is to be welcomed. Table 14 presents the prediction results for Model VI. A comparison of these results with the previous two tables shows that, on average, there is barely .25 of a per cent difference between the prediction errors of Model IV and Model VI. One cannot but conclude that the KTDA could improve its prediction technique and hence its efficiency in phasing factory construction and the provision of transport, to a considerable degree, simply by using the relatively straightforward model which excludes both year effect and farm effect variables. Any justification, from their point of view, for using the more complex models would have to lie in whatever additional information these models might provide. Some of this information is contained in the next chapter.

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[11] This is to avoid the probable existence of heteroscedasticity in the error terms if the dependent variable were simply output. For details see Chapter III and (2).

Table 14 — Weighted Mean Errors of Predictions of Output, by Divisions for Model VI for Periods 1961/62 to 1965/66 and 1964/65 to 1965/66[a]

Division	1961/62 to 1965/66	1964/65 to 1965/66
	Weighted Mean Errors (per cent)	
Githunguri	6.30	2.89
Gatundu	12.19	12.40
Buret	8.02	2.89
Kitutu	14.28	7.03
Nyamira	14.65	8.93
All Areas	11.08	6.83

[a] Model VI is given in equation (V - 15) in the text.

4. A Graphical Comparison of the Models

Having dealt at length with alternative methods of deriving average yield curves, it is instructive to compare the shape of these statistical curves with those used by the KTDA. The average yield curve ($\beta_{k.}$) obtained from Model IV is used as the basis for comparison. The actual yield coefficients are set out in Table 15 and are then plotted with the KTDA curves in Figure 10. It is immediately clear that the statistical curves are more irregular than those used by the Authority. A major reason for the difference is that the KTDA does not take into account the impact of pruning on yields. This is obviously taken account of in the statistical estimates of yield coefficients. However, the clear pattern that might be expected to emerge from the uniform pruning instructions (set out in Table 3 in Chapter I) given to growers is not in evidence. A probable reason for this disparity is the fact that in those years many growers adopted the four year pruning cycle of the estates. Figure 10 also makes it clear that a large part of the KTDA's error lies in assuming that Divisions within a District will have the same yield curve. Thus the "Extra High" rating may provide a reasonable basis for prediction of output from Kitutu and Nyamira together but is clearly inappropriate for either Division by itself.[12]

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[12] For example, the weighted mean errors of the KTDA's prediction for these areas for 1964 to 1966 decrease from the high figures of 29.6 and 20.7 per cent (Table 13) to 14.3 per cent if the areas are pooled.

Table 15 – Tea Yield Coefficients of Model IV and of the KTDA Yield Rating, by Divisions.

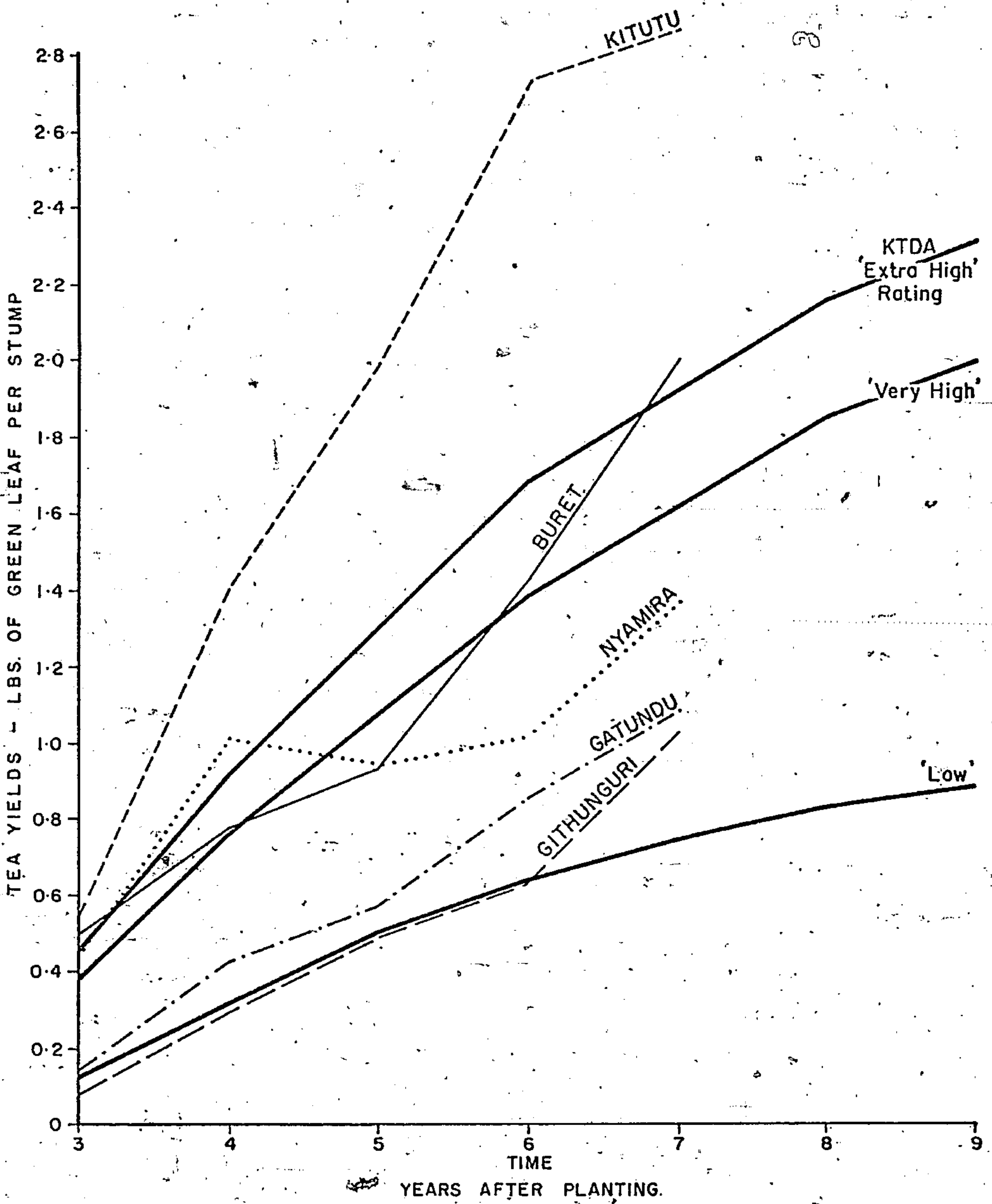
Division	Model	Yield Coefficients β_3	β_4	β_5	β_6	β_7
		(pounds of Green leaf per bush per year)				
Githunguri	IV	.0803	.2938	.4890	.6383	1.1024
	KTDA[a]	.1291	.3228	.5165	.6456	.7747
Gatundu	IV	.1452	.4219	.5725	.8630	1.0817
Buret	IV	.5001	.7826	.9283	1.4374	2.0176
	KTDA[b]	.3875	.7750	1.0850	1.3950	1.6275
Kitutu	IV	.6211	1.4889	2.0081	2.7265	2.8391
	KTDA[c]	.4650	.9300	1.3175	1.7050	1.9375
Nyamira	IV	.4403	1.0100	.9424	1.1445	1.3791

[a] This is KTDA's "low" rating (for Githunguri and Gatundu)

[b] This is KTDA's "very high" rating

[c] This is KTDA's "extra high" rating (for Kitutu and Nyamira)

Fig. 10. Tea Yield Curves Model IV and KTDA Estimates



There is conflicting evidence in these statistical curves regarding the size of the marginal increases in yields in the last two years. One concludes that data for another two or three years would be required to estimate the yield of mature tea in each area.

5. Model V

Chapter III concluded with a brief discussion of a model introducing farm effects which act upon yields in a multiplicative manner. The model is:

$$Q_{it} = \beta_{oi}\left(\sum_{k=3}^{7} \beta_k X_{kit}\right) + \varepsilon_{it} \qquad (V - 16)$$

where the notation is the same as that used previously.

The coefficients of this model were estimated by the iterative procedure outlined in Chapter III. The sample area used as a test case was Buret. The starting vector of yield coefficients (β_k^o) was that shown for Model IV in Table 15. The arbitrary epsilon chosen as the cut-off point was $\varepsilon = 0.001$. Thus the test at each iteration was:

$$\left|\left(\beta_{o.}^{r-1} \cdot \beta_k^{r-1}\right) - \left(\beta_{o.}^{r} \cdot \beta_k^{r}\right)\right| < 0.001 \qquad (V - 17)$$

for each k, (k = 1 to 5).

This termination condition was fulfilled for all coefficients except one by the fourth iteration but, in going into the fifth round, the largest change in any of the five products ($\beta_{o.} \cdot \beta_k$) was only 0.0002. A further five iterations were also tried: while the product of the mean farm effect and the yield coefficients remained virtually constant, the former continued to increase with each round while the yield coefficients declined. Thus the β_{oi} and β_k of equation (V - 16) cannot be simply interpreted as the farm effect and yield coefficients. Rather it is the product, β_{ki}, which is the yield coefficient for each farm while $\beta_{k.}$ ($\equiv \beta_{o.} \cdot \beta_k$) is the average yield curve.

As a check on the sensitivity of the final results to the choice of starting point, a new start was made on a second trial. By the fifth iteration the second set of results was virtually identical with that obtained from the first trial. Table 16 shows the starting and final vectors of the two trials.

Table 17 presents the comparative prediction results for Model IV and Model V using alternative formulations of average yield coefficients (β_{kj}, β^*_{kj} and $\beta_{k.}$).[13] The multiplicative farm effects of Model V make average yield coefficients highly sensitive to the manner in which the averaging is done. For this model predictions based on $\beta_{k.}$ are actually worse than the KTDA predictions for this area. On the other hand, when account is taken of the different groups of farmers (as in β_{kj} and β^*_{kj}) the predictions are good, although not as good as the predictions of Model IV.

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[13] Refer to the footnote to Table 12 for the meaning of these alternative average yield coefficients.

Table 16 - Initial and Final Vectors of Yield Coefficients for Two Trials of Model V for Buret

Parameter	1st Trial Start	1st Trial Finish	2nd Trial Start[a]	2nd Trial Finish
β_1	.5001	.5241	.4617	.5240
β_2	.7826	.6900	.8910	.6898
β_3	.9283	1.0253	1.2054	1.0250
β_4	1.4374	1.4256	1.5728	1.4254
β_5	2.0176	1.4787	2.2655	1.4785

[a]This vector comes from Model III using the mean farm effect and the mean year effect $\beta_{k..}$ (see equation V - 6).

Table 17 - Comparison of Predictive Results for Models IV and V, Buret Division

Model	Period	Coefficients Used[a] β_{kj}	β^*_{kj}	$\beta_{k.}$
		Weighted Mean Errors (Per Cent)		
IV	1961/62-65/66	6.12	7.18	7.15
V		8.80	7.19	11.93
IV	1964/65-65/66	1.72	2.00	2.29
V		3.83	1.09	7.24

[a]See footnote to Table 12.

The results obtained from Model V for Buret are interesting but, in view of the complexities of its estimation, do not justify its extension to other areas in this particular study.

6. Summary and Conclusions

The KTDA uses ad hoc tea yield curves both at the national and Divisional level. Yield curves are important for the efficient planning of the expansion of smallholder tea. The Authority has in its files data with which it could statistically estimate these yield curves. Alternative methods of deriving average yield curves are considered in detail. It is concluded that even a very simple model that only takes into account the age distribution of the planting stock would provide the KTDA with curves that would substantially improve the Authority's attempts at predicting output and, consequently, at calculating loan repayment schedules, the optimal phasing of factory construction and the transport requirements of the crop.

More complex models, which include farm effect coefficients for each farm, are not justified for the simple purpose of estimating tea yields. However, the KTDA has shown considerable interest in measuring farmer efficiency, and consequently these models have a practical application in addition to the calculation of yield curves. We now turn to an analysis of farm effect coefficients as a measure of the managerial efficiency of our sample of smallholder tea farmers in Kenya.

CITATIONS

1. Kenya Tea Development Authority, The Operations and Development Plans of the Kenya Tea Development Authority (Nairobi: KTDA, December 31, 1964).

2. Kuh, E. and Meyer, J.R., "Correlation and Regression Estimates when the Data are Ratios", Econometrica XXIII, No. 4 (October 1955) pp.400-413.

CHAPTER VI

THE TECHNICAL EFFICIENCY OF THE FARMERS

1. Introduction

To complete this study we now turn to a more detailed examination of the farm effect coefficients as they relate to the technical efficiency of smallholder tea farmers. The next chapter then concludes our economic analysis with a consideration of the role of labour inputs in the production function for tea.

The classical production function is statistically estimated on the assumption that technical efficiency exists. That is to say, if one is using cross-section data it is assumed that individual firms are operating on the efficient frontier of the production possibility set. Having noted, in Chapter II, the unrealistic nature of this assumption, we have explicitly allowed for the differences in technical efficiency between farmers by including "farm effect" variables in the specification of the production function. There were two major reasons for including these variables. The first was so that some comparison could be made between the relative efficiencies of different farms. For example, by how much do the yields of the top twenty-five per cent of farms differ from the average or the bottom twenty-five per cent? The second reason for including the farm effect variables was a statistical one, to avoid management bias in the regression estimates. Each of these issues will be examined in detail. However, we first turn to recent information on farmer efficiency collected independently by the KTDA.

2. The KTDA's Measure of Farmer Efficiency

Even casual observation of smallholder tea farms is enough to convince one that here, as in all fields of human endeavour, there is a wide range of variability in efficiency. Since the survey data were collected for this study, the KTDA has tried to formalize the collection of information on managerial efficiency with twice-yearly Field Reports. The current report form is shown in Table 18. The purpose of such reports is three-fold:

" (1) To provide the Authority with a progressive census of tea planted;

(2) To provide information on the cultivation standards of each farm;

(3) To give close control of field staff. " (2)

In the light of the findings of the earlier chapters of this study it is of interest to note that information on annual plantings continues to be available. Some use is made by District tea officers of the second item (information on the cultivation standards of each farm) particularly for checking on very poor farmers. However, a major purpose appears to be the construction of rough (i.e. with only three class intervals) frequency distributions of the grades of individual farmers at the Divisional level. Thus each Division will know the proportion of farmers falling in each of three grades listed towards the bottom of Table 18. The Junior Agricultural Assistants (JAAs) who make these reports are certainly kept extremely busy filling in forms. While the system does try to ensure that all farms are regularly visited (the aim is that they are visited at

Table 18 - KTDA Field Report Form

FIELD REPORT No. 1/2				Reg. No.
Growers Name:				No. Plants
Date Scored:				D.C. No.
PLUS MARKS FOR YIELDING TEA				+ (—)
Tipping/ Plucking Table : 2, 1, 0		Weeding : 1, 0		
Plucking Standard : 2, 1, 0		Windbreaks : 1, 0		D.C. Receipt No.
Population : 2, 1, 0		Soil Conservation : 1, 0		
Pruning : 1, 0		Total "Plus" Marks =		Tea Officer's Remarks
MINUS MARKS FOR PRE-YIELDING TEA				
Bad Nursery Work : — 1				
Bad Planting or Shading — 1		Total "Minus" Marks =		
Bad Weeding or Mulching — 1		GRAND TOTAL =		Head Office Remarks
Bad Pegging or Pruning — 1		FARM GRADE =		
Grade I = 8 - 10 Grade II = 5 - 7 Grade III = Under 5				
J.A.A's Name (Block Capitals)				
This report has been checked by me and is correct.				
A.A's Name:		Signature:		

least six times per year) whether this represents an optimal use of extension efforts is open to debate.

Using a sub-sample of three areas (Githunguri, Buret and Nyamira) total "plus" and total "minus" marks were obtained from the KTDA Field Reports for each farm appearing in the data matrix used in the statistical analysis of the previous chapters. These data for the period 1st July to 31st September 1969, are aggregated into the three official grades and presented in Table 19.

Table 19 – Percentage of Farms in Three Grades for Three Sample Areas

Division	Percent of Farms in Grade		
	I	II	III
Githunguri	21.4	40.4	38.2
Buret	54.5	45.5	0
Nyamira	26.6	56.6	16.7

Source: Calculated from data provided by the KTDA

On the assumption that the visiting JAA's score with the same standards in each area, the proportion of farms in each of the three grades in this Table is interesting. Ranking these three areas for efficiency, it is obvious that Buret comes first, Nyamira second and Githunguri third. However, the ranking of these three areas by their yield curves would give us the same ordering.[1] This might indicate that the differences in yields between areas is not merely a function of ecology but of managerial efficiency as well. What is less clear is the line of causation. Do low potential yields, because of a less well-endowed environment, result in poor management (as in Girthunguri) which in turn means low actual yields?

It is clear that a vicious circle is possible. But there is another possible explanation for the ranking: that is, that centrally trained JAAs, using strictly laid-down rules for grading farmers, may end up including a strong ecological bias in the farm efficiency measure. Thus JAAs who are trained on the high-yielding Tea Training Farm are likely to mark down all farmers in a low-yielding area. However, if we are really interested in farm efficiency in any one area we are interested in the performance of farmers in that area relative to what is possible in that area - not in relation to what

[1] See, for example, the figures given in Table 15 and the associated graph, Figure 10. However, in years 4 and 5 Nyamira actually outyields Buret; hence the ordering is not unambiguous. In order to compare scalars rather than vectors, these yields can be discounted to a 'present value'. It is possible to select a sufficiently high discount rate such that the higher yields in the early years in Nyamira outweigh the later high yields in Buret. Since the rate which reverses the ordering is in excess of sixty per cent - the problem can be ignored for our purpose.

is possible elsewhere. Is the difference in efficiency between Githunguri and Buret really as great as the distributions in Table 19 imply? As we shall see, a statistical analysis of the technical efficiency of farmers in these areas would suggest not.

Before examining in detail the statistical measure of technical efficiency, four important differences between the KTDA's measure of efficiency and that obtained from the regression analysis need to be noted.

First, the rationale underlying the two measures is quite different. The farm effect coefficients obtained from the estimation of the production function indicate the shift in yields from one farm to another. Using Model IV[2] as the basis of our analysis in this chapter, these coefficients (β'_{oi}) are cardinal measures of efficiency within any one area. The coefficients are both the measure of efficiency and the first year's yield of green leaf, in terms of pounds of green leaf per bush per year. When making comparisons between areas with different natural resource bases, the farm effect coefficients are not ordinal, let alone cardinal, measures of efficiency. However, by making some simple transformations of the coefficients, inter-area comparisons can be made. The total "plus" and "minus" marks in Table 18 provide us with an independent ordinal ranking of farms in terms of efficiency as defined by the marking structure established by the KTDA. But, as we have seen, it is not certain that, even if the marking were done on the same basis across Districts, the results could be strictly

[2]Model IV excludes the year effect coefficients (see p. 74).

interpreted as showing relative efficiencies between different ecological areas.

Secondly, unlike the farm effect coefficients, the weighting system and, consequently, the measure used by the KTDA does not have a yield basis. Thus, for comparative purposes, one wishes that greater weights and penalties had been given to those factors which particularly influence yields. For example, the following points system would have been more suitable for our purpose.

Tipping/Plucking table	2. 1. 0
Plucking Standard	6. 3. 0
Population	4. 2. 0
Pruning	2. 1. 0
Weeding	2. 1. 0
Windbreaks	1. 0
Soil Conservation	1. 0
Maximum possible plus marks	20

Unfortunately, without the data in its original form this re-marking cannot be done.

Thirdly, the farm, or "management", effects were estimated for the period 1961/62 to 1965/66 while the KTDA figures refer to 1969. During this period many farmers have doubled the size of their tea gardens, others have quadrupled theirs. The average number of stumps per grower in the Githunguri sample increased from 3,220 in 1966 to 5,800 in 1969. The comparable average figures for Buret are 2,809 and 6,338 stumps per holding, and for Nyamira the increase was from 1,220 to 3,515. Given the large increases in the average size of holding, it is not unlikely that some decreasing returns to management have accrued as management is "spread" over the larger gardens with more hired labour. At the same time, while KTDA extension services are of the intensive variety, the actual efforts are spread more thinly as more farmers start to plant tea and existing farmers plant more.

The fourth point is that while the farm effect coefficients obtained from the regression analysis permit a ranking of farms with no ties, the KTDA's measure results in a great many ties since, at most, there are only ten possible scores. This means that the normal measures of rank correlation such as Spearman's or Kendall's are not of use.[3] This is a pity since a listing of the two sets of figures gives one a tantalizing impression that there is a significant degree of conformity between the rankings. This can be seen in Table 20 where the following procedure was adopted in order to obtain comparable rankings. The number of farms gaining 10, 9, 8,... etc. points under the KTDA system were ranked as being in class 1, 2, 3,...etc. Then the same number of farms in the statistical ranking was put into each class. Thus, if there was one farm with 10 points then the farm with the highest "farm effect" was given the rank 1. If an additional eight had 9 KTDA points, then these farms were given the rank number 2 and the same was done for the next eight farms with the highest "farm effect" coefficients. This procedure was adopted by only using the

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[3]There seems to be little or no discussion in Statistics text books of the problem of ties. Where the problem is discussed, as in Freund (1, pp.364-366) the concern is only with occasional ties, not whole sets of ties. The problem is aggravated further by the fact that, although there are ten possible scores, in practice only five or six scores are used.

Table 20 - Regression Analysis and KTDA Measures of Farm Efficiency and their Rankings for Nyamira Farms[a]

Farm No.	Regression		KTDA	
(i)	Coefficient (β'_{oi})	Rank (class)	Measure	Rank (class)
1	.933	2	9	2
2	.563	3	9	2
3	-.255	6	5	6
4	.726	2	8	3
5	.615	3	7	4
6	-.093	5	6	5
7	.187	3	8	3
8	.435	3	5	6
9	.461	3	9	2
10	.306	3	8	3
11	-.009	4	6	5
12	-.079	-	N.A.	-
13	.883	2	8	3
14	-.093	5	8	3
15	.135	3	7	4
16	2.016	2	8	3
17	.082	3	7	4
18	-.105	6	9	2
19	.330	3	8	3
20	-.052	4	5	6
21	.704	2	7	4
22	3.741	1	10	1
23	.054	4	9	2
24	.368	3	9	2
25	-.183	6	8	3
26	.204	3	8	3
27	.067	4	8	3
28	.127	3	8	3
29	.323	3	8	3
30	.511	3	8	3
31	.715	2	8	3

[a]The rankings are by the six classes established by the KTDA's measure of farmer efficiency when only the "plus" marks from the Field Report Forms (Table 18) are used.

KTDA's "plus" marks since these would be more related to the farmers' performance in the earlier years, to which the regression analysis applies.

However, having obtained this listing there is no standard summary statistic which can be used to tell us the significance of the apparent degree of association.[4] Since a direct comparison between the ranking of farms by the KTDA measure and the farm effect coefficients is not possible, we shall attempt an indirect comparison: first, by examining efficiency factors derived from the farm effect coefficients for evidence of the large differences in efficiency in the Divisions appearing in Table 19; and secondly, by examining the two measures for evidence of potential management bias.

3. Quantifying the Technical Efficiency of Farmers

In order to quantify the differences in technical efficiency within each of the five areas analysed in the earlier chapters, the farms in each sample are divided into four even groups by the rank of their farm effect coefficients. Thus, although the vector of farm effect coefficients in each area is unique to that area, in order to compare areas we make the (weak) assumption that the top 25% of the farmers are technically efficient. If the assumption is wrong and there are in fact few, if any, technically efficient farms in any given area, then the efficiency factors given below are less meaningful. The percentage of farmers in Grade I in Table 19 suggests,

[4]It would make an interesting additional study to seek out complete sets of information from Field Reports to see the effect of applying a more appropriate weighting system.

however, that our assumption is realistic. Certainly this procedure is more appealing than using (as was suggested in equation III - 8) merely the very best farm in each area as the basis of the frontier, since our procedure is less deterministic and allows for some stochastic noise around the production possibility frontier.

In order to calculate the desired efficiency factors, the arithmetic mean farm effect is then taken for each quartile range, thus giving us four yield levels for each area. Thus

$$\overline{M}_j = \frac{\sum_{i=1}^{K} \beta'_{oi}}{K} \quad \text{for } j = 1,..,4 \qquad \text{(VI - 1)}$$

where $\overline{M}j$ is the mean of the interquartile range j and K = N/4 where N is the number of farms in the sample. When these mean farm effects ($\overline{M}_j$) are added to the ratio coefficients (β'_k, see equation (III-11)) we obtain four yield curves for each area.[5] The highest yield curve is considered to be the technically efficient curve, that is, it represents the production possibility frontier. The other curves represent interior points in the possibility set (see Figure 2, Chapter II).

A comparison between areas cannot be made by simply comparing the $\overline{M}_j$ of equation (VI - 1) because the scale of the farm effect

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[5] Rather than curves, per se, we have four sets of five yield coefficients for each area.

$$\beta_{kj} = \overline{M}_j + \beta'_k \,. \quad (k = 3 \text{ to } 7 \text{ and } j = 1 \text{ to } 4).$$

These coefficients are points on the yield curve (see Figure 10).

coefficients in any one area is a cardinal measure of efficiency that is unique to that area. The scale is unique in two senses. First, it is related to the overall intercept for each area. It will be recalled that, in order to avoid a singular moment matrix, the overall intercept is omitted from Model IV. This means that it is implicitly included in the vector of farm effect coefficients. It is a simple task to construct a new vector of farm effect coefficients net of the mean farm effect. This gives us:

$$\beta''_{oi} \equiv \beta'_{oi} - \beta'_{o.} \qquad \text{(VI - 2)}$$

However, the scale of this new vector of coefficients (β''_{oi}) is also determined by the growing conditions in any area. As was suggested earlier, the effectiveness of good (or bad) management will be more pronounced in high-yielding areas and less pronounced in low-yielding areas. This is the second reason why farm effect coefficients are unique to each area.

In order to make comparisons between areas a normalised efficiency factor needs to be devised. One possible index of technical efficiency is the following:[6]

$$\tilde{M}_{j} = \frac{\bar{M}_{j} + \beta'_{5}}{\bar{M}_{1} + \beta'_{5}} .100 \quad (j = 1,2,3,4) \qquad \text{(VI - 3)}$$

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[6] An alternative would be to test the extent to which better (or worse) farms shift the average yield curve. Thus we could have:

$$M^{*}_{j} = \frac{\bar{M}_{j} + \beta'_{5}}{\bar{M} + \beta'_{5}} .100 \quad (j = 1,2,3,4) \quad \text{where } \bar{M} \equiv \beta'_{o.}$$

Such a measure is of less interest than the one used in the text.

Where $\tilde{M}_j$ = Efficiency factor for interquartile range j (j = 1,2,3,4) (By definition, then, $\tilde{M}_1$ = 100.0)

$\bar{M}_j$ = Mean of the farm effects in interquartile range j (j = 1,2,3,4) (see equation VI - 1)

β_5' = Ratio coefficient for tea in its fifth year of maturity (see, for example, Table 9)

$\tilde{M}_j$ provides us with a normalised efficiency factor which indicates the percentage by which the technically inefficient farms fall short of the efficient frontier represented by $\bar{M}_1 + \beta_5'$. The ratio coefficient is added to both the numerator and the denominator because of the mathematical form of the yield curves. These curves shift linearly with the change in management effect and consequently one obtains somewhat different indices depending on whether one uses first year or last year yields. Thus, as the size of β_k' increases (as k goes from 4 to 7) the relative difference between any $\bar{M}_j$ and $\bar{M}_i$ for $i \neq j$ will narrow. β_5' was chosen simply because it was the middle year. The same problem would not arise with Model V since there is a multiplicative rather than an additive relationship between β_{oi}^* and β_k.[7] There is an incidental advantage to the above procedure in that it overcomes the problem of having $\bar{M}_4$ of negative sign (as was the case in Githunguri, Gatundu and Nyamira).

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[7]This was discussed in Chapter III and in Section 5 of Chapter V.

These efficiency factors would be sensitive to extreme observations among the farm effect coefficients. Hence, before proceeding with the calculations of the efficiency factors, it is necessary to examine the frequency distributions of these coefficients for each area. The five histograms are set out in Figure 11 (a), (b), (c), (d) and (e). It will be noted that Kitutu has one extreme observation while Nyamira has two. Both areas are sufficiently close to large tea estates which have experienced severe theft problems for one to suspect that these extremes reflect something other than technical efficiency in the usually accepted sense. In the Kitutu case there is little cause for concern since the ratio of the highest farm effect to the next highest is only 1.39 : 1 but for Nyamira the first and second farm effects exceed the third by 4.01 : 1 and 2.18 : 1. Nyamira also happens to be a couple of miles closer to the tea estates. Having said this, however, it is interesting to note that the two farms in question are also considered to be efficient on the KTDA ranking. The farms are number 16 and number 22 in Table 20.[8] Using Bowley's measure of skewness, which avoids extreme observations, neither of these distributions would be considered highly skewed.[9] The frequency distribution for Nyamira

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[8]A further reason for the omission of farm number 22 is the extremely small acreage upon which the extraordinary yields are obtained. This farmer had planted only 200 stumps in 1960 - according to the official reports.

[9]Bowley's measure of skewness is given by

$$sk = \frac{q_2 - q_1}{q_2 + q_1}$$

where q_1 and q_2 are the differences between the median and the lower and upper quartiles respectively. $-1 \leq sk \leq +1$, with a symmetric distribution having a value of 0. Bowley suggests that a value of 0.1 indicates a moderate degree of skewness while a value of 0.3 indicates marked skewness. (See 3, p.132)

Fig. 11. Frequency Distributions of Form Effect Coefficients by Divisions.

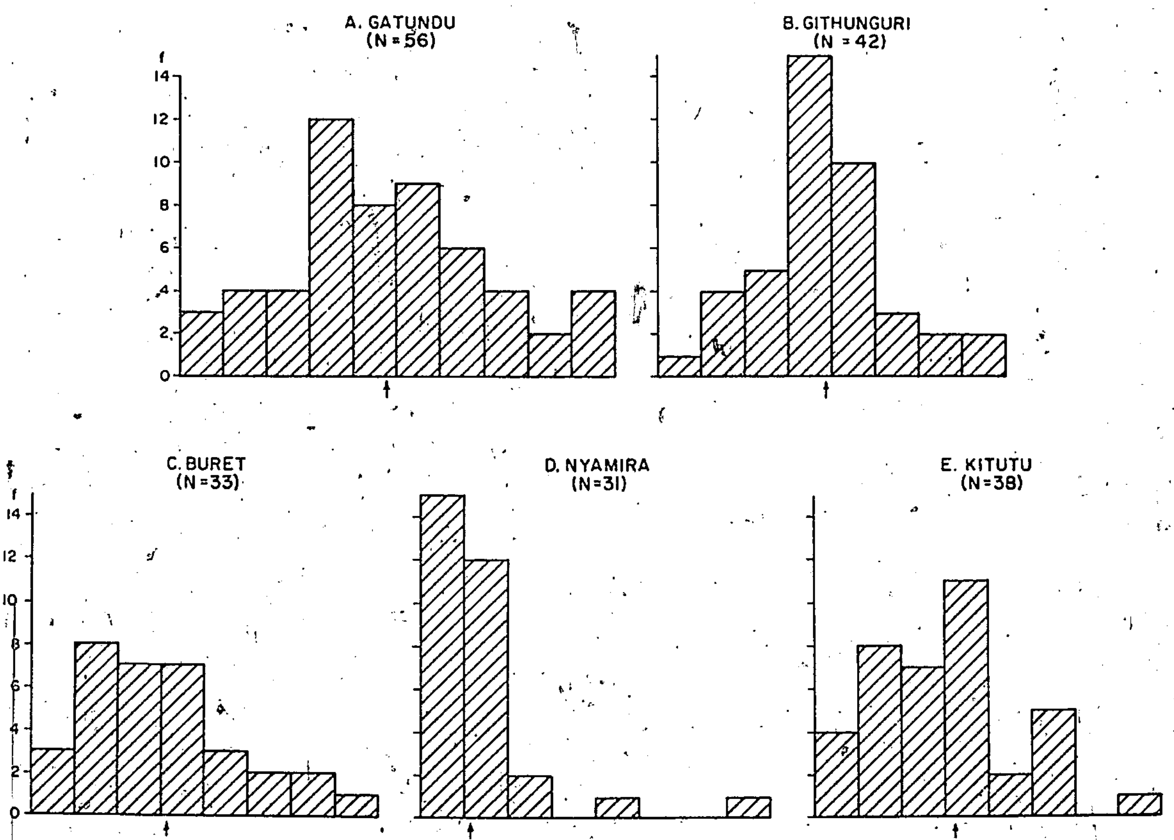
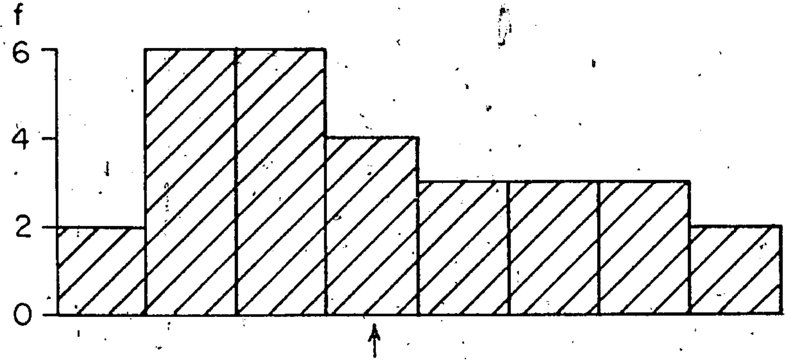


Fig. 12. Modified Frequency Distribution for Nyamira (N = 29).



is replotted in Figure 12 omitting the two extreme observations.

With the omission of these coefficients we can proceed with the calculation of the efficiency factors for each area, using equation (VI - 3). These are presented in Table 21. It is immediately apparent that there is a basic similarity between the efficiency factors of the first three Divisions (Gatundu, Githunguri and Buret). The second quartile of farmers achieves approximately 76 per cent efficiency, the third 64 per cent and the fourth about 50 per cent. The efficiency factors for Kitutu and Nyamira are, however, quite different. In the former the farmers are generally

Table 21 - Normalised Efficiency Factors for Technically Inefficient Tea Farms.*

	Efficiency Factors (%)				
Division	$\tilde{M}_1$	$\tilde{M}_2$	$\tilde{M}_3$	$\tilde{M}_4$	Skewness[a]
Gatundu	100.0	77.1	62.2	45.7	0.102
Githunguri	100.0	76.6	64.8	45.3	0.206
Buret	100.0	76.4	63.8	52.9	0.096
Kitutu	100.0	82.0	70.6	57.4	-0.140
Nyamira[b]	100.0	73.9	53.1	35.3	0.103

* The explanation of these efficiency factors is contained in the text.

[a] Using Bowley's measure of skewness (see text) where $\pm$ 0.1 is considered to be moderately skewed and $\pm$ 0.3 is highly skewed.

[b] Two extremely high observations are omitted for reasons given in the text.

more efficient while in the latter they are less so.[10]

Tables 19 and 21 essentially represent two alternative views of technical efficiency. If the farmers in the top grade in Table 19 are considered to be technically efficient, then Grades II and III show the proportion of farmers who are technically inefficient. The Table does not show the degree to which the farmers in the lower grades are inefficient. Table 21, on the other hand, shows the extent to which inefficient farms fall short but does not seek to answer the question as to how many farmers are inefficient. In spite of these two views of tech ical efficiency, it is clear that the results in Table 21 are c ainly not what we are led to expect from the KTDA grades present in Table 19. There is no evidence here to suggest that the farmers in Githunguri are substantially worse than those in Buret and Nyamira. On the contrary, the efficiency factors suggest that Nyamira is substantially worse than the others - including Githunguri.

This leads us to question again the subjective nature of the KTDA's grades both in terms of the arbitrary weighting system and of the reliance on the personal assessment of centrally trained Junior Agricultural Assistants. These JAA's all carry the same set of

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[10] This result is particularly interesting since these two areas are in the same ecological zone and are occupied by the same tribe. While it is outside the scope of this study, an investigation into the causes of this difference in efficiency would be worth pursuing - especially since a number of the explanatory variables advanced by V. Uchendu for differences in efficiency between Gussi farmers in the Kisii highlands and lowlands are eliminated. Both Magombo (Kitutu) and Kenyenya (Nyamira) are areas of more recent settlement in the highlands, the people are adherents to the same faith and have the same cash crop opportunities. (See 4).

instructions (see 2) and it would be surprising if there were not a considerable degree of uniformity in their grading. This probably means that the less favourable areas (in an ecological sense) will tend to be downgraded because of judgement based on what was taught and experienced at the Tea Training Farm, which is in an area of "high yields". Thus a possible interpretation of the Githunguri figures in the two tables may be along these lines: the reason why so many farmers fall into Grade III (Table 19) may be simply that the penalty for being technically less efficient in an area of low productivity is much greater than in an area of high natural productivity, such as Nyamira. A similar interpretation could apply for the highly productive area of Buret. It is not that 54 per cent of the farmers are technically efficient in terms of the production possibility frontier of that area, but when the judgement is based on experience outside the District, in less favourable conditions, it would not be surprising for high grades to be achieved in the KTDA's rating system. One concludes that Table 21 casts doubt on the validity of a straightforward interpretation of the KTDA grading system as being an adequate measure for comparing efficiencies between Divisions.

4. Management Bias Revisited

The second major reason for the inclusion of farm effect variables was to avoid the possibility of management bias. This question was discussed in some detail in Chapter III. We noted that it was rare to have *ex ante* evidence for the existence of management bias. Usually reliance in placed on the statistical test (i.e. an

F-test) of the significance of including the additional firm variables. However, these tests do not relate specifically to the existence or otherwise of management bias. What they do show is whether there is a significant improvement in the fit by using the extra variables. Nevertheless, the earlier analysis of this chapter provides us with the possibility of an ex post check on the existence of bias. We need to examine our data to find out whether better farmers have, in general, planted more tea. In other words, does the hypothesised positive relationship between managerial ability and other inputs actually exist? Table 22 shows the same four categories of farmers used in Table 21 but gives the average number of stumps that had been planted by those farmers in 1966. The last column gives the expected direction of the bias in the yield coefficients. Thus, using the farm effect coefficients as the basis of ranking the quality of the farmers, if on average the farmers in the higher quartiles plant more tea, we would expect an upward bias in the coefficients based on an equation omitting the farm effect variables. This was the form of our initial hypothesis, but the converse is also possible; a downward bias where the better farmers plant less tea. The figures in Table 22 would suggest that the expected upward bias might exist in only two areas (Githunguri and Buret), while a downward bias could exist in Kitutu, and no bias in the estimated coefficients would be likely in the other two areas.

Table 22 – Average Number of Tea Stumps per Farm by Managerial Class for Five Divisions in 1966

Division	Managerial Class 1	2	3	4	Expected Management Bias
	Tea Stumps				
Githunguri	5,047	3,300	2,456	2,695	Up
Gatundu	2,765	3,856	3,208	2,455	?
Buret	3,455	3,292	2,313	2,150	Up
Kitutu	1,255	1,864	1,800	2,013	Down
Nyamira	1,145	1,262	1,180	1,300	?

The actual, as opposed to the probable, existence of bias in the estimated coefficients can be checked upon by comparing Model IV, with an average farm effect, and Model VI which excludes individual farm effects and merely has an overall intercept. Thus equations (VI - 4) and (VI - 5) are being compared.[11]

Model IV $$Y_{it.} = \beta'_{o.} + \sum_k \beta'_k P_{kit} + e_{it} \qquad (VI - 4)$$

[11]For details on these equations, see the previous chapter.

Model VI $$Y_{it} = \beta'_o + \sum_k \beta'_k P_{kit} + e_{it} \qquad (VI - 5)$$

The difference between these two equations is to be seen in the intercept term. The yield coefficients derived from these equations are presented in Table 23. The last column in this table shows the observed direction of bias, if any. In comparing the final columns in Tables 22 and 23 it will be noted that in Buret and Kitutu the direction of bias is the same in both tables. However, both the "expected" and actual bias in Kitutu is in the opposite direction to that hypothesised from the only *ex ante* evidence at hand.[12] The expected upward bias in Githunguri does not show up while Gatundu demonstrates an unexpected downward bias.

The evidence for management bias being a problem in the estimation of tea yield curves is far from conclusive - either for any particular area or for smallholder tea in general. On the strength of the evidence presented one would expect that predictions based on Model VI would differ little from those based on Model IV and this is indeed what we found in Chapter V. Indeed, we went a step further and suggested that for prediction purposes 'biased' coefficients might be preferred.[13]

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[12] See footnote 6 in Chapter III.

[13] The bias can be incorporated implicitly as in Model VI, or explicitly in Model IV by using a weighted average of the farm effect coefficients. Thus:

$$\tilde{\beta}_{o.} \equiv \frac{\sum_i \beta'_{oi} \sum_k X_{ki}}{\sum_i \sum_k X_{ki}}$$

where $\tilde{\beta}_{o.}$ is the weighted average of the farm effect coefficients.

Table 23 - Tea Yield Coefficients of Model IV and Model VI, by Divisions

Division	Model	Yield Coefficients β_3	β_4	β_5	β_6	β_7	Management Bias
		(pounds of green leaf per bush per year)					
Githunguri	IV	.0803	.2938	.4890	.6383	1.1024	?
	VI	.0853	.2899	.4702	.6159	1.1210	
Gatundu	IV	.1453	.4219	.5725	.8630	1.0817	Down
	VI	.1692	.4271	.5437	.8235	.9456	
Buret	IV	.5001	.7826	.9283	1.4374	2.0176	Up
	VI	.5081	.8070	1.0059	1.4158	2.2347	
Kitutu	IV	.6211	1.4889	2.0081	2.7265	2.8391	Down
	VI	.5904	1.5113	1.8925	2.3893	2.7730	
Nyamira	IV	.4403	1.0100	0.9424	1.1445	1.3791	?
	VI	.3942	.9719	1.0231	1.2696	1.2843	

We would conclude, therefore, that from a practical point of view the inclusion or exclusion of the farm effect variable must be based on considerations other than management bias *per se*. However, it should be recalled that the smallholder tea industry is in the process of rapid expansion and the acreage of tea on any given farm is likely to be below optimum. If one were starting this study as of 1970 there would be a great deal more *ex ante* evidence regarding possible management bias. The more recent acreage figures and the KTDA's own grading procedure would be an obvious basis on which to examine the possibility of a positive correlation between acreage planted and a farmer's managerial skill. Table 24 brings together the most recent data on acreage and management for three of our five areas. The KTDA management ratings based on the Field Reports were grouped into four classes. Only the total positive marks were taken into consideration since these are more closely related to current output than are the negative marks.

Table 24 shows that by 1969 the better farmers had indeed planted more tea than the poorer farmers.[14] This pattern had already emerged in two of these areas (Githunguri and Buret) in 1966, as can be seen in Table 22. However, it is significant that these two tables represent quite different sources of evidence for possible management bias. Bringing Table 22 up to date with the 1969 planting

[14] In Githunguri two farms with large tea holdings are in the lowest class. It is quite likely that, as with the farmer with 31,000 stumps in Buret, (in class 4 in Table 24 and class 2 in Table 25), these farmers are absentee landlords investing non-farm income into tea.

Table 24 - Average Number of Tea Stumps per Farm by KTDA Managerial Class for Three Divisions in 1969.

Division	KTDA Managerial Class				Expected Management Bias
	1	2	3	4	
Githunguri	8,602	4,106	3,689	6,146[a]	Up
Buret	6,382	5,752	5,225	4,814[b]	Up
Nyamira	3,610	4,382	2,489	1,579	Up

[a]Two farms (out of 10) had almost 50% of the stumps in this class.

[b]One farmer with over 31,000 stumps was omitted. This farmer, a senior civil servant, is an absentee landlord.

Table 25 - Average Number of Tea Stumps per Farm by Statistically-Based Managerial Class for Three Divisions in 1969.

Division	Managerial Class[a]				Expected Management Bias
	1	2	3	4	
Githunguri	8,833	5,876	4,028	4,927[b]	Up
Buret	6,657	6,530[c]	5,727	4,727	Up
Nyamira	4,514	3,818	3,108	2,440	Up

[a]Based on farm effect coefficients.

[b]Two farms (out of 12) have 45% of the stumps in this class.

[c]Omits the one farm with over 31,000 stumps.

figures [15] - as is done in Table 25 - produces results that parallel those of Table 24, suggesting that the ranking of farms by the KTDA and by the regression technique are not too dissimilar.

However, the hypothesis that better farmers plant more tea cannot be accepted simply on the basis of Tables 24 and 25 since it could be countered by the antithesis that there are economies of scale: larger farms are better simply because they are larger. More evidence is required on this point, but the change in Nyamira between 1966 (Table 22) and 1969 (Table 25) is of particular interest since the ranking of the farmers was done before the 1969 holdings were established. Thus the antithesis would be rejected and the hypothesis accepted.

Our final conclusion is that, while in the analysis of the tea yield data up to 1966 there is no strong evidence of management bias, there is evidence in more recent data to suggest that the problem is more likely to exist today than it did five years ago.

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15. This exercise highlights the disequilibrium situation in the smallholder tea industry with its extremely rapid growth in the average number of bushes planted per farm.

CITATIONS

1 Freund, John E., Modern Elementary Statistics 3rd Edition (Englewood Cliffs, N.J., Prentice-Hall, 1967)

2 Kenya Tea Development Authority Standard Procedure : Technical Field Reports (Nairobi: KTDA mimeographed instructions, 1968)

3 Mills, Frederick C., Statistical Methods 3rd Edition (New York, Henry Holt & Co., 1955)

4 Uchendu, Victor C., and Anthony, Kenneth R.M., Economic, Cultural and Technical Determinants of Agricultural Change in the Tropics (Stanford, Food Research Institute, MSS 1969)

CHAPTER VII

LABOUR INPUTS IN TEA PRODUCTION

1. The High Level of Labour Inputs

Tea is indeed a labour intensive crop. This is recognised in all the standard works on tea cultivation and on the management of tea estates (see, for example 2 and 5). Only in Russia, and to a lesser extent in Japan, has there been much success in mechanizing tea "harvesting" operations.[1] East Africa, as with the major tea producing countries of India and Ceylon, continues to rely on manual labour for most field operations in tea production. This is hardly surprising considering the low opportunity cost of the labour involved.

Among smallholder tea farmers in Kenya, tea, in spite of its recent introduction and the very small size of the tea gardens, already accounts for a substantial proportion of total labour inputs. This is shown in Tables 26 and 27 which give a breakdown of the average annual labour inputs in farm and domestic work done by four groups of twelve farms in Kericho and Kisii districts.[2] It will be noted that

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[1] There is an interesting illustration of the type of combine harvester used in the Georgian S.S.R. facing p.703 of 3. This is a contrast to the Japanese level of mechanization which involves the use of hand-operated shears.

[2] The information on these 48 farms was collected during 1965/66 in the detailed farm survey conducted by the author. The farms form the final sampling stage of the survey and were selected at random from those farms which have been the basis of the major portion of the analysis thus far. Twelve of the Kericho farms feature here for the first time in this study. The Konoin Division farms were omitted from the earlier analysis because many of the farmers in this area had planted tea prior to 1959 but these plantings were pooled in the KTDA statistics with the 1959 tea stumps. Interpolation suggests that this area has yields well below Buret but somewhat higher than Gatundu.

Table 26 - Average Annual Labour Inputs per Farm on Domestic and Farm Work in Buret and Konoin Divisions, Kericho District.

Enterprise	Sample Area	Labour Inputs (Hours)								Percent of Labour Hired
		Family				Hired			Average Total Labour input (Man-equivalent)[f]	
		Farmer	Men	Women	Children	Men	Women	Children		
Tea	Buret	312.6	145.5	276.1	203.9	1179.0	98.1	23.9	2125.1	60.5
	Konoin	290.8	9.1	430.7	289.0	617.4	48.9	24.8	1553.4	43.6
Other Cash Crops[a]	Buret	0	0	0	0	0	0	0	0	0
	Konoin	0	0	0	0	0	0	0	0	0
Maize	Buret	190.6	114.6	160.4	193.9	213.3	20.9	11.8	801.9	30.0
	Konoin	124.5	7.6	284.1	249.0	223.0	74.3	30.1	863.0	36.2
Wimbi	Buret	21.0	36.8	91.3	26.8	24.9	62.5	0.9	245.7	35.7
	Konoin	53.0	22.5	564.1	127.2	124.3	215.3	30.0	1057.5	33.6
Livestock[b]	Buret	146.4	93.3	277.6	774.5	29.2	4.2	63.0	959.4	6.8
	Konoin	135.8	5.2	460.6	2368.2	109.3	8.4	123.1	1965.0	9.1
Other Farm Work[c]	Buret	135.3	80.0	229.4	109.8	147.5	4.0	3.1	742.1	20.6
	Konoin	214.0	28.2	306.5	218.6	223.1	32.3	18.6	922.6	29.0
Domestic[d]	Buret	55.1	40.7	2122.0	404.8	33.3	25.8	8.9	2483.5	2.6
	Konoin	44.8	2.3	1929.0	445.2	6.8	16.4	0.7	2222.0	1.1

Source: Survey Data

Footnotes are on a separate page following Table 27.

Table 27 - Average Annual Labour Inputs per Farm on Domestic and Farm Work, Kitutu and Nyamira Divisions, Kisii District.

Enterprise	Sample Area	Labour Inputs (Hours) Family: Farmer	Family: Men	Family: Women	Family: Children	Hired: Men	Hired: Women	Hired: Children	Average Total Labour input (Man-equivalent)*	Percent of Labour Hired
Tea	Kitutu	479.4	11.0	492.5	271.4	305.[illegible]	170.6	71.6	1630.3	31.4
	Nyamira	247.5	44.3	364.0	280.5	180.8	20.6	20.0	1007.0	19.8
Other Cash Crops[a]	Kitutu	113.8	5.8	245.2	239.6	22.1	8.0	1.9	515.6	6.0
	Nyamira	21.1	24.4	4.9	1.5	1.1	4.5	0.0	57.4	9.8
Maize	Kitutu	117.3	21.5	369.9	259.5	70.4	5.0	3.2	715.3	10.8
	Nyamira	124.9	42.7	522.7	553.9	129.6	19.4	14.2	1123.1	14.5
Wimbi	Kitutu	11.1	2.2	152.3	32.0	7.7	3.0	0.0	192.1	5.5
	Nyamira	12.0	3.9	234.6	72.7	7.2	13.7	1.9	309.6	7.0
Livestock[b]	Kitutu	401.6	2.4	359.5	887.1	28.9	2.1	1.4	1238.7	2.6
	Nyamira	204.2	22.2	276.2	1421.1	35.0	1.4	9.4	1254.2	3.3
Other Farm Work[c]	Kitutu	222.8	7.4	298.3	131.4	86.6	2.6	4.3	685.5	13.5
	Nyamira	104.3	50.4	288.7	177.1	71.1	4.7	4.8	609.5	12.8
Domestic[d]	Kitutu	115.7	11.3	1882.0	591.8	26.3	4.6	2.9	2336.7	1.5
	Nyamira	37.0	26.3	2102.5	1194.2	35.9	13.0	4.5	2814.0	1.8

Source: Survey Data

Footnotes are on a separate page following Table 27.

Footnotes to Tables 26 and 27

* "Man-equivalent" hours are calculated using the weights Men = Women = 1, Children = ½

[a] This category is insignificant in Kericho District since maize and cattle are the main alternatives. However, among the Kisii farms it includes pyrethrum, coffee and passion fruit.

[b] "Livestock" includes indigenous and European breeds of cattle plus a few sheep and goats. Most of the time is spent on herding, but milking, selling milk and spraying the cattle is also included.

[c] Includes work on vegetables, building and repairs, and supervision. It does not include communal work nor work done by the family on hired land (adding 357 hours in Buret, 49 in Konoin, 303 in Kitutu and 56 in Nyamira). It also excludes an average 192 hours spent chasing monkeys away from the maize in Konoin!

[d] Includes cooking, washing clothes, collecting water and fire-wood, etc.

in the very high-yielding areas of Buret and Kitutu, which had averages of 1.16 and .55 acres of tea respectively, labour inputs in tea exceeded those of any other enterprise. Indeed only domestic chores took more time. In Nyamira, with lower yields and an average of .44 acres of tea, both maize and livestock exceeded tea labour inputs, while in Konoin, with even lower yields but 1.07 acres of tea, only livestock took more time. However, the major input in livestock is in herding which is usually done by the younger children who would have considerable difficulty with most tea operations.

This extremely high labour input in tea immediately calls into question the assumption of the early chapters of this study. There it was assumed that current labour inputs in smallholder tea were jointly determined with output by other inputs. Given the assumption of the high degree of complementarity between labour and "capital" (i.e. a weighted addition of the bushes of differing vintage) it was argued that, provided labour was not a binding constraint, the use of a modified linear production function excluding current labour inputs was a valid approach. It is our task in this chapter to test that hypothesis.

2. Labour Operations and Work Rates

Labour inputs in tea production can be divided into a number of operations. These operations themselves can be grouped into those relating to the establishment (i.e. digging, planting, pegging, mulching), maintenance (weeding, fertilizer application, pruning) and harvesting (plucking and delivery to the buying centre) of tea.

Establishment and maintenance labour inputs of earlier periods will undoubtedly have a strong influence on current output. Variations in these inputs are likely to be highly correlated to, if not synonymous with, managerial skill. To the extent that this is the case, labour inputs do already feature in our production functions. It is the substantial time lag (two years in the case of establishment and one to two years in the case of maintenance inputs) between these inputs and the resultant output that prevents a single year's cross-section data on labour inputs from being incorporated explicitly into a production function. In retrospect, there is no way of recovering the labour input data of former years except in the implicit manner that has been used. In other words, establishment and maintenance inputs are a form of fixed cost which is not subject to change in a retroactive manner.

As tea matures, the major maintenance operations are reduced to annual fertilizer application on tea which is over five years of age,[3] and pruning which is done once every three years on mature tea. Thus by far the most important labour input on mature tea is in the form of plucking the leaves and the delivery of them to the buying centre. In Tables 28 and 29, which give average annual labour inputs per farm on tea by the different operation and labour categories, "digging and planting" and "weeding" will tend to disappear over time while "plucking" and "delivery" become increasingly important.

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[3] As was indicated in Chapter I, the campaign to get tea farmers to use fertilizer had been ineffective up to the time to which the survey data relates.

Table 28 - Average Annual Labour Inputs on Tea by Operation and Labour Categories, Buret and Konoin Divisions, Kericho District.

Operation	Sample Area	Labour Inputs (Hours)								Percent of Labour Hired
		Family				Hired			Average Total Labour input (Man-equivalent)*	
		Farmer	Men	Women	Children	Men	Women	Children		
Digging & Planting	Buret	17.2	21.2	4.3	13.0	70.4	1.6	1.2	121.8	59.7
	Konoin	53.8	2.2	15.1	46.3	1[illegible]0.4	0.8	5.7	228.2	58.6
Weeding	Buret	72.9	14.3	28.3	33.8	454.2	28.8	7.4	619.0	78.7
	Konoin	57.3	0.4	52.8	40.4	303.5	35.6	6.8	473.2	72.5
Pruning	Buret	9.3	9.3	3.0	4.8	13.0	0	0	37.1	40.5
	Konoin	18.2	1.5	0.0	4.5	12.2	0.4	0.0	34.5	36.5
Plucking	Buret	165.8	90.3	211.0	138.8	545.6	61.8	14.1	1151.0	53.3
	Konoin	130.2	4.7	319.2	175.0	147.6	11.3	11.7	706.2	23.4
Delivery	Buret	23.2	6.3	12.7	11.5	95.8	5.9	1.2	150.1	68.0
	Konoin	18.1	0.3	39.8	22.8	23.7	0.8	0.6	94.3	26.3
All Tea Work[a]	Buret	312.6	145.5	276.1	203.9	1179.0	98.1	23.9	2125.1	60.5
	Konoin	290.8	9.1	430.7	289.0	617.4	48.9	24.8	1553.4	43.6

Source: Survey Data

* "man-equivalent" hours are calculated using the weights: Men = Women = 1, Children = ½

[a] In addition to the specified operations this total includes hours of supervision.

Table 29 - Average Annual Labour Inputs on Tea by Operation and Labour Categories, Kitutu and Nyamira Divisions, Kisii District.

Operation	Sample Area	Labour Inputs (Hours) Family: Farmer	Family: Men	Family: Women	Family: Children	Hired: Men	Hired: Women	Hired: Children	Average Total Labour input (Man-equivalent)*	Percent of Labour Hired
Digging & Planting	Kitutu	55.6	0.7	17.9	27.9	11.8	1.7	3.6	103.8	14.8
	Nyamira	22.9	2.8	8.1	33.6	15.4	0.0	1.0	66.4	24.0
Weeding	Kitutu	152.4	1.9	78.3	69.3	56.3	1.2	0.7	365.0	26.8
	Nyamira	88.9	15.5	83.8	130.8	61.3	7.7	9.9	327.4	22.6
Pruning	Kitutu	11.8	0.0	0.5	0.5	19.0	0.0	0.0	31.5	60.3
	Nyamira	8.1	0.8	0.1	1.3	8.1	2.3	0.0	20.0	50.2
Plucking	Kitutu	193.3	5.3	327.4	137.9	149.3	156.1	59.7	930.1	36.0
	Nyamira	118.6	22.6	269.7	112.8	96.0	10.6	9.1	578.3	19.4
Delivery	Kitutu	48.1	0.9	60.6	35.8	28.9	11.6	7.6	171.8	25.8
	Nyamira	9.0	2.6	2.3	2.0	0.0	0.0	0.0	14.8	0.0
All Tea Work[a]	Kitutu	479.4	11.0	492.5	271.4	305.3	170.6	71.6	1630.3	31.4
	Nyamira	247.5	44.3	364.0	280.5	180.8	20.6	20.0	1007.0	19.8

Source: Survey Data

* "man-equivalent" hours are calculated using the weights: Men = Women = 1, Children = ½

a In addition to the specified operations this total includes hours of supervision.

Our initial hypothesis as regards the form of the production function specified both that labour input in harvesting was determined by output and other inputs and that labour was not a limiting factor. The first point is fairly straightforward and has been implicitly accepted in other studies.[4] Nevertheless, it is worth investigating the evidence a little further in regard to tea. Since harvesting labour is logically a function of the number of "two leaves and a bud" available to be picked and since regression analysis is neutral as regards the direction of causation, we can estimate the linear equation (VII - 1) although the direction of causation is $L = F(Q)$, where L is the total harvesting labour requirement and Q is total output.[5] We expect there to be a high degree of correlation between output and labour input. The equation is:

$$Q_i = \alpha_o + \sum_{j=1}^{6} \alpha_j L_{ji} + U_i \qquad \text{(VII - 1)}$$

where Q_i = the annual output of pounds of green leaf on farm i (i = 1,...,47)

α_o = the intercept term

α_j = the marginal product of labour type j (j = 1,..,6)

L_{ji} = the annual input of labour type j on farm i in hours

U_i = error term.

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[4] Thus Massell only uses weeding labour in the production functions for African farmers growing annual crops "because labour appeared to be a limiting factor only at weeding time..." (Massell 8, p.206).

[5] The neutrality as to the direction of causation is strictly true only of orthoginal regression. With OLS, interchanging dependent and independent variables will give different coefficients because of the direction in which the errors are measured and minimised. In the present case, with multiple labour inputs, it is not possible to estimate these inputs from output. Furthermore, the highly significant coefficients and high R^2 in equation (VII-2) suggest that the errors resulting from reversing the direction of causation are trivial.

Equation (VII - 1) is linear since tea plucking is a peculiarly individual affair so that there is no additive relationship between labour categories. The types of labour input (L_j) are those given in the heading to Tables 28 and 29 with the one exception that "hired children" (for whom there were few observations) are pooled with family children. Thus L_1 = the farmer, L_2 = other family men, L_3 = family women, L_4 = all children, L_5 = hired men and L_6 = hired women. The marginal products ($\frac{\partial Q}{\partial L_j} = \alpha_j$) should be thought of more as work rates per hour than marginal products in the usually accepted sense.

Equation VII - 1 was estimated by least squares regression techniques. For our results to be consistent and unbiased we assume:

$$E(U_i) = 0$$

$$E(U_i'U_j) = \begin{cases} 0 & \text{for } i \neq j;\ (i,j = 1,..,N) \\ \sigma^2 & \text{for } i = j;\ (i,j = 1,..,N) \end{cases}$$

The strength of these assumptions should be noted since, as is the case with so much economic survey work, the measurement of the variables cannot be assumed to be without error. What is implicitly assumed is that these errors are merely in observation and are independent of L_j.

The results are as follows:

$$\hat{Q} = \underset{(.348)}{60.83} + \underset{(4.15)}{3.47L_1} + \underset{(.399)}{0.42L_2} + \underset{(4.13)}{2.50L_3} + \underset{(3.20)}{2.07L_4} + \underset{(13.71)}{3.93L_5} + \underset{(5.03)}{3.50L_6}$$

$$\bar{R}^2 = .922 \qquad \text{(VII - 2)}$$

where the figures in parenthesis are the ratios of the coefficients to their standard errors.

With but one exception (family men other than the farmer) the work rates (α_j) are highly significant. The relative sizes of the various coefficients make a great deal of sense, hired labour having generally a higher product per hour, with the contrast between hired women and family women being particularly great. In general one would expect such a situation, where the hired women are unencumbered by family responsibilities and are probably younger. The lower work rate of farmers could be explained by the element of supervision that would go with their plucking and the fact that in most cases they are older men. The intercept is not significantly different from zero - which is satisfying. It is of interest to note that were these work rates to be normalised with respect to the average male adult marginal product then we would be close to the weighting system commonly used in Kenya and Uganda to calculate man-equivalent units. That is 1 man hour = 1 woman hour = 2 hours worked by children. (These are the weights used in the labour input tables in this chapter).

The actual sizes of the work rate coefficients are similar to those found in other tea-producing areas of East Africa. Pudsey (9), working in the Toro District of Uganda, calculated average man-equivalent plucking rates of between 3.42 and 4.84 pounds of green leaf per hour on farms with low and high yields respectively.[6] The comparable figure for Nyeri District in Kenya was 3.2 pounds per

[6]This distinction is an indication of the true direction of causation.

man-equivalent hour (4).[7] The KTDA itself used to believe that a rate of 10 pounds per hour could be achieved (see section 5(1) in Appendix I) but has revised that figure downwards to two kilos (4.4 pounds) per hour as being the rate for a good plucker. In general, plucking rates on the large tea estates are much higher than on smallholder farms. Rates of ten pounds an hour are achieved in flush periods by exceptional pluckers while six pounds an hour is considered normal. It should come as no surprise that the estates achieve these high rates since their labour force is composed of permanent, rather than casual, workers who have built up specialist skills. Furthermore, these workers are generally plucking from mature bushes (most of them considerably more than 20 years old) which allow higher plucking rates because the shoots are closer together than on the immature bushes of the smallholder.

The close fit of equation (VII - 2) to the data confirms our hypothesis of a high degree of correlation between output and hours spent plucking tea. However, it is not possible to prove the direction of causation - this must be deduced from the logic of the production process. The higher work rates on the tea estates and Pudsey's figures (7, p.35) would suggest that the labour input is indeed a function of the amount and the density of the available tea leaves. Hence, labour input is jointly determined by output and by the other inputs.

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[7]Since plucking and delivery were pooled in the Nyeri Report, an allowance of 12 per cent was made for the delivery time.

3. Labour as a Binding Constraint

We turn finally to the assumption that harvesting labour does not represent a binding constraint. On the face of it this would appear to be an overly strong assumption considering the high total labour inputs in tea. Where does this labour come from? The answer to this question is of more than passing interest considering the lengthy debates on the existence or otherwise of rural unemployment and underemployment. In the African context the topic has been the subject of at least one conference of social scientists (6). The conference on "Labour and Leisure in Traditional African Societies" suggested four rather different potential sources of labour for new productive activities: " (1) labour idle because of lack of opportunity, (2) labour employed to yield products and services of low value, (3) labour employed inefficiently, and (4) labour unemployed because of illness. " (6, p.4).

The conference admitted that in Africa today it is difficult, if not impossible, to find self-contained societies which could reasonably be called "traditional". Certainly the tea-producing areas of Kenya would not qualify. However, these four potential sources of labour are fairly universal and there is little doubt as to their importance in the areas investigated in this study.

Considering the last two items first: the difference in the hourly work rates between estate and smallholder labour indicates the potential for the existing labour force to handle a much bigger crop. One might add that the present low levels of productivity are, in part, an indication that labour is not a binding constraint.

Were it a constraint, we would expect the labour to have a higher level of productivity - attained by plucking only the easiest (closest) shoots. The degree of illness (including some stages of pregnancy) recorded on the survey farms varied considerably between farms and between areas and was far from being insignificant. While only 133 hours of absence from work due to illness were recorded in Buret, the figure was 376 hours in Konoin, 437 in Kitutu and 514 hours in Nyamira.

More important than these potential sources of labour, the smallholder tea farms have already had to draw on unemployed labour (i.e. "labour idle because of lack of opportunity") and underemployed labour yielding products and services of low value. It would be ideal to have time-series data on individual farms to check on the re-allocation of labour between crops, and between leisure and productive work, as a tea garden becomes more demanding. However, there is little doubt that the technical nature of tea production at the equator - with its relatively even labour profile - necessitates the activation of labour normally seasonally unemployed. Figures 13 and 14 show the average weekly labour input on two of the four groups of farms in Kericho and Kisii Districts. The more jagged profile of the Kitutu farms (Figure 14) is typical of farms with relatively little tea while the Buret pattern (Figure 13) is common among farms with about an acre of tea.[8]

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[8]The complete columns in the Kisii figures tend to understate the fluctuations in plucking since there is a tendency for the time spent weeding to have an inverse correlation with plucking hours. The average size of tea garden in Kitutu was .55 of an acre while in Buret it was 1.16 acres.

Fig. 13 Labour Profile of Tea Operations on Buret Farms.
Average Man-hours per Week, 1965/66

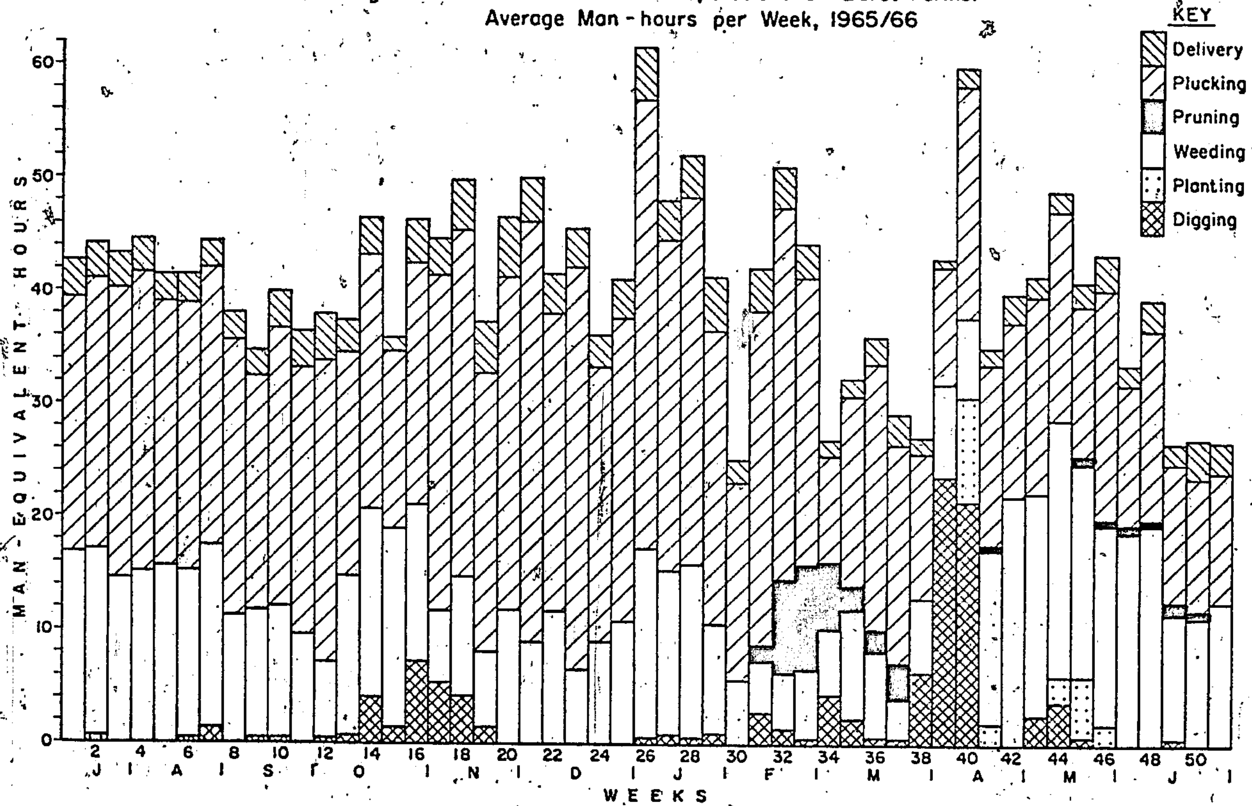
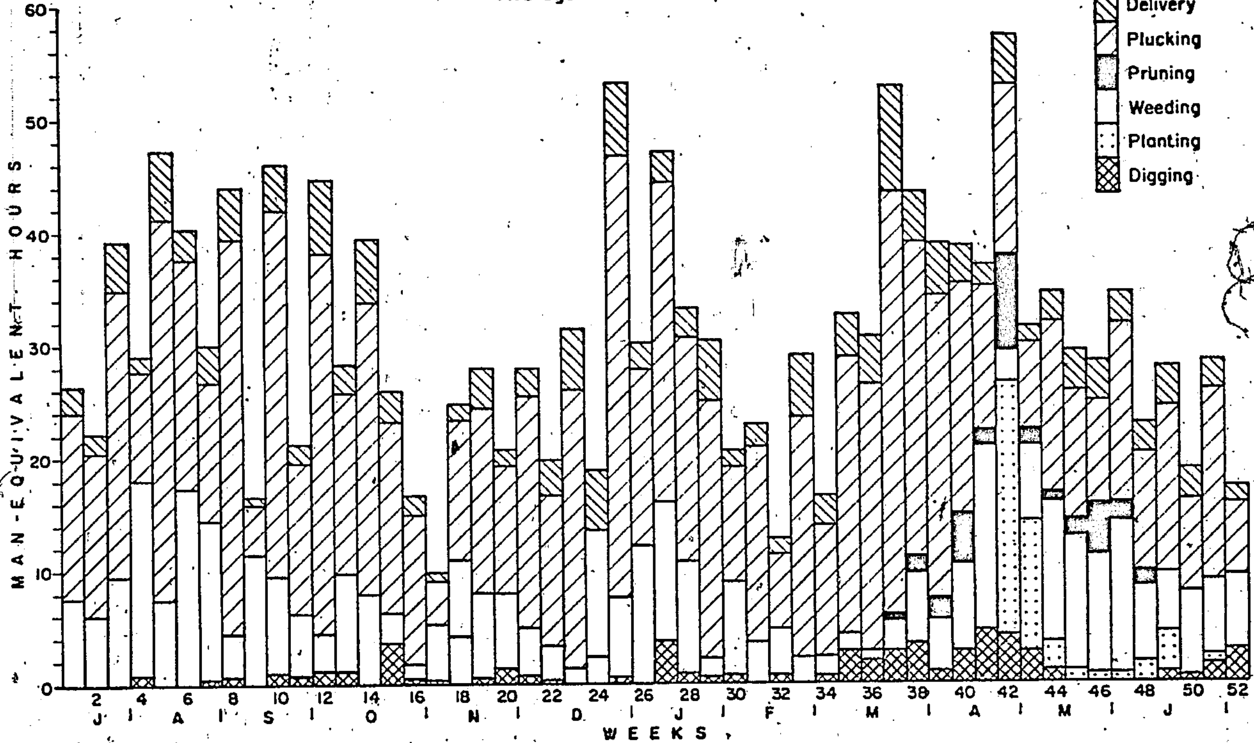


Fig. 14. Labour Profile of Tea Operations on Kitutu Farms
Average Man-hours per Week, 1965/66.



It is important to interpret these labour profiles correctly because the conclusion is vital to our assumption that labour is not yet a binding constraint. In terms of the regularity of monthly income, tea payments may be likened to the "milk cheque" of higher latitudes. However, unlike milking, tea plucking is not a daily task on smaller acreages; neither is timeliness of operation quite so crucial. Thus a postponement of plucking by two or three days is not critical. Any one bush is plucked once every week to two weeks, depending on the season. This pattern is well illustrated in Figure 14. Typically, a farmer with less than an acre of tea will arrange to stagger his plucking somewhat but will not be able to achieve as even a plucking routine as a farmer with a larger acreage. Thus a farmer with about half an acre and two adult pluckers would pluck for four hours on one day in one week and for the same period on two days the next week.[9] A farmer with the same labour force and with a mature acre of tea yielding 1,000 pounds of made tea per annum would need to work on his tea on three days in each week. One concludes that, in spite of the heavy labour demands of tea, its lack of extreme seasonality and the extent to which plucking operations can be concentrated on a few days in the week, allows tea to mesh in remarkably well with annual crops with bimodal profiles of labour requirements.

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[9]The reason for the four hour limitation is discussed in more detail below but a major reason for this is the technical necessity of getting the green leaves to the buying centre and thence to the factory within six hours of plucking. If tea is not delivered promptly it may start to ferment. This has an adverse effect on the quality of the finished product.

It was on the basis of rough calculations as to the plucking requirements of tea (and recognising its other advantages) that the KTDA and its predecessors aimed "to achieve an average of one-acre holdings, a size generally considered (to be) the maximum within the capacity of a family unit without employing labour". (7, p.8). This conclusion was also accepted in the report forming the basis of the smallholder tea industry in Tanzania (1).[10] However, it is quite clear from this study and from an earlier study in Nyeri District (4) that, in addition to mobilizing un- or under-employed family labour, the introduction of smallholder tea has resulted in the hiring of labour on tea gardens of considerably less than one acre in size. Only three of the forty eight farms studied in Kericho and Kisii Districts hired no labour for their tea operations.

The amount of hired labour employed is a function of many variables. On the supply side, the opportunity cost of the labour is obviously crucial and, as we shall see later, this cannot be gauged simply by comparing the smallholder piece-work rates with those operative on the estates. The demand for hired labour will depend greatly on the individual family situation: the size and plucking skill of the family labour force; the opportunity cost of the family's time - not only in terms of other farm or off-farm work but also in terms of their leisure preferences. The demand will also depend on the amount of leaf to be plucked. As far as these variables

[10]The Uganda experience is less relevant since the tea gardens are of a very much larger size and were never expected to be limited to family labour (9).

are concerned, the major difference between the four sample groups presented in the earlier tables of this chapter is in their average levels of production. In terms of other characteristics the differences between the groups are not as great. On a <u>ceteris paribus</u> assumption, Table 30 gives us an extremely interesting positive relationship between the amount of output (or a measure of a mature acre equivalent) and the percentage of the plucking labour that is hired.

Clearly, hired labour is extremely important in the smallholder tea sector and the KTDA was in error to assume that farmers would not hire labour until they had about an acre of tea. The KTDA had in mind farmers without off-farm occupations and it is true that the figures in Table 30 are "biased" upward by the existence - in all areas - of a number of farmers with off-farm interests. These interests range from petty trading in maize and livestock, shared duties with partners in a water mill, truck or shop, occasional work using carpentry, building or clerical skills, and plucking tea on the estates, to elected positions on cooperatives, primary school teaching and sub-chief duties, and on up to full time university students, Assistant Managers on tea estates and high-ranking Civil Servants. The existence of off-farm occupations is too common to be considered exceptional. Indeed one is hard put to find the KTDA's model farmer. Possibly the largest tea farmer in Nyamira fits the bill since, with 1.21 mature acre equivalents, he only hired five per cent of his plucking labour. But then he had four adults on the farm and two of his children were old enough to help with the plucking.

Table 30 – Average Farm Population, Green Leaf Production and the Percent of Plucking Labour Hired in Four Sample Areas.

Sample Area	Average Farm Population: Adults	Average Farm Population: Children	Average Green Leaf Production	Mature Acre Equivalent[a]	Percent of Plucking Labour Hired
	(Numbers)		(pounds)	(acres)	(%)
Nyamira	2.6	7.0	1,676	.37	19.4
Konoin	2.2	5.2	1,950	.43	23.4
Kitutu	2.6	6.6	3,378	.75	36.0
Buret	2.5	4.6	3,954	.88	53.3

Source: Survey data.

[a] A "mature acre equivalent" has been obtained by assuming, as does the KTDA, that a mature acre of tea yields 1,000 pounds of made tea or 4,500 pounds of green leaf. For our present purpose this is the correct conversion to make, although Kitutu yields are, in fact, nearly twice as high as this.

Whether or not a farmer could manage without hiring labour for plucking is somewhat of an academic question since most farmers actually do hire labour. Does this imply that labour is a binding constraint? One suspects not since hired labour was, and still is, available at extremely low rates.

At the time of the survey, piece-rate labour was paid between six and nine (Kenya) cents per pound of green leaf. At this rate labour was forthcoming although the plucking period was only for four hours in the day. The attraction of such casual work, particularly among the farmers in Kisii, was that the rest of the day was left for the labourers to look after their own <u>shambas</u> (Swahili : farm). At the same time, regular (full-time) male labourers were hired for a maximum of 60 shillings per month inclusive of maize-meal rations. The pay was typically 45 shillings cash and the equivalent of 15 shillings in rations. Such labour was used on all crops but if there were sufficient tea to be plucked regularly for four hours on four days of the week then tea alone would almost pay the full 60 shillings.[11]

However, the technical constraint of transporting tea to the factory from widely scattered buying centres within a restricted time period could well impose an indirect labour constraint in the 1970's. The collection procedure used at present is for KTDA trucks to leave the factory on their outward journey early in the morning, dropping

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[11] One worker plucking for four hours on four days per week at the rate of four pounds of leaf per hour would bring in almost 60/- per month if only the net payment of 23 cents were counted. In the meantime the farmer would be having his tea loan paid off (10c per pound), he would usually receive a second, additional, payment of up to 10 cents per pound and he would have "free" labour for other tea operations and for his other crops.

off buying clerks (collectors) at each buying centre to be visited that day. The return journey, on which the green leaf and the buying clerks are collected,[12] is started about 1 or 2 p.m. and finishes at the factory between 5 and 6 p.m. - weather permitting.[13] Initially a new buying centre is visited on one day a week and then on additional days as the deliveries of green leaf gradually increase as the tea bushes in the area become more mature. Eventually visits are made on a daily basis.

In late 1966, after the survey on which this chapter is based was completed, the KTDA concluded that the erection of buying centres such that farmers were within a radius of one mile was uneconomic in terms of their personnel and transport. The maximum distance a farmer should have to transport his tea is now laid down to be three miles. This reorganization was achieved not by closing buying centres but by delaying daily visits until a particular buying centre had regular deliveries of 6,000 pounds of leaf per day. This means

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[12]At the time of the survey this procedure was being used in Kiambu but a more time-consuming "bus stop" method (where the buying clerks remained with the truck) was the practice in Kericho and Kisii.

[13]Almost by definition, a tea-growing area has a high rainfall. The effect of rain on unpaved rural roads can be imagined. It is not a rare event for the KTDA's four-ton trucks to become bogged down in the mud - in spite of the fact that the trucks have four-wheel drive and low ratio gears. When a truck does become stuck the buying clerks have to ensure that the green leaf is regularly turned to prevent fermentation. The turning is made easier by the fact that the leaf is kept in hessian bags hung on hooks on upright metal poles built between the floor and roof of the truck (the truck has open sides to assist in the circulation of air through the leaves). By such turning the 'life' of the plucked leaf can be extended by a few hours beyond the optimal six hours.

that the farmer who does pluck daily can deliver his leaf to a nearby centre on two or three days in the week but must deliver to more distant centres on the other days.

Green leaf is a bulky crop to transport for it must not be crushed. Generally a head-load in a wickerwork basket is about 25 to 30 pounds, although where bicycles can be used two baskets weighing a total of 50 to 60 pounds may be carried.[14] The survey farmers spent an average of one to two hours per person per delivery on the delivery of their tea. The actual walking on the outward journey rarely took more than three quarters of an hour. The time spent at the buying centre varied greatly depending on the arrival times of the other growers. A grower living a mile from the buying centre would generally stop plucking at least an hour before the buying centre closed. For many farmers the new collection schedules mean that plucking must stop at least one and a half if not two hours before closure time. The KTDA is well aware that its present collection schedules are far from ideal for many farmers but it can find no suitable solution while buying centres are scattered at great distances (up to sixty miles) from the factories. Only as production increases and more factories are built will it be possible to improve the situation.[15]

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[14] As a precaution against the crushing of green leaf, the estates do not permit pluckers to carry more than 12 pounds in their plucking baskets. These baskets are designed with this weight in mind and are considerably smaller than the baskets used by smallholders to transport leaf.

[15] Of the seventeen smallholder factory sites shown on the map in Chapter I only seven had been built on by 1970.

A typical farmer is going to cease plucking about mid-day. This allows a hired worker to pluck for a maximum of about five hours in the day (from 7 a.m. to 12 noon). The range is between three and a half and five and a half hours in a day - depending on the distance of the farm from the buying centre and the distance of the buying centre from the factory.[16] The length of time for plucking by family members tends to be even more restricted. A family that has to milk cows in the morning, cook breakfast and prepare children for school, as well as complete other household chores, will find it difficult to start plucking much before 8 a.m.

A four to five hour plucking day might be ideal for family and part-time hired workers. Also it might suit farmers employing full-time workers when they have sufficient other farm work for the labour to do. But, as more and more smallholders start growing tea or expand their existing acreages, the exogenous constraint on the length of the plucking time is likely to impose an indirect labour constraint at the farm level.

On the tea estates, pluckers are assured of an eight hour working day because the large gardens and the close proximity of the factory allows many collections of the green leaf. The current estate piece-work wage rate is 10 cents per pound of leaf.[17] At an average

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[16]For reasons of equity this latter point is less important than it could be because no buying centre - even if it is right next to the factory - is allowed to remain open for leaf purchase after 3 p.m.

[17]Estate labour is, however, required to pluck at least 40 pounds a day in order to qualify for the monthly wage of 90 shillings (about $13 U.S.). Most pluckers qualify for much more than this minimum, and are paid accordingly.

plucking rate of six pounds an hour this would give a daily cash wage of 4/80 shillings. This is considerably more than the legal minimum wage of 2/95 shillings per day for agricultural labour.

Making the optimistic assumption that smallholders pluck five pounds an hour for five hours a day, and that they pay their hired workers at the same rate of 10 cents per pound, these workers could make 2/50 per day. In a six day working week (which the KTDA collection schedules allow) a plucker could earn a cash wage of 15 shillings per week or 60 shillings per month. This figure equals the present opportunity cost of hired labour in the rural areas[18] but if the more realistic sizes of the parameters given earlier (four pounds an hour for four hours a day for four days a week) are used, the daily wage is only 1/60 shillings and the monthly wage but 25/60. Clearly, in these circumstances, the labour must either be employed part-time or be given other farm work. There is still scope on both these scores since, unlike most estates, the smallholders do employ women pluckers for whom a short plucking day is particularly convenient.[19] By 1976 it would appear that the maximum demand by smallholder tea growers for part-time hired labour would amount to about ten per cent of the available labour force in the tea-

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[18] A wage of sixty shillings for full-time hired labour in the smallholder sector may be preferred to the higher estate wages because of the more congenial (less authoritarian) working conditions and the usual provision of a small subsistence garden.

[19] In Kericho District (Buret and Konoin Divisions) the employment of full-time male workers (usually of the Jaluo tribe) is the common practice. This partly explains the low (less than 10 per cent) proportion of female hired labour. In Kisii District the practice is to employ people from Kisii itself thus giving more scope to the hiring of women. In Kitutu about half of the plucking done by hired workers was done by women (see Table 29).

growing areas.[20] This requirement does not seem unduly high although in certain Districts, which have a particularly high proportion of their land devoted to tea, a shortage of such labour might become acute. However, in such cases, the very density of the tea gardens should allow the KTDA to introduce a more flexible collection schedule with more than one pick-up per day. This in turn would encourage the use of more full-time labourers. Clearly a move in this direction will be necessary if labour is not to become a binding constraint in the smallholder sector of the tea industry.

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[20] By 1976 60,000 acres of tea should be yielding about 60 million pounds of made tea - or 270 million pounds of green leaf. Plucking at a rate of 3.5 pounds per hour for 16 hours per week for 50 weeks implies a total requirement of 100,000 persons. If one-third of the plucking is done by <u>part-time</u> hired labour then 33,000 such workers would be required. Using the 1962 census figures for the populations of the twelve tea Districts, and allowing for a 3 per cent rate of population growth, their total population will be about 4 million. With the present rapid growth of population half this number would be too young for plucking. If, in addition, only a quarter of this population is actually in, or in easy reach of, tea-growing areas within each District, then the 33,000 workers would be drawn from a potential labour force of 350,000 - due allowance being made for the actual tea farmers and their wives.

CITATIONS

1 Bridger, G.A., Peasant Tea in Tanganyika (Addis Ababa: UN.ECA/FAO Joint Agricultural Division, April 1961)

2 Eden, T., Tea, Second Edition (London: Longmans, 1965)

3 Encyclopaedia Britannica, 1966 Edition, Vol. 22, (Chicago: Encyclopaedia Britannica, Inc. 1966)

4 Farm Economic Survey Unit, Some Aspects of Agricultural Development in Nyeri District, 1962, Report No. 21, (Nairobi: Ministry of Finance and Economic Planning, 1964)

5 Harler, C.R., Tea Growing, (London: Oxford University Press, 1966)

6 Jones, W.O., "Labor and Leisure in Traditional African Societies", Items Vol. 22, No. 1 (March 1968)

7 K.T.D.A., The Operations and Plans of the Kenya Tea Development Authority (Nairobi: KTDA 1964)

8 Massell, B.F., "Farm Management in Peasant Agriculture: An Empirical Study", Food Research Institute Studies Vol. 7, No. 2, (1967)

9 Pudsey, D., The Economics of Outgrower Tea Production in Toro Western Uganda (Mimeographed report, November 1967)

CHAPTER VIII

SUMMARY AND CONCLUSIONS

The smallholder sector of the Kenya tea industry is in the midst of a very rapid expansion programme. Starting with barely two thousand acres in 1960, the sector has expanded to about thirty thousand acres in 1970. It is planned that this figure should be raised to sixty thousand by 1975, by which date half the national tea acreage will be in the hands of African farmers. The expansion of the sector has occurred because of the removal of the legal and technical constraints that formerly prevented the smallscale farmer from participating in the growing of a crop that flourished on the large estates. The removal of these constraints has been a major function of a public bi-lateral monopoly, the Kenya Tea Development Authority (KTDA).

Thus, the developments of the last ten years have been symptomatic of an adjustment to a situation of disequilibrium. It is not that tea prices have suddenly become more favourable. If anything, the relative price of tea has fallen over the period in harmony with the excess supply situation that has been developing on the world tea markets. The climax to these events has been the signing of a new International Tea Agreement in 1970. Under this agreement, Kenya has an export quota of 76 million pounds of made tea. This would appear to compare favourably with the record export in 1969 of 72.6 million pounds. However, even without the additional plantings planned for the next five years, Kenya's output of tea will expand rapidly as the bushes, planted in ever-increasing numbers over the last ten years, reach maturity. In these circumstances, knowledge of the rate of maturation of the tea plant becomes important if predictions of output are to be made. Besides their importance with respect to Kenya's obligations under the Tea Agreement, these predictions are needed for the optimal phasing of factory construction, the provision of transport and the calculation of international debt repayment schedules.

The major burden of this study has been the specification and estimation of a multi-period production function for smallholder tea in Kenya (Chapters II and III). The most important subset of variables considered was the number and age distribution of the stock of tea bushes on a random sample of tea farms. An important consequence of this was the derivation, from the function, of tea yield coefficients for bushes of differing ages. These coefficients were then used as a basis for <u>ex post</u> predictions of output for a separate sample of farms. The predictions were then compared with those obtained by the KTDA. In all cases the statistically derived yield coefficients gave much more accurate predictions of output.

However, the coefficients obtained in this study (and indeed any that could be obtained for planting data up to 1967 and output data to 1969) cannot be assumed to remain constant for the future. Two specific changes in technology are taking place. In the first instance, new planting material is now vegetatively propagated (VP) and, being based on specially selected clones, promises to provide substantially higher yields. Secondly, the KTDA is now actively promoting the use of fertilizer. The production function developed in this study can be modified to handle both these changes. "VP" plants can be introduced as a new set of variables. Thus we have:

$$Y_{it} = \beta'_{oi} + \sum_{k=3}^{9} \beta^*_k P^*_{kit} + \sum_{k=3}^{10} \beta'_k P_{kit} + u_{it} \qquad \text{(VIII - I)}$$

The only change from the equations contained in the body of the study is the introduction of the asterisked terms:

β^*_k is the "ratio coefficient" showing the contribution to the overall yield (Y_{it}) of the proportion of the total stock of bushes that are vegetatively propagated and are k years of age (K = 3,.., 9).

P^*_{kit} is the proportion of the total stock of tea bushes that are VP and are k years of age (K = 3,..., 9)[1] on farm i in year t.

The production function, both here and in previous chapters, includes the use of dummy farm variables which are used to estimate the farm (management) effect coefficients, β'_{oi}. These variables were included both as a precaution against management bias and as a check on the technical efficiency of farmers. By 1966 there was little evidence that better farmers had actually planted larger acreages of tea but by 1969 a clear pattern along these lines had emerged. Thus there was an indication - which needs further investigation - that higher yields of larger tea farms are due to the skills of these farmers and not to economies of scale.

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[1]VP bushes start yielding one year earlier and achieve maturity one year before bushes grown from seed. For the ninth year and beyond all bushes, because they are mature, will be in one category. Alternatively there could be three categories of mature bushes, one category for each of the three years in a pruning cycle. P^*_{2it} is omitted to avoid a singular moment matrix.

In the present situation of disequilibrium, there is little purpose in investigating the allocative efficiency of the farmers. Technical efficiency is, however, important - as the KTDA's own attempts to measure it show. We concluded that, while there were differences in technical efficiency between areas, these differences did not follow the clear pattern established by the KTDA's measure whereby lower-yielding areas were considered to be less efficient. Our results suggested that the KTDA's system of grading farmers has a built-in ecological bias.

Because of the essential linearity of the production process, the management effect could not be conveniently introduced so as to have a multiplicative effect on yields (though this is possible using an iterative procedure). Although it is also not entirely satisfactory, the actual procedure adopted could now be used to check on the effectiveness of the application of nitrogen fertilizer compounds. These have been imported in increasing quantities during the last two years by the tea estates and are now being more actively promoted by the KTDA.[2] Equation (VIII - 1) can be rewritten so as to include a fertilizer variable:

$$Y_{it} = \beta'_{oi} + \gamma F_{it} + \sum_k \beta^*_k P^*_{kit} + \sum_k \beta'_k P_{kit} + u_{it} \qquad \text{(VIII - 2)}$$

where F_{it} is the number of pounds of fertilizer applied by farm i in year t.

γ is the marginal contribution to yield of a pound of fertilizer $\left(\frac{\partial Y}{\partial F}\right)$

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[2] Imports of fertilizer compounds used exclusively on tea (these are 25-5-5, 25-10-10 and 20-10-10, NPK) as estimated from fertilizer subsidy claims, were for the period July/June in 1967/68, 4738 metric tons; 1968/69, 9027 m.t. and 1969/70, 13,289 m.t. Only about 1,100 m.t. were used by the KTDA in 1969.

Since $$Y_{it} \equiv \frac{Q_{it}}{\left(\sum_{k=2}^{9} V_{kit} + \sum_{k=3}^{10} X_{kit}\right)} \qquad \text{(VIII - 3)}$$

where V_{kit} is the number of VP tea bushes of age k on farm i in year t.

then equation (VIII - 2) can be rewritten by dividing through the right hand side by the denominator of (VIII - 3). Recognising that the fertilizer is only applied to tea bushes of five years age and older, and collecting the terms, we get:

$$Q_{it} = \beta'_{oi}V_{2it} + \sum_{k=3}^{4}\left(\beta'_{oi} + \beta^*_k\right)V_{kit} + \sum_{k=5}^{9}\left(\beta'_{oi} + \beta^*_k + \gamma F_{it}\right)V_{kit}$$
$$+ \sum_{k=3}^{4}\left(\beta'_{oi} + \beta'_k\right)X_{kit} + \sum_{k=5}^{10}\left(\beta'_{oi} + \beta'_k + \gamma F_{it}\right)X_{kit} + e_{it} \qquad \text{(VIII - 4)}$$

By taking the average farm effect and by re-defining our terms in the manner done in Chapter III, (VIII - 4) can be simplified for prediction purposes to:

$$Q_t = \sum_{k=2}^{9} \bar{\beta}_k V_{kt} + \sum_{k=3}^{10} \beta_k X_{kt} + \gamma F_t \left\{\sum_{k=5}^{9} (V_{kt} + X_{kt}) + X_{10t}\right\}$$
$$+ e_{it} \qquad \text{(VIII - 5)}$$

where Q_t is the total output for the particular tea growing area in year t

$\bar{\beta}_k$ and β_k are the "natural" yields of VP and seedling bushes of age k. $\bar{\beta}_k = (\beta'_{oo} + \beta^*_k)$ and $\beta_k = (\beta'_{o.} + \beta'_k)$.

The last term (ignoring the error term) gives the contribution to total output gained by the application of fertilizer to bushes (both VP and seedling) which are five years of age and older.

Fertilizer is seen in these equations to have an additive effect on yields. Thus, in addition to the "natural" yield of a bush (or an acre of such bushes), there is the output attributable to the application of fertilizer. It would be more desirable to have fertilizer enter into an equation in both a curvalinear and a multiplicative manner. The first problem is simply solved by including higher order terms for fertilizer inputs in equation (VIII - 2).[3] The second problem can only be solved once the natural yield parameters for an area have been established. Then the necessary weights would be available for the calculation of a "mature bush (or acre, hectare, etc) equivalent". This could then enter as one of the arguments - along with fertilizer - in a Cobb-Douglas or CES production function.

The equations presented in the early chapters and in the conclusions omit labour as an explanatory variable except in so far as it is implicitly included in the management variable. Tea is indeed a labour intensive crop but, it was argued (in Chapter VII), the labour input is jointly determined by output and the other inputs. During the period analysed in this study labour was not considered a binding constraint so that its exclusion from the production function was correct. However, smallholder farmers hire much more labour than was envisaged by the KTDA and it is possible

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[3] Given the very low levels of fertilizer currently used by the smallholder farmers it is highly unlikely that additional terms would be significant.

that the collection schedules of the Authority, by limiting the length of a "plucking day" to about five hours, may indirectly cause labour to become a binding constraint in the future - particularly if the labour/tea price ratio should increase significantly.

The techniques developed in this study for the estimation of the yield parameters of perennial crops have general validity in cases where labour is not a binding constraint. An assumption along these lines is probably realistic for most of the perennial crops produced in the tropics and, since the data demands are not excessive, it should now be possible to estimate more accurately the yield performance of such crops under a wide range of field conditions. This is clearly of interest not only to the agricultural botanist but also to the economist concerned with the optimum allocation of resources. The economist is also interested in knowing the parameters of the lag between investment decisions and the resulting output. By knowing the life cycle of a perennial crop the economist is more able to assess the true supply response of farmers to changing producer prices (1).

The Kenya population is estimated to be growing at over three per cent per annum. Given that ninety per cent of the population live in the rural areas and that the urban population is growing at six per cent per annum, the vast majority of the increase in the total population will have to be absorbed in the rural areas. The problems created by this situation become particularly acute in situations where land is scarce and expectations are rising rapidly. The Kenya Conference on Education, Employment and Rural Development (6) found no easy solutions, but among its agricultural recommendations it pointed out the need to concentrate on labour-intensive technology and to rely on the profit motive of farmers. Tea is labour-intensive in an almost unique manner among agricultural crops: it is harvested throughout the year, providing regular, rather than seasonal, employment for the farmers, their hired labour, the wage labour of the factories, and the associated transport network - all of whom are, necessarily, located in the rural areas. In this respect alone the crop is of tremendous significance to Kenya. The solution of many of the technical difficulties inherent in tea as a smallholder crop (7) has resulted in an important redistribution of incomes within the country. This redistribution has occurred in the most constructive manner possible since new productive capacity has been created in many areas of the country. While it is also clear that the potential in terms of available land has hardly been touched (2), the possibility of tea remaining a profitable crop and hence of tea exports acting as a classic "engine of growth" for the rural areas appears to be severely limited by a weak international market.

Tea in general has low price and income elasticities of demand (3, p.217).[4] However, the world market is not for a single undifferentiated product. Quality is a significant factor and in recent years Kenya teas have improved their relative position

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[4] As the FAO commodity review makes clear, the income elasticity of demand for tea in the less developed countries is subtially higher than in the developed countries (5, p.23).

vis-à-vis Ceylonese and Indian teas.[5] Having but a small share of the world market, the high quality teas being produced in Kenya would seem assured of a reasonable future. However, Kenya is not alone in realising the attractions of tea as a smallholder crop when it is effectively organized. In addition to the expansion programmes in all the East African countries, the giants of the industry - India and Ceylon - are also anxious to expand the level of their tea exports since the crop is a major source of foreign exchange (3 and 5). The future policies of India are likely to be crucial for the development of the industry in East Africa (3). India is by far the largest tea producer but nearly half her current production is consumed domestically. If India allows domestic consumption to continue to increase, gradually reducing the share, and absolute amount, of her crop going for export - as did Pakistan before her - then the build-up of the smallholder tea industry in Kenya may turn out to be one of the most significant agricultural development schemes in Africa since the Second World War.

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[5] Thus there has been a steady upward trend in relative prices. Expressing the price per pound realised in London by Kenya teas as a percentage of the prices realised by Ceylon and North East Indian teas, the following figures are representative of the trend:

Year	% of Ceylon price	% of N.E. India price
1960	85.4	86.5
1965	96.4	94.3
1969	100.0	106.7

Source: (4, p.25)

CITATIONS

1 Bateman, M.J., "Supply Relations for Perennial Crops in the Less Developed Areas" in Wharton, C. (Ed.) Subsistence Agriculture and Economic Development (Chicago: Aldine, 1969)

2 Brown, L.H., A Report on the Tea Growing Potential of Kenya (Nairobi: Ministry of Agriculture, January 1966)

3 Butterwick, M., "Prospects for Indian Tea Exports", International Journal of Agrarian Affairs, (Vol.IV, No. 4, June 1964)

4 Hainsworth, E., "The East African Tea Industry, Production and Productivity". TEA - Journal of the Tea Boards of East Africa (X, No. 4, January 1970)

5 Monthly Bulletin of Agricultural Economics and Statistics (Vol.17, No. 2, February 1968)

6 Sheffield, J.R. (Ed.), Education, Employment and Rural Development (Nairobi: East African Publishing House, 1967)

7 Wickizer, V.D., "The Smallholder in Tropical Export Production", Food Research Institute Studies (I, No. 1, 1960)

APPENDIX I

KENYA TEA DEVELOPMENT AUTHORITY INSTRUCTIONS ON TIPPING AND PLUCKING

1. TIPPING

(1) After pruning, the bushes grow undisturbed for about 12 weeks and are then 'tipped in' to form a flat top or plucking table: to start with, the height of the table should be 8 inches above the level of the prune, or 20 inches above ground, whichever is the greater.

(2) The reason for tipping in 8 inches above the prune is to ensure sufficient 'maintenance' leaf between the main frame and plucking table, which is essential for the health and productivity of the bush. Tipping in at less than 8" is a common fault on many smallholder gardens and is a probable cause of low yields after the first year of the cycle.

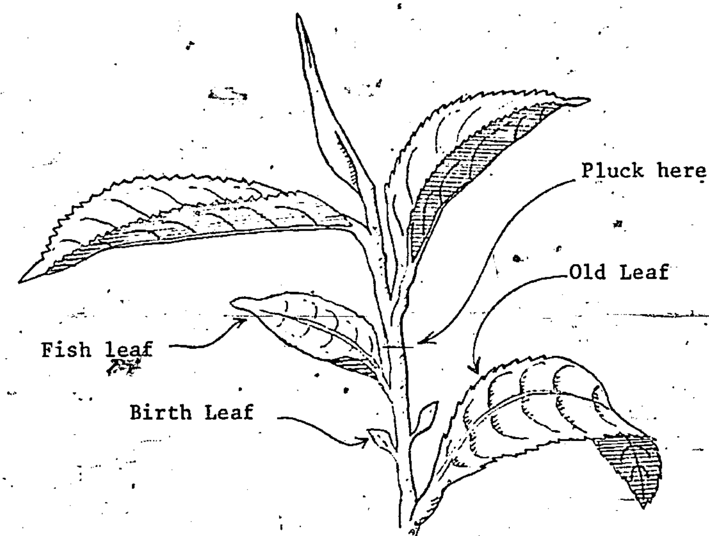
(3) Before tipping, the new branches are allowed to grow two leaves and a bud (i.e. about 2" -3") above the required height of the table so that the first plucking brings the level down to the correct height. After removal of the tip, remaining lengths of stem which have grown too tall are broken back to the right height. All necessary breaking back is done at the same time as the tipping, not later.

(4) The leaves and stems discarded from breaking back represent a waste of growth and the amount thrown away should be kept to a minimum by tipping in during several plucking rounds.

(5) The plucking table should be formed parallel to the slope of the ground. To achieve this, two forked sticks are cut at the required height and placed upright in the centre of two bushes in adjoining rows. A stick placed in the forks, up and down the slope, shows the correct height and angle of slope (see diagram). Tipping in should always be done with the aid of two measuring sticks, never by eye. A single T shaped measuring stick is unsuitable because when placed in the middle of a bush it gives only the height but not the slope of the table. The use of single measuring sticks has resulted in undesirable 'stepped' growth on steep slopes in many K.T.D.A. gardens.

2. PLUCKING

(1) In the development of a tea shoot, periods of active growth alternate with periods of resting or dormancy. When a bud begins to unfold, the first one or two leaves are usually very small rudimentary 'scale' leaves, oval in shape and not serrated: sometimes called the 'janam' (birth leaf - Assamese). These are occasionally, but not always, followed by a mal-formed leaf, partially serrated and rather rounded: sometimes called the 'fish' leaf or 'gol-pat' (round leaf - Assamese) - see diagram below. These rudimentary leaves are followed by the true serrated leaves which may number about five, sometimes more and sometimes less. At the end of any active growth period the shoot enters another resting phase, known as 'banjhi', easily recognised from the size of the bud which is generally less than half the length of the mature leaf below it. In an active growing shoot the bud is much larger. A high proportion of banjhi shoots indicates a resting period which may sometimes, but not always, be the result of over-plucking or other bad management.



(2) The K.T.D.A. requires 'fine plucking' in which only two true (serrated) leaves and a bud are taken, as distinct from 'coarse plucking' in which three leaves and a bud are harvested. Fine plucking is essential for the making of high quality tea. A slightly opened bud, in which a third leaf is just starting to unfold, is acceptable at the buying centres, but banjhi shoots and shoots with three leaves and a bud should be rejected.

It is sometimes argued that fine plucking gives a lower yield than coarse plucking, but there is no conclusive evidence to support this in Kenya at the time of writing.

(3) The following rules must be carefully observed:-

(a) Except when it is wanted to raise the height of the bush, 'hard plucking' should be practiced in which all shoots are taken off down to the level of the table.

(b) Plucking should never in any circumstances be below the level of the table.

(c) A shoot should never be plucked off below the fish leaf, if there is one. Breaking back below the rudimentary leaves is only done occasionally if essential to restore the evenness of the table.

(d) Hard plucking should be continued until the bush begins to show signs of 'crowfeet', i.e. the appearance of numerous twiggy stems near the surface of the table - and a falling off in yield. As soon as these symptoms of over-plucking start to show, the bushes must be rested and the top canopy of maintenance leaf renewed by raising the level of the table, as described in paragraph (5) (b) below.

(4) Much crop, and consequently profit, is lost in K.T.D.A. gardens through inefficient management. Common faults are:-

(a) Under-Plucking, in which the plucking round is too slow - resulting in needless waste of leaf and the plucking table rising too rapidly. This is especially likely to occur after nitrogen application when growth is fast.

(b) Careless plucking, in which shoots are overlooked and left on the bush.

(c) Over-Plucking, or hard plucking for too long without a rest; leading to crowsfeet, denuded tables, and low yields.

(5) The poor condition of the plucking table, resulting from these faults, is corrected as follows:-

(a) Unevenness. Avoid severe breaking back to re-form a table once it has been lost through under-plucking or carelessness. There may be some breaking back of the tallest stems but, apart from minor adjustments, the table should be left as it is until the next prune. On no account should heavy breaking back or 'skiffing' (described later in General paragraph (11)) be resorted to as these may only increase the loss.

(b) Over-plucked denuded tables. When the symptoms, described in paragraph (2) (d) and (4) (c), start to appear, the table should be raised 1" - 2" by allowing the shoots to grow taller (up to three true leaves and a bud), during one plucking round, and the tips then broken off immediately above the third leaf which is left on the bush to form a new canopy. This is sometimes referred to as 'plucking over a leaf'.

(6) Plucking tables must be as level as possible at all times. Unevenness results in loss of crop because shoots produced in the hollows tend to be missed. A level table can best be maintained by placing a straight stick across the tops of the bushes when plucking; and this is especially useful as a guide to height if any breaking back is necessary.

(7) As a rough guide the plucking round should be about 5 - 7 days during the flush season, decreasing to 10 days or longer at other times.

(8) Side shoots should never be removed. The aim is always to encourage maximum spread of the bush. If side plucking occurs, lateral growth is retarded, and yields reduced.

(9) During a three year cycle the level of the table should rise by about 1 foot, or 4 inches a year, under hard plucking, allowing for occasionally plucking over a leaf. Any greater rise indicates under-plucking and loss of crop.

(10) Breaking back, when necessary for maintaining the table, should occur immediately after the bush has been plucked and not as a separate operation later on. Under efficient management, only one or two shoots at most should require breaking back on each bush. The need for more than this indicates carelessness during the previous round.

(11) After hail, frost, or other severe set-backs, raise the table by about 2" to renew the maintenance leaf, as described in paragraph (5) (b) above.

(12) 'Skiffing', or shallow slashing of top growth, should never be practiced. This is sometimes done to reduce the height of plucking tables or to level off unevenness. Skiffing usually results in a flush of new leaf followed by prolonged dormancy and reduced yield.

GENERAL

(1) When outside labour is employed, payment is best made according to the weight of leaf plucked - not on a monthly basis. Current rates vary between 6 - 9 cents per pound of green leaf. If monthly paid labour is used, the minimum task should be 30 - 40 pounds of green leaf daily - (depending on the locality and circumstances), plus an additional payment at the standard rates for any leaf plucked over the minimum. An experienced worker should be able to pluck about 1/5th acre daily during the flush season, bringing in about 50 - 70 pounds of leaf and spending approximately ½ - ¾ minute on each bush.

(2) Proper plucking baskets should be used, carried on the back. A bag carried in one hand slows down the work and is inefficient; furthermore, since the bag is usually dragged on the ground, it may result in bruising of the leaf and loss of quality.

(3) Green leaf should never be pressed down hard in the basket, otherwise it starts to ferment and turns red. Red leaf makes poor tea and is refused at buying centres. Leaf must be kept cool and shaded while awaiting transport.

(4) Finally, it must be stressed that efficient plucking, on which the whole enterprise depends, can only be achieved by constant watch over the growing crop, followed by careful supervision of labour.

KTDA
Nairobi:
23rd December, 1964.

APPENDIX II

MODELS WITH ADDITIVE FARM EFFECTS AND YEAR EFFECTS

Among the alternative models discussed in Chapter III were those with output as the dependent variable and actual plantings as the independent variables, together with dummy variables for farm and year effects. The two models, which we called Model I and Model II, were rejected because of the additive manner in which the management variables entered the production function and because of the probable heteroscedastic distribution of the error term. The models are:

Model I

$$Q_{it} = \beta_{oi} + \beta_{oot} + \sum_{k=3}^{7} \beta_k X_{kit} + e_{it}$$

Model II

$$Q_{it} = \beta_{oi} + \sum_{k=3}^{7} \beta_k X_{kit} + e_{it}$$

where Q_{it} is the output of pounds of green leaf on farm i in year t (i = 1 to N)

X_{kit} is the number of tea stumps of age k on farm i in year t (t = 1961/62 to 1965/66)

β_k is the yield coefficient of stumps of age k years (k = 3 to 7)

β_{oi} is the farm effect coefficient on farm i

β_{oot} is the year effect coefficient for year t.

In spite of the unsatisfactory nature of the specification of these functions, the results obtained from the estimation of the yield coefficients (β_k) showed that even these models gave predictive results superior to those obtained by the KTDA. This Appendix gives the values of the estimated coefficients in Tables A-1 and A-2 for the models relevant to each area.[1]

Model I, which includes the year effect variables, was only significant in Buret and Kitutu. Only four of the five years have coefficients since the fifth (dummy) year variable was omitted to avoid a singular matrix of the input variables (and hence a singular moment matrix). Ranking the year effects of the four relevant years in Table A-2 and Table 11 (in Chapter IV) shows that the rankings derived from Models I and III are not the same. With only four observations it is not possible to come to more meaningful conclusions other than to note two things: first, that the rankings of the year effects in Model III conform more closely to the ranking of rainfall than do the rankings derived from Model I. Secondly, 1963/64 continued to be the worst year - probably for the reasons advanced in the text. Given the lack of significance of the individual coefficients for Buret and the unsatisfactory rankings, the results for Model II are also given for these two areas in Table A-3. For ease of comparison, the yield coefficients of Model II are presented in Table A-4

[1]For all samples the F-test for the inclusion of the farm effect variables was significant at the one per cent level. The statistical test (the Chow test) for pooling sample areas gave the same conclusions as before. That is, the samples from within a Division could be assumed to have come from the same population. Only the resultant pooled samples are presented here.

Table A-1 - Tea Yield Coefficients of Model II for Samples from Githunguri, Gatundu and Nyamira Divisions

Item	Coefficient	Administrative Division		
		Githunguri	Gatundu	Nyamira
Year of Maturity		Yield Coefficients		
3	β_3	-0.0086[a] (0.0565)	0.2637 (0.0574)	0.5557 (0.2103)
4	β_4	0.2361 (0.0511)	0.5576 (0.0493)	0.8810 (0.2043)
5	β_5	0.5411 (0.0513)	0.6538 (0.0506)	0.7429 (0.1955)
6	β_6	0.5349 (0.0498)	0.7334 (0.0560)	1.0887 (0.1874)
7	β_7	1.2067 (0.0549)	1.0162 (0.0666)	1.5878 (0.1798)
	Other information			
R^2		.867	.837	.589
Number of:				
Farms		49	62	31
Observations		182	261	133

Standard Errors are given in parentheses.

[a] Not significant.

Table A-2 - Tea Yield Coefficients of Model I for Samples from Buret and Kitutu Divisions

Item	Coefficient		Administrative Division: Buret		Administrative Division: Kitutu
Year of Maturity			Yield Coefficients		
3	β_3		0.3733 (0.1811)		0.6136 (0.2115)
4	β_4		0.6872 (0.1610)		1.1178 (0.2183)
5	β_5		1.2686 (0.2143)		1.5041 (0.2747)
6	β_6		1.7055 (0.2576)		2.2681 (0.3047)
7	β_7		2.0662 (0.2866)		1.7535 (0.4162)
Year		Annual Rainfall (Litein) mm.	Year Effects	Annual Rainfall (Kisii Town) mm.	Year Effects
1961/2	β_{oo1}	2,011	460.15[a] (599.38)	2,227	-1151.89[b] (614.28)
1962/3	β_{oo2}	1,801	524.35[a] (461.48)	2,609	-773.92[b] (432.91)
1963/4	β_{oo3}	1,724	-361.77[a] (323.79)	1,969	-1398.78 (283.46)
1964/5	β_{oo4}	1,178	21.46[a] (213.84)	1,545	-890.41 (191.98)
Long Term Average Rainfall		1,648		1,801	
Other Information					
R^2			.865		.899

Standard Errors are given in parentheses.

[a] Not significant. - [b] Significant at the five per cent level.

Table A-3 – Tea Yield Coefficients of Model II for Samples from Buret and Kitutu Divisions

Item	Coefficient	Administrative Division Buret	Kitutu
Year of Maturity		Yield Coefficients	
3	β_3	0.3390 (0.1915)	0.4178 (0.2257)
4	β_4	0.6657 (0.1267)	1.1378 (0.1655)
5	β_5	0.9862 (0.1506)	1.5841 (0.1905)
6	β_6	1.6740 (0.1706)	2.4810 (0.2226)
7	β_7	1.9667 (0.2170)	2.5071 (0.3057)
Other Information			
R^2		0.838	0.851
Number of:			
Farms		33	38
Observations		117	140

Standard Errors are given in parentheses.

Table A-4 – Tea Yield Coefficients of Models II and IV and of the KTDA Yield Rating, By Divisions

Division	Model	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
		(Pounds of green leaf per bush per year)				
Githunguri	II	.0086	.2361	.5411	.5349	1.2067
	IV	.0803	.2938	.4890	.6383	1.1024
	KTDA	.1291	.3228	.5165	.6456	.7747
Gatundu	II	.2637	.5576	.6538	.7334	1.0162
	IV	.1452	.4219	.5725	.8630	1.0817
	KTDA	.1291	.3228	.5165	.6456	.7747
Buret	II	.3390	.6657	.9862	1.6740	1.9667
	IV	.5001	.7826	.9283	1.4374	2.0176
	KTDA	.3875	.7750	1.0850	1.3950	1.6275
Kitutu	II	.3437	1.0078	1.5441	2.0189	2.6712
	IV	.6211	1.4889	2.0081	2.7265	2.8391
	KTDA	.4650	.9300	1.3175	1.7050	1.9375
Nyamira	II	.5557	.8810	.7429	1.0887	1.5878
	IV	.4403	1.0100	.9424	1.1445	1.3791
	KTDA	.4650	.9300	1.3175	1.7050	1.9375

together with those of Model IV (which was the main model used in the text) and the KTDA "model".

Finally, Table A-5 compares the weighted mean errors of prediction for Models II and IV and the KTDA model for the last two years. Given the completely linear form of Model II it is not immediately clear how the equation should be used for prediction. Is an average intercept used? Or should one use the average times the number of farmers in the area?[2] In the first case the effect of the intercept on the prediction is negligible; in the latter case the prediction is completely swamped. In making the predictions in Table A-5 the intercept was ignored. We discover that not only are the predictions of Model II vastly superior to those of the KTDA, but that, on average, the predictions are better than those of Model IV. However, this result is achieved mainly because of a substantial improvement in the Gatundu prediction. It shows that, as far as prediction is concerned, the choice of functional form is not crucial. However, the manner in which the farm effects enter Model IV clearly makes more sense in terms of the logic of the production process.

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[2]Thus, should one predict using

$$\hat{Q}_t = \beta_{o.} + \sum_k \beta_k X_{kt} \qquad \text{where} \quad \beta_{o.} = \frac{\sum_i^N \beta_{oi}}{N}$$

or

$$\hat{Q}_t = M.\beta_{o.} + \sum_k \beta_k X_{kt}$$

where M is the number of farmers whose output one is trying to predict?

Table A-5 - Weighted Mean Errors of Prediction of Output for Models II and IV and the KTDA Yield Rating, By Divisions for the Period 1964/5 to 1965/66

Division	Model II	Model IV	KTDA
Githunguri	3.57	3.38	13.83
Gatundu	2.79	9.25	28.38
Buret	5.58	2.29	6.74
Kitutu	10.00	8.38	29.65
Nyamira	8.47	9.94	20.75
All Areas	6.08	6.65	19.87

APPENDIX III

OUTPUT, PLANTINGS AND PREDICTION RESULTS, BY YEAR AND SAMPLE AREA

A great many variations on a common theme were investigated in Chapter V. There is little justification for presenting the detailed results for each of the variants used for prediction. The summary results for these were given in Tables 12 and 13 of the text. The following tables (Tables A-6(a) to A-10(d)) give the actual plantings and output figures for the farms not used in the statistical estimation of yield coefficients. Thus, the data for each of the five sample areas considered in this study refer to two thirds of the data set. The tables also present the yield coefficients and prediction results for the KTDA model, Models I and II, one variant each of Models III and IV, and Model VI. In the first two statistical Models the yield coefficients are used for prediction and the actual farm and year effects are ignored (see Appendix II). These Models are referred to in the following tables as "Additive" Models. In Model III the yield coefficients are derived from the ratio coefficients plus separate group farm effects and separate year effects.[1] Model IV uses the average of the farm effects.[2] In Model VI the coefficients were estimated without either farm or year effect variables.[3] These latter three Models are referred to as "Multiplicative" Models. Finally, the results of the iterative model - Model V - are given for Buret Division.[4] All predictions are rounded to the nearest integer.

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[1]This variant is theoretically the most complete and is that given in the first column of Tables 12 and 13 in Chapter V.

[2]This is given in column 6 of Tables 12 and 13.

[3]See equation (V-15). [4]See equation (V-16).

Table A-6(a) - Number of Tea Stumps Planted, By Year, for Githunguri

1959	1960	1961	1962	1963
69,854	45,462	56,572	83,240	12,042

Table A-6(b) - Tea Yield Coefficients, Various Models, for Githunguri

Model	Years	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
KTDA	All	0.1291	0.3228	0.5165	0.6456	0.7747
I	All	0.0057	0.2510	0.5877	0.5656	1.2077
II	All	0.0086	0.2361	0.5411	0.5349	1.2067
	1961/62	0.1313	-	-	-	-
	1962/63	0.0373	0.2857	-	-	-
III	1963/64	0.0349	0.2605	0.4728	-	-
	1964/65	0.0539	0.2800	0.4695	0.6218	-
	1965/66	0.1088	0.3409	0.5309	0.6504	1.0739
IV	All	0.0803	0.2938	0.4890	0.6383	1.1024
VI	All	0.0853	0.2899	0.4702	0.6159	1.1210

Table A - 6(c) - Prediction Results, Various Models, for Githunguri

		KTDA Model		Additive Models				Multiplicate Models					
				Model I		Model II		Model III		Model IV		Model VI	
Year	Actual Output	Prediction	Error[a]	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error
	lbs.	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1961/62	10,861	9,018	-16.97	398	-96.33	601	94.47	9,172	-15.55	5,609	-48.35	5,959	-45.14
1962/63	24,305	28,418	16.92	17,792	-26.79	16,884	-30.53	21,653	-10.91	24,174	- 0.54	24,129	-0.73
1963/64	42,724	58,058	35.89	52,787	23.55	49,018	14.73	46,844	9.64	52,058	21.85	50,850	19.02
1964/65	83,248	97,587	17.22	80,901	-2.82	76,037	-8.66	85,106	2.23	90,124	8.26	87,900	5.59
1965/66	160,468	141,110	-12.06	164,285	2.38	158,978	-0.93	164,305	2.39	159,112	-0.85	158,065	-1.50
	Weighted Mean Error[b]		17.10		10.32		10.16		4.40		7.14		6.30

[a] % Error = $\frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100$ where Q_t is actual output and $\hat{Q}_t$ is predicted output

[b] Weighted Mean Error = $\frac{\Sigma |\hat{Q}_t - Q_t|}{\Sigma Q_t} \cdot 100$

Table A-7(a) - Number of Tea Stumps Planted, By Year, for Gatundu

1959	1960	1961	1962	1963
57,673	50,911	75,500	107,800	37,170

Table A-7(b) - Tea Yield Coefficients, Various Models, for Gatundu

Model	Years	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
KTDA	All	0.1291	0.3228	0.5165	0.6456	0.7747
I	All	0.2476	0.5397	0.6043	0.6522	0.9034
II	All	0.2673	0.5576	0.6538	0.7334	1.0162
	1961/62	0.1219	-	-	-	-
	1962/63	0.1454	0.3816	-	-	-
III	1963/64	0.1631	0.4390	0.5265	-	-
	1964/65	0.1910	0.4446	0.5718	0.7982	-
	1965/66	0.2265	0.4856	0.5908	0.8566	0.9701
IV	All	0.1452	0.4219	0.5725	0.8630	1.0817
VI	All	0.1692	0.4271	0.5437	0.8235	0.9456

Table A - 7 (c) - Prediction Results, Various Models, for Gatundu

Year	Actual Output	KTDA Model Prediction	KTDA Model Error[a]	Additive Models: Model I Prediction	Model I Error	Model II Prediction	Model II Error	Multiplicate Models: Model III Prediction	Model III Error	Model IV Prediction	Model IV Error	Model VI Prediction	Model VI Error
	lbs.	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1961/62	5,536	7,446	34.49	14,280	157.94	15,208	174.72	7,030	26.99	8,374	51.27	9,758	76.27
1962/63	29,580	25,189	-14.84	43,732	47.84	45,584	54.1[illegible]	29,410	-0.57	31,725	7.25	33,246	12.39
1963/64	62,590	55,969	-10.58	81,022	29.45	86,004	37.41	65,029	3.90	65,460	4.58	65,875	5.25
1964/65	140,496	101,818	-27.53	135,818	-3.33	146,109	3.99	129,302	-7.97	126,424	-10.32	125,660	-10.56
1965/66	219,658	156,140	-28.92	198,313	-9.72	215,218	-2.02	204,931	-6.70	200,423	-8.76	189,841	-13.57
Weighted Mean Error[b]			25.14		14.71		12.92		6.56		8.99		12.19

[a] % Error = $\frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100$ where Q_t is actual output and $\hat{Q}_t$ is predicted output

[b] Weighted Mean Error = $\frac{\Sigma |Q_t - Q_t|}{\Sigma Q_t} \cdot 100$

Table A-8(a) - Number of Tea Stumps Planted, By Year, for Buret

1959	1960	1961	1962	1963
28,743	27,975	38,056	58,684	36,788

Table A-8(b) - Tea Yield Coefficients, Various Models, for Buret

Model	Year(s)	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
KTDA	All	0.3875	0.7750	1.0850	1.3950	1.6275
I	All	0.3733	0.6872	1.2686	1.7055	2.0662
II	All	0.3390	0.6657	0.9862	1.6740	1.9667
	1961/62	0.7703	-	-	-	-
	1962/63	0.5297	1.0316	-	-	-
III	1963/64	0.2446	0.6322	1.0192	-	-
	1964/65	0.4116	0.8620	1.1347	1.5747	-
	1965/66	0.3650	0.7943	1.1198	1.4455	2.2108
IV	All	0.5001	0.7826	0.9283	1.4374	2.0176
VI	All	0.5081	0.8070	1.0059	1.4158	2.2347
V[a]		0.5240	0.6898	1.0858	1.5374	1.8464

[a] These Coefficients are derived from the β^*_{jk}

Table A - 8 (c) - Prediction Results, Various Models, for Buret

Year	Actual Output	KTDA Model Prediction	KTDA Model Error[a]	Additive Models: Model I Prediction	Model I Error	Model II Prediction	Model II Error	Multiplicate Models: Model III Prediction	Model III Error	Model IV Prediction	Model IV Error	Model VI Prediction	Model VI Error
	lbs.	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1961/62	26,039	11,138	-57.23	10,730	-58.79	9,744	-62.58	22,141	-14.97	14,374	-44.80	14,604	-43.91
1962/63	47,526	33,116	-30.32	30,195	-36.47	28,618	-39.79	44,470	-6.43	36,485	-23.23	37,410	-21.29
1963/64	64,303	67,613	5.15	69,894	8.69	59,870	-6.89	56,289	-12.46	67,607	5.14	70,825	10.14
1964/65	131,322	122,683	-6.58	132,569	0.95	120,932	-7.91	133,963	2.01	126,415	-3.74	129,363	-1.49
1965/66	200,545	186,830	-6.84	209,439	4.43	192,427	-4.05	206,638	3.04	197,854	-1.34	208,169	3.80
Weighted Mean Error[b]			11.70		10.30		12.38		5.05		7.15		8.02

[a] $\% \text{ Error} = \frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100$ where Q_t is actual output and $\hat{Q}_t$ is predicted output

[b] $\text{Weighted Mean Error} = \frac{\Sigma \left| \hat{Q}_t - Q_t \right|}{\Sigma Q_t} \cdot 100$

Table A-8(d) - Prediction Results, Model V, for Buret

Year	Actual Output	Prediction	Error[a]
	lbs.	lbs.	%
1961/62	23,039	15,061	-42.16
1962/63	47,526	34,485	-27.44
1963/64	64,303	70,447	9.56
1964/65	131,322	131,566	0.19
1965/66	200,545	197,158	-1.69
	Weighted Mean Error		7.19

[a] See footnotes to Table A-8(c)

Table A-9(a) - Number of Tea Stumps Planted, By Year, for Kitutu

1959	1960	1961	1962	1963
20,400	35,650	30,850	23,460	20,950

Table A-9(b) - Tea Yield Coefficients, Various Models, for Kitutu

Model	Years	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
KTDA	All	0.4650	0.9300	1.3175	1.7050	1.9375
I	All	0.6136	1.1178	1.5041	2.2681	1.7535
II	All	0.4178	1.1379	1.5842	2.4810	2.5071
	1961/62	0.7098	-	-	-	-
	1962/63	0.6826	1.5050	-	-	-
III	1963/64	0.3080	0.9973	1.4258	-	-
	1964/65	0.6687	1.3754	1.6708	2.2354	-
	1965/66	1.2601	1.9979	2.3108	2.7422	2.2695
IV	All	0.6211	1.4889	2.0081	2.7265	2.8391
VI	All	0.5904	1.5113	1.8925	2.3893	2.7730

Table A - 9 (c) - Prediction Results, Various Models, for Kitutu

				Additive Models				Multiplicate Models					
		KTDA Model		Model I		Model II		Model III		Model IV		Model VI	
Year	Actual Output	Prediction	Error[a]	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error
	lbs.	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1961/62	11,621	9,486	-18.37	12,517	7.71	8,523	-26.66	14,480	24.60	12,670	9.03	12,044	3.64
1962/63	45,171	35,549	-21.30	44,678	-1.09	38,108	-15.64	55,037	21.84	52,516	16.26	51,878	14.85
1963/64	69,487	73,377	7.04	89,463	28.75	85,773	23.44	74,142	6.70	113,205	62,92	110,699	59.31
1964/65	158,537	121,350	-23.46	148,769	-6.16	151,995	-4.13	163,285	2.99	187,713	18,40	176,684	11.45
1965/66	259,161	172,513	-33.43	202,109	-22.01	223,913	-13.60	288,615	11.37	265,009	2.26	247,955	-4.32
Weighted Mean Error[b]			25.82		16.21		12.54		9.48		16.02		14.28

[a] $\% \text{ Error} = \frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100$ where Q_t is actual output and $\hat{Q}_t$ is predicted output.

[b] $\text{Weighted Mean Error} = \frac{\Sigma \left| Q_t - Q_t \right|}{\Sigma Q_t} \cdot 100$

Table A-10(a) - Number of Tea Stumps Planted, By Year, for Nyamira

1959	1960	1961	1962	1963
39,894	13,208	1,100	22,176	5,500

Table A-10(b) - Tea Yield Coefficients, Various Models, for Nyamira

Model	Years	Yield Coefficients				
		β_3	β_4	β_5	β_6	β_7
KTDA	All	0.4650	0.9300	1.3175	1.7050	1.9375
I	All	0.7409	1.1797	1.2648	1.5960	2.1423
II	All	0.5557	0.8810	0.7429	1.0887	1.5876
	1961/62	0.4852	-	-	-	-
	1962/63	0.1642	1.0331	-	-	-
III	1963/64	0.0000	0.4619	0.8046	-	-
	1964/65	0.0923	1.0990	1.5980	1.0985	-
	1965/66	0.0000	0.9589	1.4394	1.0962	1.3752
IV	All	0.4403	1.0100	0.9424	1.1445	1.3791
VI	All	0.3942	0.9719	1.0231	1.2696	1.2843

Table A - 10 (c) - Prediction Results, Various Models, for Nyamira

				Additive Models				Multiplicate Models					
		KTDA Model		Model I		Model II		Model III		Model IV		Model VI	
Year	Actual Output	Prediction	Error[a]	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error	Prediction	Error
	lbs.	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%	lbs.	%
1961/62	16,905	18,551	9.74	29,557	74.84	22,169	31.14	19,357	14.50	17,565	3.91	15,726	-6.97
1962/63	37,348	43,243	15.78	56,849	52.21	42,486	13.76	43,383	16.16	46,108	23.46	43,980	17.76
1963/64	37,908	65,355	72.40	66,854	76.36	41,885	10.49	38,199	0.77	51,421	35.65	54,086	42.68
1964/65	75,414	96,756	28.30	98,104	30.09	66,537	-11.77	68,186	-9.58	68,981	-8.53	73,973	-1.91
1965/66	107,772	124,445	15.47	138,172	28.21	101,125	-6.17	92,189	-14.46	95,990	-10.93	92,851	-13.85
	Weighted Mean Error[b]		26.51		41.47		10.86		11.47		14.94		14.65

[a] % Error = $\frac{\hat{Q}_t - Q_t}{Q_t} \cdot 100$ where Q_t is actual output and $\hat{Q}_t$ is predicted output

[b] Weighted Mean Error = $\frac{\Sigma \left| Q_t - Q_t \right|}{\Sigma Q_t} \cdot 100$

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