PRODUCTION FUNCTION ANALYSIS

OF SMALL RUBBER FARMS IN SRI LANKA

by

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D E C L A R A T I O N

Except where otherwise indicated, this dissertation is my own work.

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A B S T R A C T

The main purpose of this study has been to estimate the Cobb-Douglas production function from the cross-section input-output data of small rubber farms in the Agalawatta district of Sri Lanka. Twelve factors of production believed to affect output of rubber were identified, out of which four factors, namely, planting density, farm size, tapping frequency, and tapping age of the trees were considered in the estimating equation. The function was estimated for clone PB86 and clone Tjir 1 separately; and for each clone, the Cobb-Douglas function was estimated by two different techniques, namely, the Ordinary Least Squares method which estimates the average function, and the Linear Programming method which estimates the best or the frontier function.

As a first step in the analysis, simple correlation and simple regression methods were employed with a view to bringing out relationships between each of the specific factors and the output per acre. Next, the relationship between the four factors of production and the output of rubber was examined within the framework of multiple regression analysis.

The estimated coefficients were used to predict output per acre for each clone. For both clones, the results strongly suggested that for every farm or group of farms for every year or group of years, there is a separate yield curve. Instead of a single production function, there exists a family of functions depicting various efficiency levels.

For both clones, the estimated coefficients of the frontier function indicated that the frontier had shifted non-neutrally upward from the average function.

Vectors of technical efficiency relative to the average and relative to the frontier were generated. The results showed that there existed a wide range of technical efficiency at farm level. This big difference in efficiency could be due to soil quality, management, or even be due to errors of measurement in the variables used for the production function analysis. It is clear that further research is needed to clarify the true meaning of these "efficiency" indices as applied to the rubber smallholders.

When the efficiency ratings from the average and the frontier functions were compared, it was found that the ranking of the farms were similar irrespective of whether the ratings were calculated relative to the average or to the frontier function.

Marginal returns to factors of production for individual farms revealed that there was no significant relationship between farm size and the marginal returns to the land. Under the assumption of perfect markets, and assuming that the price of rubber was Rs. 1.00 per pound and the average wage rate was Rs. 5.00 per day, it was found that for PB86 farms, the majority of the smaller farms had overused the tapping labour, and nearly all the larger farms had underutilized this input; for Tjir 1 farms, all the smaller farms and about 50 per cent of the larger farms had overused the tapping labour, and underutilization of tapping labour occurred only in the larger farms. Underutilization of labour in larger farms, which were thought to be held by absentee landlords, could be due to a shortage of labour or an unattractive nature of the share-arrangement or the wage-payment.

Since there were substantial amounts of non-rubber crops such as paddy, coconut and tea in the area, it may have been a mistake to ignore these crops in an economic survey and to obtain information relating only to rubber. Hence, great caution is needed when using the analysis from such a survey to give any crop-specific advice because the information could be quite irrelevant in a mixed enterprise situation.

CONTENTS

		Page
ACKNOWLEDGEMENTS	.. ..	(iii)
ABSTRACT	.. ..	(iv)
LIST OF TABLES	.. ..	(x)
LIST OF FIGURES	.. ..	(xii)

* * *

CHAPTER

1	INTRODUCTION	1
	1.1 Objectives of This Study	1
	1.2 Nature of the Data and Limitation of the Study	2
	1.3 Brief Notes on the Importance of Rubber in Sri Lanka	2
	1.4 The General Setting	6
	1.4.1 The Physiography of the Area ..	6
	1.4.2 The Farm Structure	6
	1.4.3 Sampling Procedure	7
	1.4.4 Samples for the Present Study ..	8
2	AVERAGE AND FRONTIER PRODUCTION FUNCTIONS: THEORETICAL CONSIDERATIONS	10
	2.1 The Production Functions	10
	2.2 Properties of the Cobb-Douglas Function ..	11
	2.3 Ordinary Least Squares Procedure	14
	2.4 Frontier Production Function	15
	2.4.1 Method of Estimation	18
	2.5 Estimation of Technical Efficiency	19

Contents (continued) -

CHAPTER		Page
3	RUBBER CULTIVATION AND FACTORS AFFECTING RUBBER PRODUCTION	21
	3.1 Cultivation of Rubber	21
	3.1.1 Planting Materials	24
	3.1.2 Exploitation of Rubber Trees ..	25
	3.1.3 Commercial Rubber Sheets	28
	3.2 Factors Affecting Rubber Production ..	29
	3.2.1 Annual Inputs controlled by the Smallholder	30
	3.2.1.1 Labour Input in Tapping Rubber Trees	30
	3.2.1.2 Supplementary Inputs ..	31
	3.2.1.3 Management Factor	32
	3.2.1.4 Types of Cut in Tapping Rubber Trees	34
	3.2.2 Lagged Values of the Inputs Applied in Previous Years	34
	3.2.2.1 Planting Density	34
	3.2.2.2 Size of the Farm	35
	3.2.2.3 Age of the Trees	35
	3.2.2.4 Clone or Variety of Rubber	36
	3.2.2.5 Distance of the Holding	36
	3.2.3 Completely Exogenous Variables ..	36
4	SPECIFICATION OF THE VARIABLES AND THE ANALYSIS OF SPECIFIC FACTORS AFFECTING OUTPUT	38
	4.1 Specification of the Variables	38
	4.1.1 Output	39
	4.1.2 Planting Density	40

Contents (continued) -

CHAPTER Page

4.1.3 Tapping Frequency 40

4.1.4 Farm Size 42

4.1.5 Tapping Age of the Trees 42

4.1.6 Management 42

4.2 Analysis of the Specific Factors Affecting Output 43

4.2.1 Bivariate Analysis 46

4.2.1.1 Affect of each Selected Variable on Yield 50

4.2.1.1.1 Yield per Acre by Age 50

4.2.1.1.2 Yield per Acre by Planting Density 57

4.2.1.1.3 Yield per Acre by Tapping Frequency .. 61

4.2.1.1.4 Yield per Acre by Farm Size .. 66

4.2.1.2 Summary 70

5 EMPIRICAL PRODUCTION FUNCTION 72

5.1 Modified Form of Cobb-Douglas Function .. 72

5.2 Test for Significant Differences in Clone Effect 74

5.2.1 Results of the Chow Test 76

5.3 Multicollinearity 80

5.4 Average Production Function: Estimated Coefficients and the Related Statistics 80

5.4.1 Production Elasticities 81

5.4.1.1 Production Elasticity of Tapping Frequency .. 82

Contents (continued) -

CHAPTER		Page
	5.4.1.2 Production Elasticity of Planting Density ..	82
	5.4.1.3 Production Elasticity of Farm Size	85
	5.4.1.4 Production Elasticities of Age Factors	85
	5.5 Frontier Production Function	96
6	TECHNICAL EFFICIENCY AND MARGINAL PRODUCTIVITY	100
	6.1 Technical Efficiency	100
	6.1.1 Comparison of the Efficiency Ratings from the Average and the Frontier Production Functions	102
	6.2 Marginal Returns to Factors of Production	103
7	SUMMARY AND CONCLUSIONS	119

* * *

BIBLIOGRAPHY 124

* * *

APPENDIX TABLE I: TECHNICAL EFFICIENCY RATINGS AND RANKING 127

APPENDIX TABLE II: MARGINAL PRODUCTIVITIES OF INPUT FACTORS BY INDIVIDUAL FARMS 135

* * *

LIST OF TABLES

Table	Title	Page
1.1	Composition of Exports of Sri Lanka, 1969-73	3
1.2	Area under Rubber Cultivation by size of Holdings	4
1.3	Annual Export of Rubber from Sri Lanka ..	5
1.4	Crop Acreage and Number of Holdings ..	7
1.5	Number of Observations by Age	9
3.1	Weight of Scrap as a Percentage of the Weight of Rubber Sheets	26
4.1	Summary of the Analysis of Variance: Mean Yield by Clone	45
4.2a	Simple Correlation Coefficients between Yield and the Selected Variables: PB86 Farms	48
4.2b	Simple Correlation Coefficients between Selected Variables: Tjir 1 Farms	48
4.3	Summary of the Analysis of Variance: Yield per Acre by Tapping Age	52
4.4	Summary of the Analysis of Variance: Yield per Acre by Planting Density	58
4.5	Summary of the Analysis of Variance: Yield per Acre by Tapping Frequency ..	63
4.6	Summary of the Analysis of Variance: Yield per Acre by Farm Size	67
5.1	Summary of the Estimated Coefficients and the Related Statistics	77
5.2a	Simple Correlation Coefficients between Selected Variables of PB86	78
5.2b	Simple Correlation Coefficients between Selected Variables of Tjir 1	79
5.3	Predicted Yield in lbs per Acre of RSS ..	86
5.4a	Mean of Planting Density and Tapping Frequency according to Tapping Age: Clone: PB86	94

List of Tables (continued) -

Table	Title	Page
5.4b	Mean of Planting Density and Tapping Frequency according to Tapping Age: Clone: Tjir 1	95
5.5	Coefficients of Production Functions Estimated by Ordinary Least Squares and Linear Programming Methods	97
6.1a	Geometric Means, Production Elasticities and Marginal Productivities of Selected Inputs for Different Ages, Rubber Clone: PB86	106
6.1b	Geometric Means, Production Elasticities and Marginal Productivities of Selected Inputs for Different Ages, Rubber Clone: Tjir 1	107

* * *

LIST OF FIGURES

Figure	Title	Page
1.1	Main Rubber-growing Areas of Sri Lanka ..	(xiv)
1.2	Area where Survey was carried out	(xv)
2.1	Technical and Price Efficiency	16
4.1	The Effect of Management Bias	44
4.2A	Frequency Distribution of PB86 Farms: Variations of Yield within each Age ..	53
4.2B	Frequency Distribution of Tjir 1 Farms: Variations of Yield within each Age ..	54
4.3A	Mean Yield of PB86	55
4.3B	Mean Yield of Tjir 1	56
4.4A	Yield per Acre by Planting Density: Clone PB86	59
4.4B	Yield per Acre by Planting Density: Clone Tjir 1	60
4.5A	Yield per Acre by Tapping Frequency: Clone PB86	64
4.5B	Yield per Acre by Tapping Frequency: Clone Tjir 1	65
4.6A	Yield per Acre by Farm Size: Clone PB86	68
4.6B	Yield per Acre by Farm Size: Clone Tjir 1	69
5.1	Effect of Tapping Frequency on Yield with other Input Levels held Constant	83
5.2	Effect of Planting Density on Yield with other Input Levels held Constant	84
5.3A	Alternative Interpretation of Rubber Yield and their Paths over Time. Clone: PB86 (budgrafted)	88
5.3B	Alternative Interpretation of Rubber Yield and their Paths over Time. Clone: PB86 (budgrafted)	89
5.3C	Alternative Interpretation of Rubber Yield and their Paths over time. Clone: PB86 (budgrafted)	90

List of Figures (continued) -

Figure	Title	Page
5.4A	Alternative Interpretation of Rubber Yield and their Paths over Time. Clone: Tjir 1 (C.S.)	91
5.4B	Alternative Interpretation of Rubber Yield and their Paths over Time. Clone: Tjir 1 (C.S.)	92
5.4C	Alternative Interpretation of Rubber Yield and their Paths over Time. Clone: Tjir 1 (C.S.)	93
6.1A	Efficiency Ratings of Clone PB86 Farms ..	104
6.1B	Efficiency Ratings of Clone Tjir 1 Farms	105
6.2A	Clone PB86: Marginal Productivity	111
6.2B	Clone Tjir 1: Marginal Productivity ..	112
6.3A	Marginal Productivity of Land in Relation to Area: Clone PB86	113
6.3B	Marginal Productivity of Land in Relation to Area: Clone Tjir 1	114
6.4A	Marginal Value Product of Tapping Days in Relation to Area: Clone PB86	115
6.5A	Marginal Value Product of Tapping Days in Relation to Area: Clone Tjir 1	116

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FIGURE 1.1

MAIN RUBBER-GROWING AREAS OF SRI LANKA

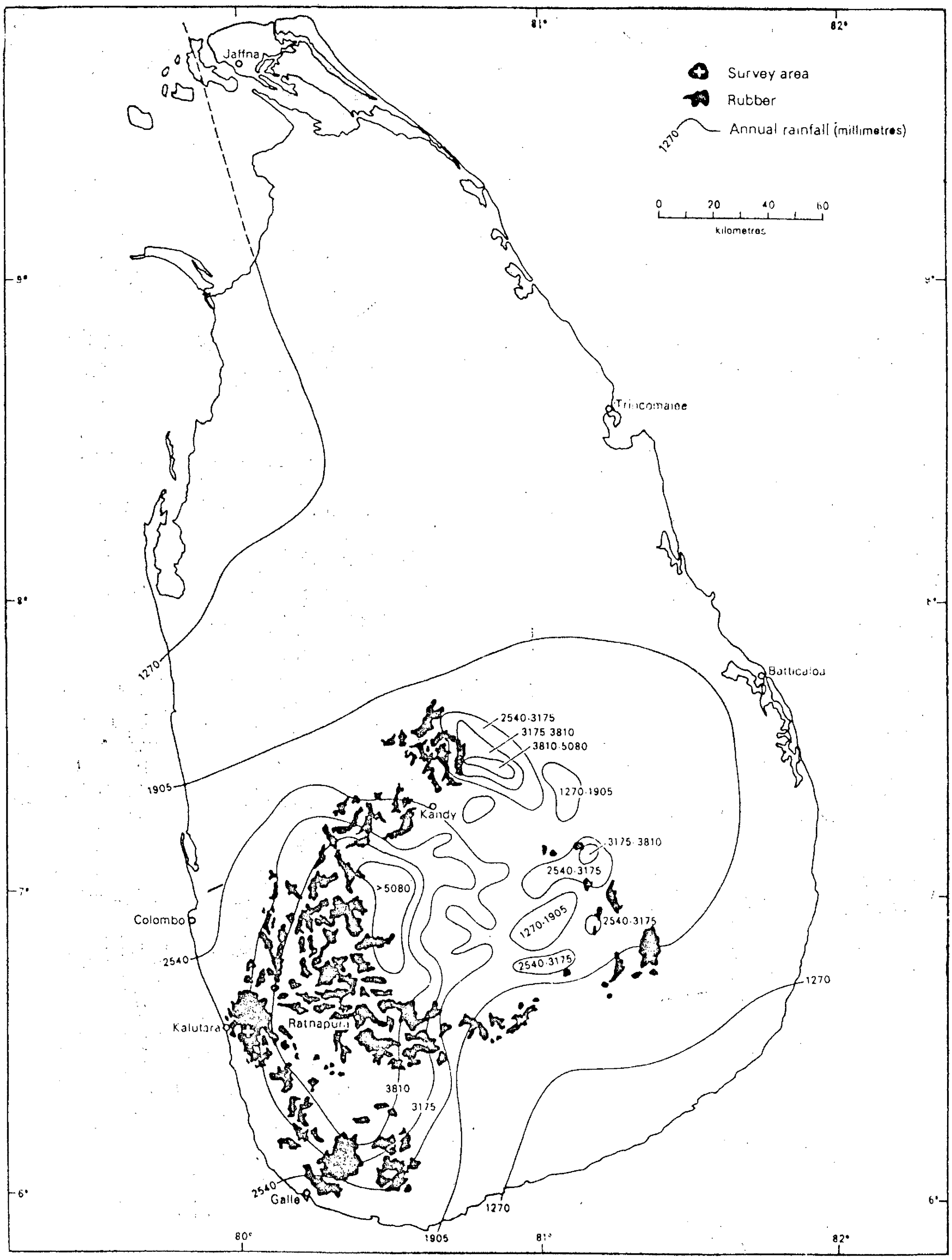
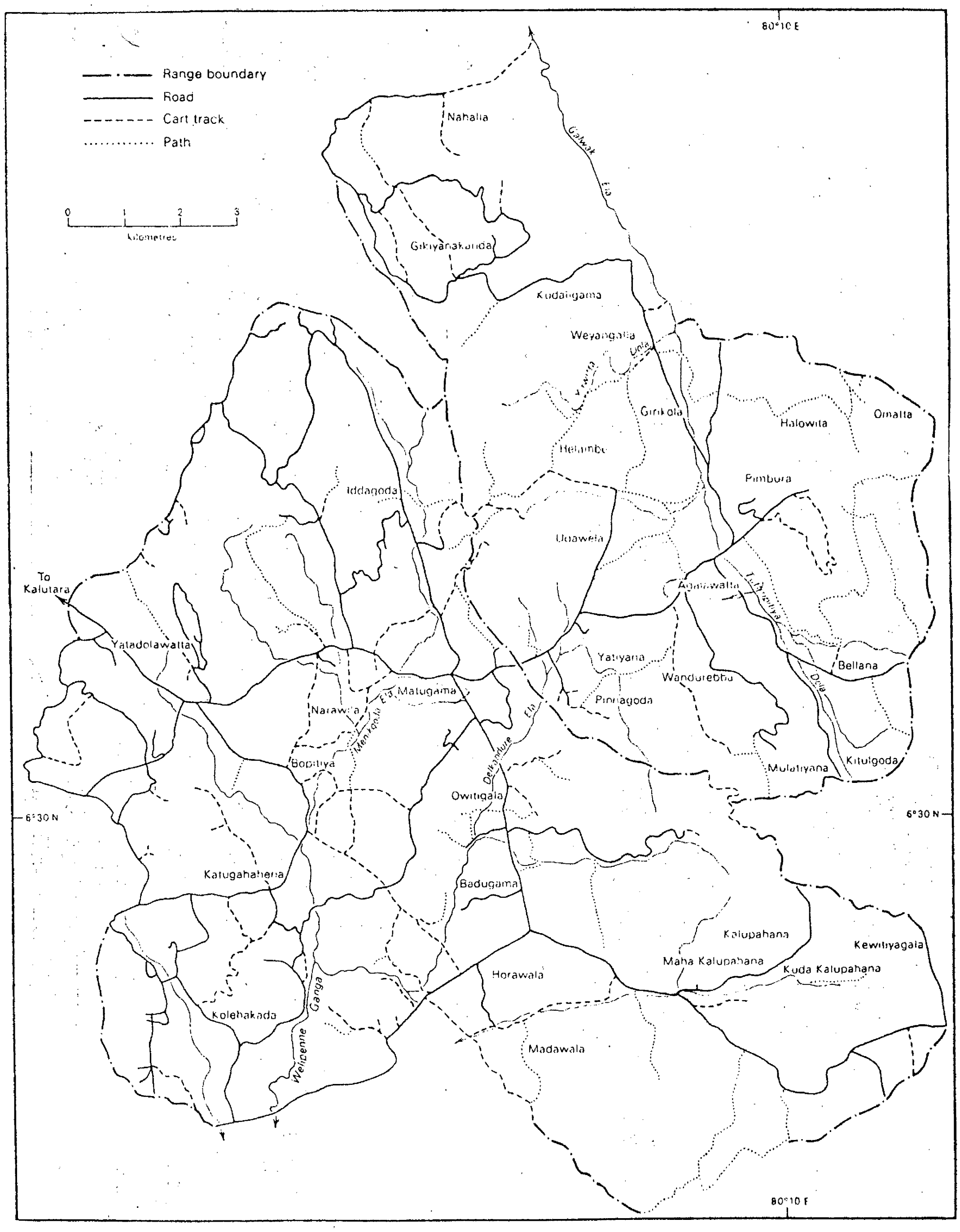


FIGURE 1.2

AREA WHERE SURVEY WAS CARRIED OUT



CHAPTER 1

INTRODUCTION

1.1 Objectives of This Study

This study is an attempt to derive a production function for smallholder rubber of the Agalawatta District in Sri Lanka. There is extensive literature relating to the estimation of production functions; for example, Heady and Dillon (1961), Paris (1966), Timmer (1970) and Muller (1974), just to name a few. However, literature on the estimation of production functions for perennial crops in peasant agriculture is still very limited. One such example is the study by Etherington (1973) on smallholder tea in Kenya.

There is a wide variation in output per acre in the production of rubber in the smallholder conditions, and the present study has been taken up with the following objectives:

(a) To identify the main physical factors of production.

(b) To relate yield per acre to individual factors one at a time.

(c) To fit the same functional form of Cobb-Douglas type production function to each rubber clone by the Least Squares and Linear Programming techniques.

(d) To predict the possible shapes of the yield curves.

(e) To estimate the technical efficiency of individual farms of each rubber clone relative to the average and relative to the frontier production functions respectively.

(f) To compare the efficiency vectors of the average and frontier functions.

(g) To estimate the marginal productivity of factors of production.

1.2 Nature of the Data and Limitation of the Study

The data were taken from a study by the Rubber Research Institute of Sri Lanka in 1971 of 289 rubber smallholdings. The survey by the Institute was aimed to secure basic data on the small farm economy, and especially on the relationships between major inputs and outputs. The data were a cross-section study of small farms with different ages of rubber stand for different farms. Although other crops were planted, no data were available for them.

The writer has not had an opportunity to conduct his own survey to collect the necessary data for this analysis. It is to be realised that this reliance on the available secondary data poses some limitations to the analysis. These limitations are particularly obvious in this study on perennial crops in which age of the tree is one of the most important factors that affects output. Time-series data would be more suitable for production function analysis for perennial crops. Thus great caution needs to be exercised to interpret the results and the conclusions drawn from this study. Therefore, it is to be stressed here that the main purpose is to demonstrate the usefulness of the analytical techniques.

All the analyses in this study were carried out using the computer DEC-10. The package programme, Statistical Package for the Social Sciences or SPSS-10, was used for the analysis. The linear programming was run on Parametric Linear Programme or AGPLP.

1.3 Brief Notes on the Importance of Rubber in Sri Lanka

The agricultureal sector plays a vital role in the economic development of many developing nations. In Sri Lanka, the rubber industry is the second major foreign exchange earner as shown in Table 1.1.

The industry is also a source of employment and supplementary incomes to a large sector of the population. It is estimated that over 100,000 persons are employed in the large rubber estates and there are

TABLE 1.1

COMPOSITION OF EXPORTS OF SRI LANKA, 1969-1973

Commodity	Value in million rupees				
	1969	1970	1971	1972	1973
1. Tea	1062 (55)	1120 (55)	1144 (59)	1162 (58)	1261 (48)
2. Rubber	431 (22)	440 (22)	307 (16)	265 (13)	592 (23)
3. Various coconut products	225 (12)	240 (12)	280 (14)	266 (13)	145 (5)
4. Other domestic exports	157 (8)	195 (10)	199 (10)	300 (15)	598 (23)
Total Domestic Exports	1876 (98)	1995 (98)	1930 (99)	1993 (99)	2596 (99)
Re-exports	41 (2)	38 (2)	17 (1)	16 (1)	21 (1)
TOTAL	1916 (100)	2033 (100)	1947 (100)	2009 (100)	2617 (100)

Note: Figures in brackets denote percentage of total exports.

Source: Ceylon (1973), Report of the Central Bank.

TABLE 1.2

AREA UNDER RUBBER CULTIVATION BY SIZE OF HOLDINGS

Size of Holding	Number of Holdings	Acreage	Percentage
Smallholdings (less than 10 acres)	149,346	208,617	46.1
Medium scale estates (10 to 100 acres)	6,067	153,891	22.9
Large estates (100 acres and over)	843	311,457	31.0
TOTAL	156,256	673,965	100.00

Source: Administration Report of Rubber Controller (1969).

nearly 150,000 smallholders who own plots of up to 10 acres of rubber (Jayasuriya, 1973). The distribution of rubber holdings by size of area is shown in Table 1.2. It is clear that smallholdings occupy more than one-third of the total area under rubber cultivation. The overall average size of the smallholdings is about 1.5 acres, which is regarded as very small.

During the last decade, many of the larger estimates have shifted to production of latex and sole crepe; production from smallholders is still in the form of Ribbed Smoked Sheets (RSS). Sheet is the main form in which rubber was exported to China under the rubber-rice barter agreement.

TABLE 1.3

ANNUAL EXPORT OF RUBBER FROM SRI LANKA

Year	Quantity (tons)
1961	88,077
1965	121,637
1966	122,863
1967	133,421
1968	142,378
1969	140,850
1970	151,575
1971	135,603

Source: International Rubber Study Group (1972).

Although domestic consumption is rising, more than 95 per cent of the rubber produced is exported. Table 1.3 shows the annual quantity of rubber exported from Sri Lanka. The government of Sri Lanka introduced a Rubber Replanting Subsidy Scheme in 1953 which was designed to promote the replacement of existing low yielding trees with the new higher-yielding varieties. By 1974, about 55 per cent of the total rubber area had been replanted chiefly with high-yielding materials. The present study was taken from a survey of smallholdings with mature high-yielding rubber which have been replanted with budgrafts or selected seedlings since 1953.

1.4 The General Setting

1.4.1 The physiography of the area

The survey was carried out in Matugama and its adjoining area of Agalawatta. These two areas cover some 87 square miles in the main rubber growing area of Sri Lanka. A map of Sri Lanka showing the main rubber growing areas and a map of the area where the survey was carried are presented in Figure 1.1 and Figure 1.2, respectively.*

The topography of the area includes a wide range of conditions: it is characterized by small hills of up to 500 feet and winding valleys; there is jungle in the inaccessible high places, rubber on the slopes and high ground, and paddy in the valley bottoms. These areas receive rainfall from the south-west monsoon, and they are located in the "wet zone". The average rainfall in Agalawatta (for five years) is about 170 inches. Rainfall is not evenly distributed throughout the year; January, February, August and September are comparatively dry months.

1.4.2 The farm structure

The 289 farms in the survey covered about 507 acres of mature rubber, all of which are high-yielding. The farms studied also included some

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* Further information about the survey, together with a tabular analysis of results was given by Barlow, Peries, et al. (1975).

immature rubber; and over half the farms had considerable areas of paddy. A few holdings had coconut and tea and some holdings had abandoned areas. Table 1.4 shows the total area of each crop and the number of holdings growing them.

TABLE 1.4

CROP ACREAGE AND NUMBER OF HOLDINGS

Crops	Total area in acres	Number of holdings	Average area per holding
Mature rubber	508	289	1.76
Immature rubber	111	229	0.48
Paddy	328	173	1.90
Coconut	33	34	0.97
Tea	19	6	3.20
Abandoned land	28	23	1.20

1.4.3 Sampling procedure

A random sample of all high-yielding farms with sheet production records was selected in the area of each town or village. The records of output were obtained through the checking of available production records. This study was limited to those farms with recorded sheet production because yields of rubber enumerated verbally and relying on smallholders' memories were found to be unreliable. This restriction of the study to farms with recorded outputs was a source of sampling bias which could not be avoided. The output records were obtained from processers who rolled and smoked rubber sheets and from shopkeepers or dealers to whom smallholders sold their rubber. The records kept were the number of sheets handled on each occasion, their weights often being omitted. The weight of the sheets had to be estimated by weighing a few representative sheets, using a special sampling system derived for the purpose following prior estimates of variability.

1.4.4 Samples for the present study

Of the 289 rubber smallholdings surveyed, 249 were selected for analysis in the present study. These selected farms were planted with either budgrafts of clone PB86 or selected seedlings of Tjir 1. The trees were within the age groups of three to ten years of their period of tapping. This period corresponds to the first of the three equal periods of ten years of the entire exploitation cycle observed by Lim (1972).

The number of farms in each age group are presented in Table 1.5. The data gave no variation of age of trees within each farm. The number of farms selected in each age group varied from a minimum of 20 in year 4 of tapping to a maximum of 39 in year 9. The number of observations selected for each age group is quite evenly spread.

Farms in the age groups 1 and 2 were rejected because of small samples and inconsistency in the recorded output. Likewise, farms in the age groups 11 and above were rejected because of small sample size. In addition, tapping in these farms would have been carried out on renewed bark, and Lim (1972) has shown that yield patterns on the renewed bark are totally different from those of the original bark. To include them in the analysis would require more complicated production functions. The number of observations are also too small to justify a separate analysis. This study, therefore, refers to yields from tapping on the original or the virgin bark only. Eight farms have been rejected because they have been planted with mixed materials.

TABLE 1.5

NUMBER OF OBSERVATIONS BY AGE

Tapping age* in years		No. of observations (farms)
1		4
2		8
3	Farms selected for this study	23
4		20
5		31
6		36
7		37
8		35
9		39
10		27
11		17
12		7
13		1
14		1
15		2
16		1
	TOTAL	289

* Years from commencement of tapping on 6th year after planting.

CHAPTER 2

AVERAGE AND FRONTIER PRODUCTION FUNCTIONS: THEORETICAL CONSIDERATIONS

2.1 The Production Functions

A production function is a mathematical expression showing the transformation of a given set of inputs into a set of outputs. Numerous algebraic forms may be used and there is no presumption that a single form should be used to characterise agricultural production under all environmental conditions. Various functional forms have been discussed in detail by Heady and Dillon (1961).

Yotopoulos (1967) has pointed out the difficulties underlying the choice among alternative functional forms:

> It is difficult to establish empirically that a functional form adequately describes the logic and the mechanics of the production process. Yet, research of nearly four decades in this field has established a strong presumption that a number of functions are competent initial approximations of the 'true' form. Among those functions a comfortable choice of a specific algebraic form can be made on the basis of its theoretical implications and its computational manageability.

In this study, the unrestricted Cobb-Douglas form, that is, an equation linear in the logarithms of the variables, was chosen partly for its ease of manipulation and interpretation and for its good fit to the data; and more importantly, its log linear form permits easy calculation of the "frontier" production function by the application of a conventional linear programming package. Several other forms were tried such as quadratic functions, without any appreciable improvement in the results.

Some other forms, such as CES functional form could have been chosen for the purpose, but with more than two factors of production, the CES function becomes quite complicated and it is not possible to estimate using a linear programming technique.

Having selected the appropriate functional form, two different methods of fitting the function are applied: the ordinary least squares method which estimates an average function; and the linear programming method which estimates the frontier or best production function.

Muller (1974) has suggested that the concept of the "frontier" is relative and artificial:

> . . . To add more of one input, i.e., production knowledge, should of course, increase output, so the frontier function can at best be defined with respect to a fixed level of information only, or for that matter, at any fixed level of other left-out factors. Once all inputs are taken into account, measured productivity differences should disappear except for random disturbances. In this case the frontier and the average function are identical. They only diverge if significant inputs have been left out in the estimation.

Due to data limitation, it is not possible to include all the inputs as suggested by Muller. Those factors which are commonly associated with management and "information" as defined by Muller were not available.

2.2 Properties of the Cobb-Douglas Function

The Cobb-Douglas functional form commonly used is:

$$q_j = b_o\, x_{1j}^{b_1} \ldots\ldots x_{ij}^{b_i} \ldots\ldots x_{nj}^{b_n} \qquad \ldots\ldots(2.1)$$

where q_j is the output of farm j

x_{ij} is the factor input i used by farm j

b_o is the constant

b_i is the parameter associated with the i^{th} input.

For computational purposes, this form becomes linear in logarithms of the variables. Thus (2.1) can be written in log (capital letters) linear form as -

$$Q_j = b_o + b_i x_{ij} + \ldots\ldots\ldots + b_i x_{ij} + \ldots\ldots\ldots + b_n x_{nj} \qquad \ldots\ldots(2.2)$$

The marginal product of each input factor is the partial derivative of the output with respect to an input, with all other inputs held constant. Thus, differentiating the function (2.1) with respect to one input, x_i, we have:

$$\begin{aligned} MPx_i &= \frac{\partial q}{\partial x_i}, \\ &= b_i b_o x_1^{b_1} \ldots\ldots\ldots x_i^{b_i - 1} \ldots\ldots\ldots x_n^{b_n}, \\ &= b_i \frac{q}{x_i} \qquad \ldots\ldots(2.3) \end{aligned}$$

Since $\frac{q}{x_i}$ is the measure of average product, equation (2.3) shows that the marginal product of the i^{th} input is equal to the average product multiplied by its exponent.

The elasticity of production of each input is defined as the percentage change in output for a one per cent change in that input, while the other input levels are held constant. The marginal product is employed in deriving the elasticity of production.

The output elasticity of the i^{th} input factor, η_{qxi}, is:

$$\begin{aligned} \eta_{qxi} &= \frac{\partial q}{\partial x_i} \cdot \frac{x_i}{q}, \\ &= [b_i \frac{q}{x_i}] \frac{x_i}{q}, \\ &= b_i \qquad \ldots\ldots(2.4) \end{aligned}$$

Therefore, the coefficients b_i ($i = 1,2,\ldots\ldots n$) are the elasticities of production, and each of these remains constant throughout the production surface.

The degree of homogeneity of the function and the returns to scale are measured by the sum of the elasticities of production. Hence, if $\sum_{i=1}^{n} b_i$ is greater than unity, there are increasing returns to scale; if it is less than one, decreasing returns to scale occur. If the sum of the exponents is equal to one, there are constant returns to scale.

Marginal productivity changes for different levels of input can be derived from equation (2.3). The second derivative of (2.3) gives:

$$\frac{\partial^2 q}{\partial x_i^2} = b_i \ (b_i - 1) \ \frac{q}{x_i^2} \qquad \text{.....(2.5)}$$

which is negative since $b_i < 1$. Thus we have diminishing marginal productivity for increasing input levels.

Under the assumption of perfect markets, the equilibrium condition is the point at which the marginal value product of each of the resources is equal to its marginal cost. The first order condition for profit maximization is that the marginal product of each factor is equal to the ratio of the price of the factor and the product. Hence, for the i^{th} factor, profit maximization occurs when

$$\begin{aligned} MP_{xi} &= \frac{\partial q}{\partial x_i} , \\ &= b_i \frac{q}{x_i} , \\ &= \frac{P_{xi}}{P_q} . \end{aligned} \qquad \text{.....(2.6)}$$

where

P_{xi} is the price of the i^{th} factor

P_q is the price of the product

Under the assumption of perfect markets, direct comparison between the marginal productivity of a factor and its opportunity cost will measure the existence of resource misallocation of a particular firm in the production process.

In spite of the many attractive properties of the Cobb-Douglas function, there are a few drawbacks. One of the most limiting characteristics is that the function assumes a constant and unit elasticity of substitution between the input factors. Nevertheless, as long as we keep the limitations of this functional form clearly in mind, we can always exercise the necessary caution in interpreting its results.

2.3 Ordinary Least Squares Procedure

In order to estimate the Cobb-Douglas function, the log linear form of equation (2.2) is used. Since this estimation is made from a sample, an error term is introduced. The equation (2.2) becomes:

$$Q = b_o + b_1x_1 + \ldots\ldots\ldots + b_ix_i + \ldots\ldots\ldots\ b_nx_n + U \qquad \ldots\ldots(2.7)$$

where U is the stochastic error term.

Equation (2.7) now expresses the exact linear relationship between the dependent variable Q and the n explanatory or independent variables x_1, x_2 ..... x_n and the error term U which may be composed of measurement error and/or error due to the omission of certain variables.

Ordinary least squares method is used to estimate the unknown parameters b_i (i = 0, 1, 2, ... n) and the error distribution. The sample estimates of equation (2.7) are

$$\hat{Q} = \hat{b}_o + \hat{b}_1x_1 + \ldots\ldots\ldots\ \hat{b}_1x_1 + \ldots\ldots\ldots\ \hat{b}_nx_n + \hat{U} \qquad \ldots\ldots(2.8)$$

The least squares method of estimation is unbiased given the following assumptions:

(a) the error terms are random with zero mean;

(b) the error terms are uncorrelated and have a common variance 0^2 ;

(c) the explanatory variables are not correlated with the error terms;

(d) the number of observations is greater than the number of parameters to be estimated.

This method has been well discussed in many econometric text books e.g. Johnston (1963); Dhrymes (1970); Koutsoyiannis (1973).

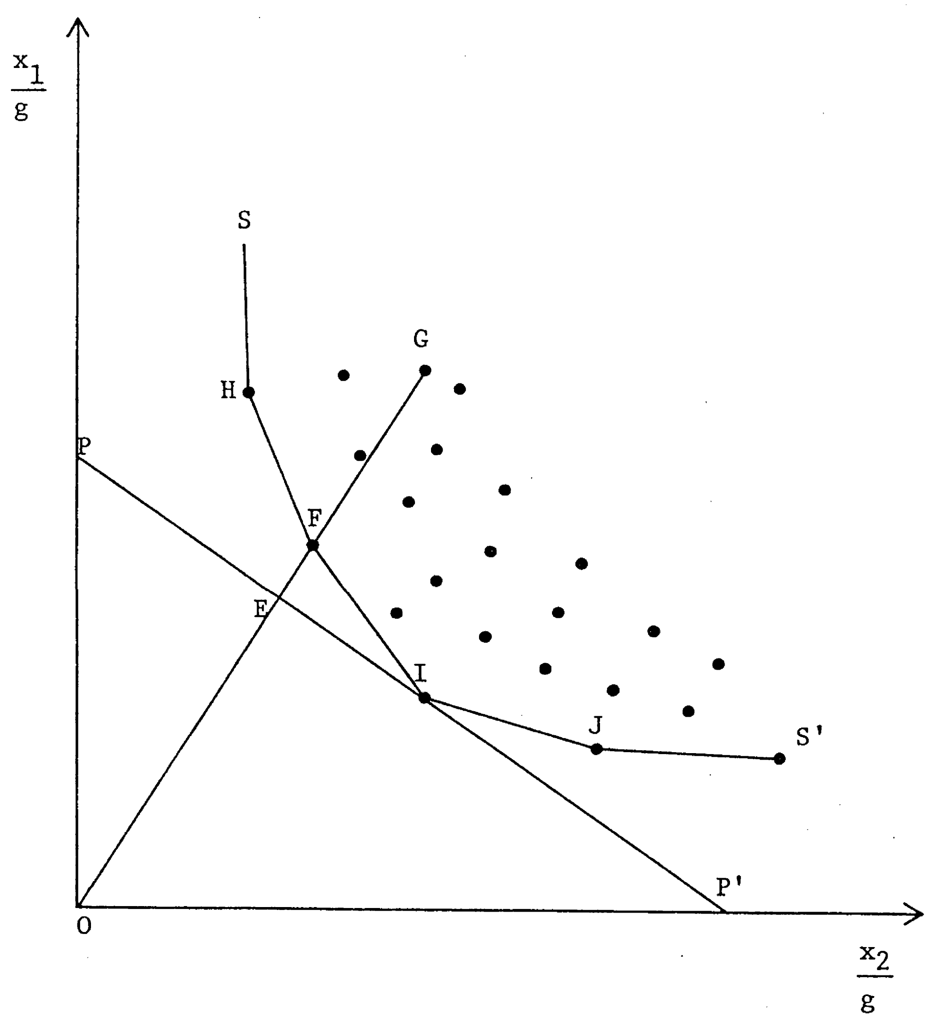
2.4 Frontier Production Function

The Cobb-Douglas function, estimated by ordinary least squares which minimises the sum of squares of the error terms on both sides of the estimated function could only represent the average function. The linear programming technique minimises the sum of squares of the error terms all constrained to one side of the function; hence, the frontier or the best function. It expresses the maximum product obtained from the combination of factors at the existing state of technical knowledge.

Farrell (1957) pioneered the method of estimating an efficient production function which is illustrated in Figure 2.1, for the two inputs, one output case (Seitz,1970). Under the assumption of constant returns to scale, the production function can be specified in the form of a unit isoquant. Each observation represents the input combination used by a single firm to produce one unit of output. The curve SS' is the locus of points indicating the minimum quantities of the factors of production required to produce one unit of output with varying factor proportions. This curve thus represents the frontier and no observation lies between this curve and the origin, 0. All those firms which lie on the frontier, such as H,F,I,J are said to be 100 per cent technically efficient; those lying above SS' are technically inefficient. Physical or technical inefficiency of observation G is defined as the ratio of the distance between the origin and point F to the distance between the origin and the point G, i.e. $\frac{OF}{OG}$. On this basis, all firms will have a technical efficiency rating of 1 or less. The points G and F are on the same ray from the origin and thus represent identical factor proportions.

FIGURE 2.1

TECHNICAL AND PRICE EFFICIENCY



If PP' represents the isocost line, the price inefficiency of F is the ratio of the distance between the origin and point E to the distance between the origin and point F i.e. $\frac{OE}{OF}$. In this respect, although firm F is technically efficient, it is not price efficient; hence, firm F is not economically efficient.

The firm represented by the point I, is both technically and price efficient as the isocost line PP' is tangent to the efficient unit isoquant SS' at I. Hence firm I is economically efficient.

Technical efficiency is measured in relation to those firms at the frontier whereas price efficiency is measured in relation to the isocost line. The product of these two separate efficiencies,

$$\frac{OF}{OG} \times \frac{OE}{OF} = \frac{OE}{OG}.$$

measures the economic efficiency of the firm at G.

Given the Farrell techniques, and since technical efficiency is measured in relation to those firms on the frontier, any additional observations may reduce but cannot increase the technical efficiency of a given firm. However, additional observations may change the slope of isoquant SS' and the slope of isocost line PP' on which the price efficiency depends; hence price efficiency is more sensitive to additional observations and also to errors in factor prices. It was decided not to measure price efficiency because accurate price data were not available.

Nerlove (1965) and Bressler (1967) criticised Farrell's method because it utilises only the "marginal" observations and operates in an input-input space under the assumption of constant returns to scale which raised a number of theoretical and operational difficulties. In 1968, an "improved" method was developed by Aigner and Chu. By constraining errors to one sign and fitting least lines with linear programming technique, a fitted envelope function could be obtained using all observations in the estimation. This method operates in the output-input space and the assumption of constant returns to scale need not be made.

The analysis in this study uses the Aigner and Chu method which has been clearly explained by Timmer (1970).

2.4.1 Method of Estimation of Frontier Production Function

The Cobb-Douglas model in general form, linear in logarithm, given by equation (2.7), can be written as:

$$Q_j = \sum_{i=o}^{n} b_i x_{ij} + U_j \qquad .....(2.9)$$

where one column of x_i is a vector of ones to allow for an intercept.

To make this a frontier function all U_j must be constrained to one side of the estimated production surface. Thus, the production function (2.7) should be estimated such that:

$$\sum_{i=o}^{n} \hat{b}_i x_{ij} = \hat{Q}_j \geqslant Q_j \qquad .....(2.10)$$

Only "efficient" firms satisfy the final equality - all others have a small actual output than would be achieved if they too were efficient by the standard of the estimated production function. The criterion used here is to minimise the linear sum of the errors, i.e. minimise:

$$\sum_{j=1}^{m} u_j = \sum_{j=1}^{m} \sum_{i=o}^{n} \hat{b}_i x_{ij} - \sum_{j=1}^{m} Q_j \qquad .....(2.11)$$

subject to

$$\sum_{i=o}^{n} \hat{b}_i x_{ij} \geqslant Q_j$$

and $\quad \hat{b}_i \geqslant o \qquad .....(2.12)$

For any particular data set $-\sum_{j=1}^{m} Q_j$ is a constant, and hence can be dropped from the equation (2.11). Minimising (2.11) is the same as minimising:

$$\sum_{j=1}^{m}\sum_{i=o}^{n} \hat{b}_i x_{ij} \quad .....(2.13)$$

Dividing (2.13) by m farms, the number of observations, the objective function becomes:

$$\sum_{i=o}^{n} \hat{b}_i \bar{x}_i$$

$$= \hat{b}_o + \hat{b}_1\bar{x}_1 + \hat{b}_2\bar{x}_2 + \ldots\ldots\ldots + \hat{b}_n\bar{x}_n \quad .....(2.14)$$

where

$$\bar{x}_i = \frac{1}{m}\sum_{j=1}^{m} x_{ij} \text{ and } \bar{x}_o = 1$$

The problem then is to minimise the object function:

$$\hat{b}_o + \hat{b}_1\bar{x}_1 + \hat{b}_2\bar{x}_2 + \ldots\ldots\ldots + \hat{b}_n\bar{x}_n \quad .....(2.15)$$

subject to the linear constraints

$$\begin{array}{ccccccc}
\hat{b}_o + & \hat{b}_1 x_{11} + & \hat{b}_2 x_{21} + & \ldots\ldots\ldots + & \hat{b}_n x_{n1} & \geq & Q_1 \\
\hat{b}_o + & \hat{b}_1 x_{12} + & \hat{b}_2 x_{22} + & \ldots\ldots\ldots + & \hat{b}_n x_{n2} & \geq & Q_2 \\
'' & '' & '' & & '' & & '' \\
'' & '' & '' & & '' & & '' \\
'' & '' & '' & & '' & & '' \\
\hat{b}_o + & \hat{b}_1 x_{1m} + & \hat{b}_2 x_{2m} + & \ldots\ldots\ldots + & \hat{b}_n x_{nm} & \geq & Q_m
\end{array} \quad .....(2.16)$$

and

$$\hat{b}_i \geq 0$$

This can be solved by a linear programming package.

2.5 Estimation of Technical Efficiency

Technical efficiency refers to the maximum quantity of output that can be achieved from a given set of resources; the greater the output relative to the inputs, the higher the level of efficiency. The average and the best functions so estimated will enable us to predict the average and the maximum physical output levels that could be obtained from each possible input combination. The efficiency level of each farm relative to the <u>average</u> farm is measured by the ratio of the actual observed output to the output predicted from the average production function. Similarly, the efficiency level of each farm relative to the <u>best</u> farm is measured by the ratio of the actual observed output to the output predicted from the best production function.

$$\text{Efficiency index} = \frac{q_j}{\hat{q}_j}$$

$$= \text{Antilog of } (Q_j - \hat{Q}_j) \qquad .....(2.17)$$

where

Q_j is the log of the observed output of the j^{th} farm

$\hat{Q}_j$ is the estimated output level from the average or the best function.

Is there any relationship between these two methods of computing technical efficiency? Will the farm that is most technically efficient/inefficient relative to the average function be also most technically efficient/inefficient relative to the best function?

CHAPTER 3

RUBBER CULTIVATION AND FACTORS AFFECTING RUBBER PRODUCTION

3.1 Cultivation of Rubber

The Para rubber, whose Botanical name is *Hevea brasiliensis* belongs to the Euphorbiaceae family. The rubber tree grows to about 60 feet high. The bark is of variable colour, which is mainly light brown. The tree sheds its leaves once a year, in a process commonly known as "wintering" which may last for about two months.

The rubber tree will grow well in the area ten degrees north or south of the equator. It needs a rainfall in the region of 100 inches a year, and an average temperature of 75 to 85 degrees fahrenheit. The tree will not flourish in waterlogged soil, or at heights above 2,000 feet. In general, the most suitable soils for rubber are loamy, naturally drained, sandy clays, rich in mineral nutrients and organic matter. However the rubber tree is a very hardy plant and able to adapt to a very wide range of soil conditions and topography of the land.

In the establishment of a rubber holding, the first stage is the tedious and expensive process of clearing the jungle in the case of new planting or clearing the old rubber trees in the case of replanting. Shrubs and trees are felled, and allowed to dry out before being burnt on the site. This may be followed by digging up the roots, but this operation is not always carried out. Removal of roots will facilitate freedom of movement and assist in combating root diseases. However, this operation will add considerably to the costs of clearing. On sloping grounds, removal of old roots may cause serious erosion of the soil.

After clearing the ground, the young plants can be planted out. The conventional practice is to germinate the seeds in a germination bed, and the young seedlings planted in the nursery. After the young plants have been about a year in the nursery, they are transferred to their permanent positions in the field. After preparing and pegging out the land, planting out is always done in the rainy season. This is to avoid desiccation of the young plants before the roots can take hold and also to minimise the "transplanting shock". However, modern techniques have bypassed the nursery stage and the seedlings are planted straight in the field; budgrafting is carried out in the field when the young plants are about a year old.

In the field, the number of trees planted is generally in excess of the number which will eventually be allowed to mature for tapping. The number of trees will be thinned down both by natural losses such as wind damage or pest attack, and also by selective thinning. Only the most vigorous plants are allowed to remain. Budgrafted trees, and trees planted from selected seedlings are planted at different distances apart. This distance normally varies from 20 feet by 20 feet to 14 feet by 14 feet. The table below shows the planting distances and the approximate number of trees in an acre or the planting density.

Planting Distance (feet)	Number of Trees per acre
30 x 30	48
20 x 20	108
20 triangle	125
14 x 14	222
12 x 12	302
10 x 10	435

In a well-managed estate, by the time the trees are ready for tapping, only some 100 to 120 trees remain in an acre after progressive elimination of all but the best specimens. On smallholdings, using low-priced or family labour, however, densities of up to 200 trees per acre may be appropriate.

During the period of establishment, suitable ground cover of vegetation, mainly creeping legume plants known as cover crops are planted between the rows of young rubber trees in most estates. The cover crops are to serve two main functions, namely, to combat erosion, especially immediately after clearing the jungle, and it is believed that legume plants are beneficial to the growth and establishment of the young rubber trees. In the case of smallholdings, the space between the rows of young rubber trees when they are still not productive may be used for growing cash crops such as peanuts, maize, vegetables, or sometimes tapioca and sweet-potatoes. When the rubber trees are planted on sloping ground, terraces are made following the contours. The trees are planted on the terraces. Suitable fertilizers are necessary to keep the trees in a good condition, especially during the establishment period of the first six years.

Healthy conditions of the trees are essential in order to keep them productive. One of the common diseases, which is believed to be due to a physiological disturbance, and which is connected strongly with over-tapping, is known as "brown bast". It is a canker of the bark on the tapping panel. Several other diseases are due to fungi, for example, Oidium heveae attacks the leaves; Corticium salmonicolor or pink disease attacks the forks between the branches; Fomes attacks the roots. The most dangerous of all diseases is the Dothidella ulei, commonly known as South American leaf blight, which attacks the leaves and may lead to complete destruction of the trees. This is the main cause of the difficulties encountered in establishing rubber plantations in South America, even though it is the original home of hevea. Fortunately for countries in South East Asia, the disease is not found in the region, and stringent precautionary measures are taken to prevent the spread of this disease to this part of the world.

3.1.1 Planting Materials

Planting materials are usually obtained from a clone or from selected seedlings.

All trees obtained by vegetative propagation from a single mother tree, either directly or by multiplication, are said to constitute a clone. The clone is then given a name, which is merely that of the mother tree, e.g. Prang Besar 86, Avros 49, Tjirandji 1, etcetera. Budding with high-yielding clones, especially carried out on good root stock, has made it possible to double, and even treble, yields as compared to the ordinary unselected trees.

The process of budding consists of removing a bud or "eye" from a branch of high-yielding rubber tree of verified quality, and inserting it under the bark of the lower stem of a young tree. If the budding is successful, a branch is produced. The part of the tree just above the branch growing out of the bud is cut off. Only this branch develops; it grows upwards and ultimately becomes the trunk of the mature tree.

Selected seeds may have come from several sources:

(a) natural random pollination of flowers of a high-yielding tree. Seeds thus obtained are sometimes called illegitimate seeds;

(b) by natural cross-pollination between different trees of the same clone. Seeds thus obtained are called clonal or selected seeds;

(c) by artificial cross-pollination of high-yielding trees, the result of which is called legitimate seeds.

These three types of seeds produce trees superior in quality to those obtained from unselected seeds. Legitimate seeds give the best seedlings, and clonal seeds come next, followed by the illegitimate variety.

3.1.2 Exploitation of the Rubber Trees

The latex is contained in a network of capillary tubes, or latex vessels, in the bark of the trunk. The vessels exist in a series of concentric rings. They are mostly concentrated near the cambium or the generating tissues in a layer 2 mm to 3 mm thick. Exploitation, or tapping, is a process of extracting rubber by making an incision in the bark of the tree. The latex vessels are opened, and a high turgor pressure in the bark tissue and latex vessels forces out a milky liquid known as latex. Immediately after tapping, latex flow is rapid, but it slows down progressively. The flow ceases in about two to five hours, depending partly on the surrounding air temperature. The flow finally stops, due to the formation of a barrier known as a "plug" in the cut latex vessels. The last portion of the exuded latex coagulates over the incision. The latex, deposited in a cup fastened to the trunk of the tree, is then collected. If it is left to stand, the latex coagulates, so it is normally collected and processed without delay. However, there will be still some "late dripping" from the vessels. The material coagulates through natural process and is collected in the next tapping round. This forms lower grade rubber known as "scrap".

The amount of latex and scrap that can be obtained from a tree at a given tapping varies with several factors. Generally, it depends on the growth-vigour and production efficiency of the tree. Growth-vigour differs greatly between types of planting materials, namely, clones and seedlings.

While growth-vigour is not necessarily correlated with production efficiency, there is a definite indication that trees with larger girth produce relatively more latex, the larger circumference being associated with a larger number of latex vessels in the bark. The quantity of the lower grade rubber varies according to clones, age, and tapping system adopted. Table 3.1 shows the weight of scrap, as a percentage of the weight of the rubber sheets, according to planting materials and tapping systems.

TABLE 3.1

WEIGHT OF SCRAP AS A PERCENTAGE OF THE WEIGHT OF RUBBER SHEETS

Rubber Clone	Years in Tapping		
	3 and below	4 to 9	10 to 15
	%	%	%
(a) Tapping System s/2,d/2			
RRIM 501	16.3	12.3	14.1
PB 5/51	16.9	11.3	11.8
PB 86	19.5	9.9	10.9
Tjir 1 CS	11.9	13.1	15.5
(b) Tapping System s/2,d/3			
RRIM 501	22.6	10.2	16.2
PB 5/51	18.6	11.7	13.1

Source: Extracted from Economics and Planning Division Report No. 7, Rubber Research Institute of Malaya, Kuala Lumpur, Malaysia, "Guide to Estate Management, June 1970".

Latex is regenerated after the initial tapping. If the wound is reopened successively, the amount of latex obtained becomes more abundant. It is this special characteristic of hevea known as "wound response" which means that these trees can be exploited throughout the whole year. Since the latex flows more freely from the tree in the morning, tapping is usually carried out in the early hours of the morning.

Tapping is an operation requiring great care and great skill; the yield of latex depends upon the length and depth of the cut. If the cut is not deep enough, the full quantity of latex is not obtained; and if it is too deep, it may damage the cambium layer on which the growth of the tree depends. The actual incision is made with a gouge or a special knife. The cut itself slopes from left (high) to right (low) at 20 to 30 degrees to the horizontal. At its lower end, the cut is extended into a vertical channel, terminating in a metal spout. Below this is attached a cup for collecting the latex. At each successive tapping, the tapper reopens the groove by removing, along its lower edge, a shaving of bark about one-sixteenth of an inch thick and the latex begins to flow again. Depending on the skill and speed of the tapper, he may visit as many as 500 to 600 trees in a morning; the number of trees he taps on a tapping day is known as his "task size".

The first groove on the bark is usually "opened" at about three to four feet from the ground. The tapper continues systematically, removing a sliver of bark on each tapping day, until a panel has been cut away down the side of the tree. This commonly takes four to five years. After this, the process is repeated on the other side of the tree. After a further four to five years, while the second side of the tree is being tapped, the first side has recovered and is ready for tapping again. And so the process could be continued for as long as the tree remains alive. However, the overall yield of latex from the renewed bark is relatively lower than that from the virgin bark.

The trees are usually in their sixth or seventh year after planting when tapped for the first time. The economic life of a tree is considered to be about thirty years of tapping. After this period, there is no more tappable bark reserve, or the yield is too low to justify further exploitation.

Continuous research into the physiology of rubber trees has led to the discovery of methods of stimulating the yield by the application of chemical substances known as yield stimulants. Recent development of soil and leaf analysis techniques now enable more effective fertilizer use, with applications being tailored to actual requirements instead of following a general guide. Progress in these directions, together with that due to selection, are an assurance of considerable advances in the future.*

3.1.3 Commercial Rubber Sheets

The latex collected in the cups is bulked and transported to processing centre. The dry rubber content in the latex is normally around 30 percent.

In the processing centre, the latex is coagulated and rolled into sheets. After drip-drying, these sheets are hung in a smokehouse for the purpose of impregnating the sheets with creosote-like substances which act as preservatives. After drying, the sheets are graded in various qualities on the basis of appearance, taking into account the existence of bubbles, blemishes, black spots, mottling, etcetera. The sheet rubber is then known commercially as RSS, that is, ribbed smoked sheets. The various grades of RSS are indicated by numbers from No. 1, the standard quality, to No. 5, the inferior fair average quality. An efficient plantation factory usually turns out more than 90 percent of No. 1 quality.

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* For example, see Handbook of Rubber Production, Sri Lanka.

Smoked sheets are prepared by smallholders along the same lines but using crude, manual methods, a hand-operated mangle and a crudely constructed smokehouse. Those smallholders who do not have the facility of smokehouse may sell their rubber as unsmoked sheets. The RSS from smallholders are usually of inferior quality.

3.2 Factors Affecting Rubber Production

The physical annual outputs from smallholder rubber production are believed to be basically influenced by the following factors:

(i) Annual inputs controlled by the smallholder in a particular year:

- L Labour input in tapping rubber trees;
- P Supplementary inputs such as fertilizers, weeding, insecticides;
- M Management factor;
- W Type of tapping.

(ii) Lagged values of the annual inputs applied in the previous years:

- X Planting density;
- B Land input of the farm;
- G Age of the trees;
- V Clone or variety of rubber;
- D Distance of the tapper's house from the farm and distance from the "buying" centre.

(iii) Completely exogenous variables both current and lagged:

- T Topography of the farm;
- S Soil type(s);
- C Climatic conditions.

Mathematically, the above might be expressed as:

$$Q = f(L,P,M,W,X,B,G,V,D\ T,S,C) \qquad \ldots\ldots(3.1)$$

where Q is the total output of rubber from the farm in that particular year. Total output of rubber is made up of rubber sheets and scrap.

3.2.1 Annual inputs controlled by the smallholder

Annual inputs are under the immediate control of the farmer and can be changed at any time.

3.2.1.1 Labour input in tapping rubber trees

Rubber is a labour intensive crop. This is recognised in all the standard works on rubber cultivation, and on the management of rubber estates.* There seems to be no way that harvesting of the rubber, that is, tapping of rubber trees, could be conveniently mechanised.

Labour inputs can be divided into a number of operations which can be grouped into those relating to the establishment period (digging, planting, bud-grafting), maintenance period (weeding, fertilizer application, pest and disease control), harvesting (tapping the trees) and processing the latex into sheets and delivering to the buying centre. Establishment and maintenance labour inputs of earlier periods will have a strong influence on current output. Variations in these inputs are likely to be highly correlated to managerial skill. It is the substantial time lag (six 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 to adequately measure the labout input in a production function.

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* For example, see Handbook of Rubber Production published by the Rubber Research Institute of Sri Lanka.

As rubber matures, the major maintenance operations are reduced to annual fertilizer application and weeding, pest and disease control. Thus by far the most important labour input on mature rubber is in the form of tapping the trees and processing the latex thus obtained into rubber sheets and delivering them to the buying centre.

Unlike tea, where labour input for harvesting is determined by the number of "two leaves and a bud" Etherington (1973), harvesting of rubber tree or tapping does not have to be on such regular timing. Latex, stored in the tree, does not deteriorate and can be harvested at will.

The number of man days equivalent spent on tapping may be computed as the product of the number of tapping days per year and the number of tappers. However, this value would be grossly misrepresented if the number of tapping days for each tapper is not the same. Unless the number of tapping days for each tapper is known, it is not possible to compute the value of labour input as man days equivalent.

Alternatively, the labour input in tapping may be represented by the number of times the trees are tapped each year; a rubber tree is never tapped more than once a day. Within limits, the more days the tree is tapped, the greater is the output. A particular tapper may tap every alternate day, or once in every three days. However, this is not strictly adhered to because tapping cannot be satisfactorily carried out during rainy days. Therefore the number of days the trees are tapped depend not only on the tapping system adopted, but also on the interference of rainy days.

3.2.1.2 Supplementary inputs

Supplementary inputs include fertilizer, weeding labour, chemicals to control pest and diseases, yield stimulants and the cost of labour for their application. Supplementary inputs are very important in estates, but in the case of smallholders, very few of them use any of these items, except, perhaps weeding labour occasionally. Use of fungicide may be important in areas of high humidity due to high incidence of fungus attack on tapping panels or branches. Weeding labour could be important because thick undergrowth hinders the movement of the tapper from tree to tree.

The use of supplementary inputs is mainly associated with the management standard of the holding. Most of these supplementary inputs are of long term effect, and unless time series data are available, it is not possible to measure their effects satisfactorily.

3.2.1.3 Management factor

In considering the technical efficiency of the smallholder, management standard becomes a crucial factor. Timmer (1970) observed that in agriculture, the better managers usually tend to use more of most inputs and consequently derive higher output.

Management standard has always been difficult to define and to measure. Timmer (1970) observed that since it is a non-observable, non-measurable input, management is judged by the results of its decisions, that is, by the degree of efficiency achieved in production. Muller (1974) used factors like education, age and experience, and production knowledge to measure the impact of management on production.

Some of the factors believed to be associated with management in rubber production are:

(a) the farmer's education level and his willingness to follow recommendations given by extension agents;

(b) his experience and technical knowledge on rubber cultivation;

(c) his age; it is believed that older farmers are more cautious with any changes from the routine, or taking risk;

(d) cultivation of non-rubber crops;

(e) his skill in tapping, and the quality of the rubber sheets he could produce;

(f) general conditions of his holding, presence or absence of weeds, pests and diseases.

Unfortunately, the data for this study did not record, or recorded unsatisfactorily, all of the factors mentioned above, except the information on the acreage of cultivation of non-rubber crops.

Although management input is considered here in relation to annual input controlled by the farmer, it must be noted that management input actually covers the current year and the previous years. In his study on tea Etherington (1973), has pointed out that while management is of importance throughout the life of the plant, it is the careful nurture of the young plants that is particularly critical, and thus the multiperiod production function could be described as a point-input multipoint-output process. This also applies to rubber. As most extension workers will be able to testify, it is unfortunate that the importance of management input during the establishment period of the tree is often not appreciated by smallholders.

There are many stages in the cultivation of rubber during which it is possible for the farmer not to achieve technical efficiency. Any bad practice at any stage in the life of the plant could have a resultant adverse effect on yield.

The crucial problem here is that poor planting, weeding and tapping practices in the early years will affect the structure and formation of the tree in a manner that cannot be reversed. It is therefore reasonable to consider there to be a single management variable on each fram that does not change over time. Thus the ultimate responsibility for inefficiency is placed on the managerial abilities of the farmer.

3.2.1.4 Types of cut in tapping rubber trees

Tapping refers to the method of harvesting of rubber trees. There are several types of tapping systems* and the type adopted should take into account the long-run yield without interfering with the growth of the trees; the rate of bark consumption should not be faster than the rate of normal bark renewal. As rubber trees of different ages, planting materials, life history, react differently to different systems of tapping, the appropriate tapping system to use varies with the actual situation in each case.

3.2.2 Lagged values of the inputs applied in previous years

These are the inputs whose effect is felt during the whole life of the trees. They are not under the immediate control of the farmer.

3.2.2.1 Planting Density

Planting density experiments in Malaysia have shown that low densities result in higher yield per tree but relatively lower yield per acre, and vice versa Westgarth and Buttery (1965). Under estate conditions, about 125 trees per acre was a fair optimum, while a density of 150 to 175 trees was considered to be appropriate for smallholding Barlow and Lim (1967).

The normal tapping age of the trees begins at about six years after planting when the trunk of the tree reaches a certain minimum girth. In Sri Lanka, the tree comes into tapping when the girth reaches 18 inches at a height of three feet from the ground. However, not all the trees have grown to this girth at six years' old. Therefore, during the early stages

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* For information on tapping systems and related topics, see Ceylon Rubber Handbook, 1971; Planters' Bulletin, Rubber Research Institute of Malaya, Nos. 11, 22, 25, 29, 38, 45, 56 and 58.

of tapping, the number of trees tapped per acre is usually less than the number of trees in that acre. Those trees which are not yet mature do not contribute anything to the output of rubber. Consequently, it is the actual number of trees in tapping, or in production, that will affect the output.

3.2.2.2 Size of the farm

This is the input of land on a given farm. There are two aspects: the quantity and the quality. Once the area is allotted and planted with rubber, there is not much a farmer can do to change it. Spacing of the trees depends on the material used and also the topography of the land. Consequently, there is no fixed relationship between the quantity of the land and the number of trees planted. However, under estate management, planting density is strictly enforced and the number of trees per acre is about 120 trees.

As far as quality is concerned, soil fertility will undoubtedly vary somewhat between holdings and between fields on a given holding. The quality of the land is a completely exogenous variable.

3.2.2.3 Age of the trees

Once the trees are planted, the age of the trees is totally beyond the control of the smallholder. Trees of different ages respond differently to various input factors and yield differently. Generally, rubber yield rises during the early years of tapping, remains relatively stable for a short period, and then begins to decline rather sharply. The mix of controlled inputs and exogenous inputs will affect the shape of the yield curve over time.

Different sections of a large holding may have trees of different age, but in smallholdings of about two to three acres, the age of the trees within the holding usually does not differ significantly.

3.2.2.4 Clone or variety of rubber

Different varieties of rubber perform differently under a given condition. A clone is one of those variables where technical progress could be embodied in the relevant vintage. Hence different types of planting material of a given clone can be very different in yielding capacity.

In this study the two major varieties were PB86 which were budgrafted and Tjir 1 which were selected seedlings.

3.2.2.5 Distance of the holding

Distance of the smallholder's house from his holding might act as a limiting factor on the output of rubber in that tapping is generally carried out in the early hours of the morning. Time spent in travelling from his house to the holding is unproductive. Distance of the "buying" centre has some influence because a tapper from a remote area may reduce his tapping time in order that he could reach the shop before it is closed. On the other hand, he might store up his output and sell the rubber in bulk at less frequent intervals, thus gaining some advantage in marketing margins.

3.2.3 Completely exogenous variables

These are the variables both current and lagged which are beyond the control of the smallholder. They are soil type, climatic factors and topography. Climatic conditions have a substantial effect on yields. Rainfall affects both the quality and quantity of rubber produced through loss of tapping days, late tapping, early collection, or a total loss of latex. However, though excessive rain may depress yields by interfering with tapping, low rainfall tends to reduce the latex flow.

Wind damage is another important factor in areas subject to regular strong winds and storms. This factor is also confounded with manuring regime and tapping intensity.

Annual defoliation known as "wintering" following a dry spell occurs early in the year, around February-March. Wintering depresses yield ranging from 10 per cent to 30 per cent of normal yield, depending on duration and severity which in turn interact with clone and localities.

Topography of the land could change the number of trees in an area and also reduce the speed and ease of movement of the tapper during tapping and collection.

Different soil types will affect the level of nutrients available to the trees and also will affect the ability of the trees to absorb fertilizer.

CHAPTER 4

SPECIFICATION OF THE VARIABLES AND THE ANALYSIS OF SPECIFIC FACTORS AFFECTING OUTPUT

4.1 Specification of the Variables

The analysis is carried out under the assumption that the same functional relation applies to all farms. There are two crucial conditions attached to this assumption. Firstly, the specification of variables must be complete. Secondly, the specification of variables must be correct. The choice of variables to be included was largely dictated by the availability of data.

A complete specification of variables is impossible because of the existence of unobservable variables in a production process. It is also impossible to have complete control of specification errors. Consequently, the "true" production function is not known. Nevertheless, a close substitute could be estimated.

Of the twelve types of variables listed in equation (3.1) and discussed in Chapter 3, it is believed that the planting density, tapping frequency, farm size, and tapping age of the rubber stand, are the most important variables that affect the output of rubber. The other variables are omitted because of unavailability of the necessary data.

The most common specification error is the omission of the relevant variables. Griliches (1957) has shown that if the omitted input variables are positively correlated with the included ones, the result will have a tendency to bias upwards one or more of the coefficients of the included variables. The converse is true in the case of a negative correlation between included and omitted variables.

The way input and output variables are defined and measured is crucial for the applicability of an empirically estimated production function Yotopoulos (1967). The following paragraphs describe the variables used in this study.

4.1.1 Output

In this study, we consider only one produce from the farm, namely, the output of rubber. About 75 per cent of the farms had other crops such as paddy and coconut. The only information available on these other crops was the area they occupied. Therefore, output of these other crops could not be included in the production function.

Output of rubber is defined as the quantity in pounds of rubber sheets (RSS) produced by the farm for the twelve months preceeding the survey. This definition of output is an under-estimate of the actual output which is the total quantity of dry rubber produced. The dry rubber is the total weight of rubber sheets and scrap rubber. There is no record of the weight of scrap. Under such circumstances, the weight of scrap could be assumed to be 20 per cent of the total weight of dry rubber sheets produced. However, in this analysis we do not propose to add this assumed weight of scrap to the output of rubber sheets because there is such a great variability in the percentage of scrap due to differences in clones, age, and tapping systems as shown in Table 3.1.

For most agricultural products, part of the output is retained by the farm for home consumption. This situation does not apply in the case of rubber; everything produced is marketed. Hence, there is no difference between gross output and net output.

With regards to the homogeneity of the output, there could be different grades of RSS produced. No data were available on these different grades. However, in smallholder situations where poor processing methods were employed, only the lower RSS grades of rubber were normally produced. It was thus assumed that there was very little or no difference in the qualities of output from different farms in the area.

4.1.2 Planting Density

The number of trees in tapping or the number of trees per acre currently in production was not recorded in the data. Hence, the number of actual stands per acre, or the planting density, is used as one of the variables. No account is taken of the difference between the number of trees and the number of trees currently in production. Thus there is a somewhat over-estimation of the number of productive trees. The degree of over-estimation will vary mainly according to the age of the trees, and to a lesser extent to the physical condition of the trees. Not all the trees will come into maturity and be ready for tapping at the same time during the first few years of tapping. The percentage of immature trees varies according to the standard of management and soil type. Since this study includes only those trees already in tapping for three years or more, any immature trees by this time would have been considered as unwanted, and could have been removed by the farmer.

As the stand becomes older, all the trees left are assumed to be productive trees. There still exists a small proportion of trees not in tapping, due mainly to physiological disturbance causing dryness of the tapping panels, either temporarily or permanently. However, these are normally very minor cases.

4.1.3 Tapping frequency

The quantity of labour supplied in tapping was recorded as the total number of tapping days per year in the data. No information was available on the number of working hours per tapping day. The number of tapping hours per day is limited mainly by the time during which "turgor pressure" in the bark is sufficiently high, usually from around 6 a.m. to 11 a.m.

No attempt is made to correct the tapping labour input for quality differences, e.g. age, sex, educational level or working experience. The data necessary to do this were not available.

The presence of other crops, especially paddy, means that farm labour input was not confined to rubber alone. Paddy is a labour intensive crop, especially during the planting and harvesting periods. Labour would have been withdrawn from rubber to paddy during these periods, but to what extent this affected the number of tapping days was not known.

A somewhat more accurate measure of tapping labour input could have been the number of times the trees are tapped per year. This could be computed from the following formula*:

$$W = \frac{D.S.T.}{P}$$

where

W is the number of times trees are tapped per year

D is the total number of tapping days per year

S is the task size of a tapper per day, assuming that his task size is constant. A task size is the number of trees a tapper taps in a day.

T is the number of tappers in the holding

P is the total number of trees in the holding

However, the above "refined approach" did not improve the goodness of fit for the present analysis, so it was decided to use the total number of tapping days to represent the tapping frequency. This could be somewhat an over-estimation of the number of times the trees were tapped. With larger holdings, there may be two or more tasks, only one of which is

* This formula was suggested by Dr C. Barlow

tapped on a given tapping day. Thus, just taking "tapping day" to represent tapping frequency means that this input is over-estimated for the larger holdings. However, in this sample, there were very few farms with task size greater than one; hence this over-estimation is probably not a serious error.

It is also assumed that all the farmers had adopted the same type of cut when tapping the trees, that is S/2 system, although this aspect was not adequately recorded.

4.1.4 Farm size

Farm size is the measure of land input in physical units, in acres. It is recognised that there exists qualitative differences between land grades, but such complete specification is not feasible. We define the farm size as the total area of mature rubber stand belonging to one farmer.

4.1.5 Tapping age of the trees

The data had been presented with the assumption that there was no difference in the age of mature trees within each farm. This assumption seems plausible for those farms below 2 acres in size, but it is doubtful whether the "larger" farms had uniform age stand within each farm. However, about 85 per cent of the farms were below 2 acres.

All the farmers were assumed to have obtained grants from the Replanting Board. With the grant, it was most probable that the farmers had planted the whole area at once, rather than in stages.

Commencement of tapping was assumed to be at six years after planting.

4.1.6 Management

In addition to the sampling bias pointed out in Chapter 1, there may be another major form of bias due to the known exclusion of a factor of production - management - from the estimated production function. Consequently, its exclusion from the function involves mis-specification, and it may involve the introduction of "management bias". The problem of management bias (Hoch, 1962; Massell, 1967) arises if both inputs and output are functionally ralated to a farmer's managerial ability. Griliches (1957) has shown that, if the correlation between the true management variable and all the included variables are positive, the relationship will be biased upward, and downward bias will exist for those variables with a negative relationship.

The effect of management bias is illustrated in Figure 4.1. There are a series of observations, B and C, on two types of managers, good and bad, who use production functions F_2 and F_1 respectively. (F_2 and F_1 are linear in logs.) In agriculture, it is generally argued that better managers use more of most inputs. Then, in the absence of information about which observations pertain to good managers, and which to bad, the fitted function would be F rather than the two separate functions F_2 and F_1 which do discriminate between classes of management. That is, the elasticity of output with respect to the input will be over-estimated.

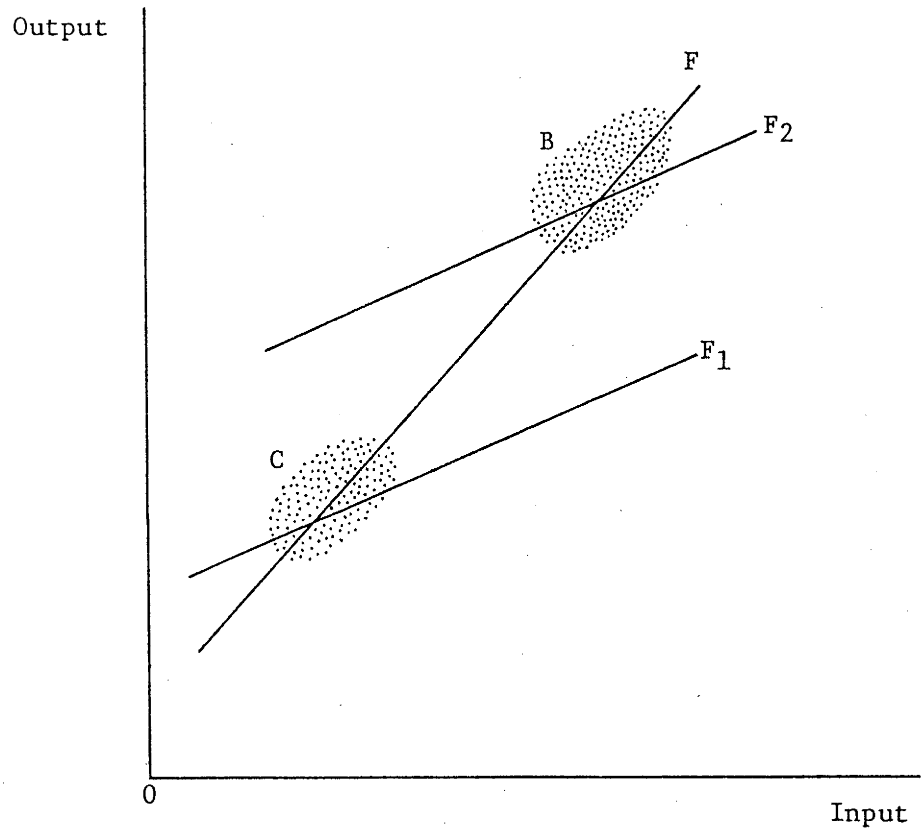
One of the solutions to the problem is the use of a time series of cross-section observations. The statistical technique for the estimation procedure is that of analysis of co-variance. This method of estimation to overcome management bias has been suggested independently by Hoch (1962) and Mundlak (1961). There is no time series observations available for the present data, hence, this technique could not be adopted for the present study.

4.2 Analysis of the Specific Factors Affecting Output

This section is devoted to the discussion of the relationship between each of the selected variables and output per acre. The output of rubber at any one time is the result of simultaneous interactions of all the factors of current, lagged and exogeneous variables. Taken in isolation,

FIGURE 4.1

THE EFFECT OF MANAGEMENT BIAS



the relationship between a specific factor and yield may not be very obvious due to lack of domination and the possible effects of other factors obscuring the picture. Nevertheless, as a first step in the analysis, and as a means of increasing our understanding of the data, the relationship between each pair of factors is examined below. It is hoped that certain relationships may become evident which - when compared to the results of the multivariate analysis of the next Chapter - will lead to a better "feel" for the output-input relationship.

Before going into the output-input relationship, we first test if yield from different rubber clones are different from each other.

Analysis of variance of yield per acre by clone was carried out with the following results:

TABLE 4.1

SUMMARY OF THE ANALYSIS OF VARIANCE: MEAN YIELD BY CLONE

Clone	Mean Yield	Standard Deviations	No. of Observations
PB86	933	287.62	110
Tjir	756	484.48	138
Total	854		248
		F value = 11.462	

F value is significant at 1 per cent level of significance indicating that the true sub-population means are different, and that the means could not have come from the same population.

On this basis the farms are divided into two groups according to their planting materials, namely, budgrafts of clone PB86 and selected seedlings of Tjir 1. A formal test of the effect of different planting materials, using Chow test, will be carried out later.

4.2.1 Bivariate Analysis

Simple correlation provides an immediate picture of the association between two variables. The correlation coefficient indicates the degree to which variation (or change) in one variable is associated with the variation in another. It summarises the strength of a linear relationship between a pair of variables and also provides an easy means for comparing the strength of relationship between one pair of variables and a different pair.

Significant correlation between two variables does not necessarily imply that one is causally related to the other; two variables may move together because some third variable or collection of variables influences both. Likewise, lack of correlation does not necessarily mean that variables are not associated with each other. The association may be non-linear or masked by variations in other variables. With these caveats firmly in mind, the aim of this chapter is to undertake an analysis of the pairwise association between the variables to begin building up a picture of correlation between these variables. Each of these relationships may be obvious under strictly controlled circumstances, that is, when all other factors are held constant. But it needs not follow that when so many factors vary from farm to farm that the relationship will be sufficiently strong to be evident.

This section will establish the extent to which these simple associations are evident. Our prime interest in this study is "to explain" yield per acre in terms of the other variables. Consequently, the correlation coefficients of prime interest will be the top row of each Table. An analysis of the coefficients of the other variables lies outside the scope of this thesis.

Table 4.2a shows the simple correlation coefficients between selected variables of PB86 farms. Each of the associations of tapping age, planting density and tapping frequency with yield is positive and significant at the 1 per cent level of significance. These relationships indicate that for PB86 below the tapping age of ten years, higher yield could be expected from the older trees, the more trees there are to an acre, and the higher the labour input, as represented by the tapping frequency. The negative correlation between farm size and yield indicates that smaller farms generally have higher yield per acre.

The relationship between each pair of the other variables are not significantly different from zero. This indicates that on a pairwise basis, the relationship between yield per acre and each of the variables can be thought of as largely independent from the influence of the other variables.

Approximately 20 per cent of the variance in yield is associated with the planting density; 14 per cent with tapping frequency; and only 9 and 3 per cent with age and farm size respectively. (The proportion of variance "explained" is equal to the square of the correlation coefficient.) Thus in this sample of PB86 smallholders, it appears, at this simple level of analysis, that age of the rubber stand and farm size are less important factors than planting density or tapping frequency in explaining yield.

The simple correlation coefficients between selected variables of Tjir farms are presented in Table 4.2b. Correlation of planting density and yield per acre is significant at 1 per cent level of probability; while the relationship of the other variables with yield are not significantly different from zero.

TABLE 4.2a

SIMPLE CORRELATION COEFFICIENTS BETWEEN YIELD AND THE SELECTED VARIABLES

PB86 farms

Variables	1	2	3	4	5
1. Yield per acre	1.00	0.30*	0.45*	-0.17***	0.38*
2. Tapping age		1.00	0.14†	0.04	0.08
3. Planting density			1.00	-0.15†	-0.05
4. Farm size				1.00	-0.07
5. Tapping frequency					1.00

TABLE 4.2b

Tjir farms

Variables	1	2	3	4	5
1. Yield per acre	1.00	-0.05	0.36*	-0.09	0.12
2. Tapping age		1.00	-0.36*	0.27*	0.09
3. Plant density			1.00	-0.24*	-0.22**
4. Farm size				1.00	0.22**
5. Tapping frequency					1.00

* significant at 1% level of probability

** " " 2% " " "

*** " " 5% " " "

† " " 10% " " "

Unlike the statistics for PB86, there are many significant associations between tapping age, planting density, farm size and tapping frquency. The association between farm size and the age of the rubber stand is positive and significant at 1 per cent level indicating that smaller holdings generally have younger trees. Barlow, Peries et al.(1975) attributed this relationship to the greater difficulties in replanting faced by smaller farmers who were less able to sacrifice current income and thus could not take advantage of the replanting scheme when it was first introduced in the fifties.

In Tjir farms, due to the strong associations between the other variables, there is a possibility of some other variable or collection of variables acting to hide or suppress the relationship between yield and each of the variables. In order to find out if such possibility exists, partial correlation coefficients between yield and each of the variables were computed. It was found that the correlation coefficient between tapping frequency and yield improved from 0.12 (not significant) to 0.21 (significant at 5 per cent level) when the effect of planting density was removed; while there was no significant change in the coefficient of tapping frequency-yield relationship when the effect of tapping age and/or farm size were removed. Therefore, the lack of significance in the simple correlation between yield and tapping frequency was largely due to the masking effect of planting density. However, partial correlation did not improve the age-yield or farm size - yield relationships. Further investigation within a multiple regression production function framework will be discussed in Chapter 5.

To summarise, as we might have expected, the correlation coefficients indicate that for PB86 farms, yield per acre is positively correlated with tapping age, planting density, and tapping frequency respectively, but it is negatively correlated with size of farm. The planting density and farm size are negatively correlated.

In the case of Tjir farms, yield per acre is positively correlated with planting density. Although simple correlation shows that the relationship between yield and tapping frequency is not sifnificant, partial correlation indicates that this lack of relationship may be due to the masking effect of planting density. However, partial correlation shows that there was no change in the lack of relationship between yield and tapping age or yield and farm size, when the effects of the other variables were removed.

We now look at each of the pairwise associations in more detail.

4.2.1.1 Effect of each selected variable on yield

4.2.1.1.1 Yield per acre by age

In order to see the effect of different ages on yield, the farms were grouped into subpopulations according to the various tapping ages of the rubber stand. The summary of the analysis of variance of yield by age for PB86 and Tjir 1 are presented in Table 4.3.

The observed F value for PB86 is significant, indicating that the null hypothesis that the true subpopulation means are equal, and that the deviations which occur are the result of sampling error, can be rejected. However, the null hypothesis cannot be rejected in the case of Tjir 1, because the observed F value is not significant.

The large value of standard deviation of yield for each age indicates a great variability of yield. This is clearly illustrated in the histograms in Figure 4.2a and 4.2b for PB86 and Tjir 1 respectively. The range of yield within each age is very wide; most of them ranging from 500 lbs to 1,300 lbs in an acre.

The coefficients of variations in Table 4.3 indicate that the variations of yield do not differ with different ages of the rubber stand.

The mean yield for each individual age tends to show that, in the early years of tapping, Tjir 1 has higher yield than PB86; after about the fifth year of tapping, the yield from PB86 is consistently higher. The overall mean yield of PB86 is considerably higher than that of Tjir 1.

The mean yields of PB86 and Tjir 1 are presented in Figure 4.3a and 4.3b. The yield for this study refers to the RSS only. For comparison purposes, yields from other sources are presented. These yields are for total rubber output (that is, RSS plus scrap) and they are from commercial estates of Malaysia and Sri Lanka. The yield curve for Tjir 1 from Sri Lanka was not available.

The yield curve for this study does not present a "smooth" curve. One must keep in mind that the data were for smallholder conditions, thus greater variations are expected. In addition, the lower yield for ages 8 and 9 for PB86 could be due to tapping on new panel, or on renewed bark, though this was not recorded in the data.

The mean yields of Tjir 1 seem to be rather "haphazard". The great variation could be partly explained by the fact that Tjir 1 were selected seedlings.

In order to relate the yield per acre to age of the rubber stand, a number of regressions of yield per acre (Y) on age (X) of linear, log linear, and polynomial forms were fitted, and the best fitted regressions are as follows:

Clone	Equation	R^2
PB86	$\ln Y = \ln 5.755 + 0.509 \ln X$ (t = 4.228)	0.12
Tjir 1	$Y = 442.239 + 116.877X - 9.611X^2$ (t = 1.286) (t = 1.386)	0.03

TABLE 4.3

SUMMARY OF THE ANALYSIS OF VARIANCE: YIELD PER ACRE BY TAPPING AGE

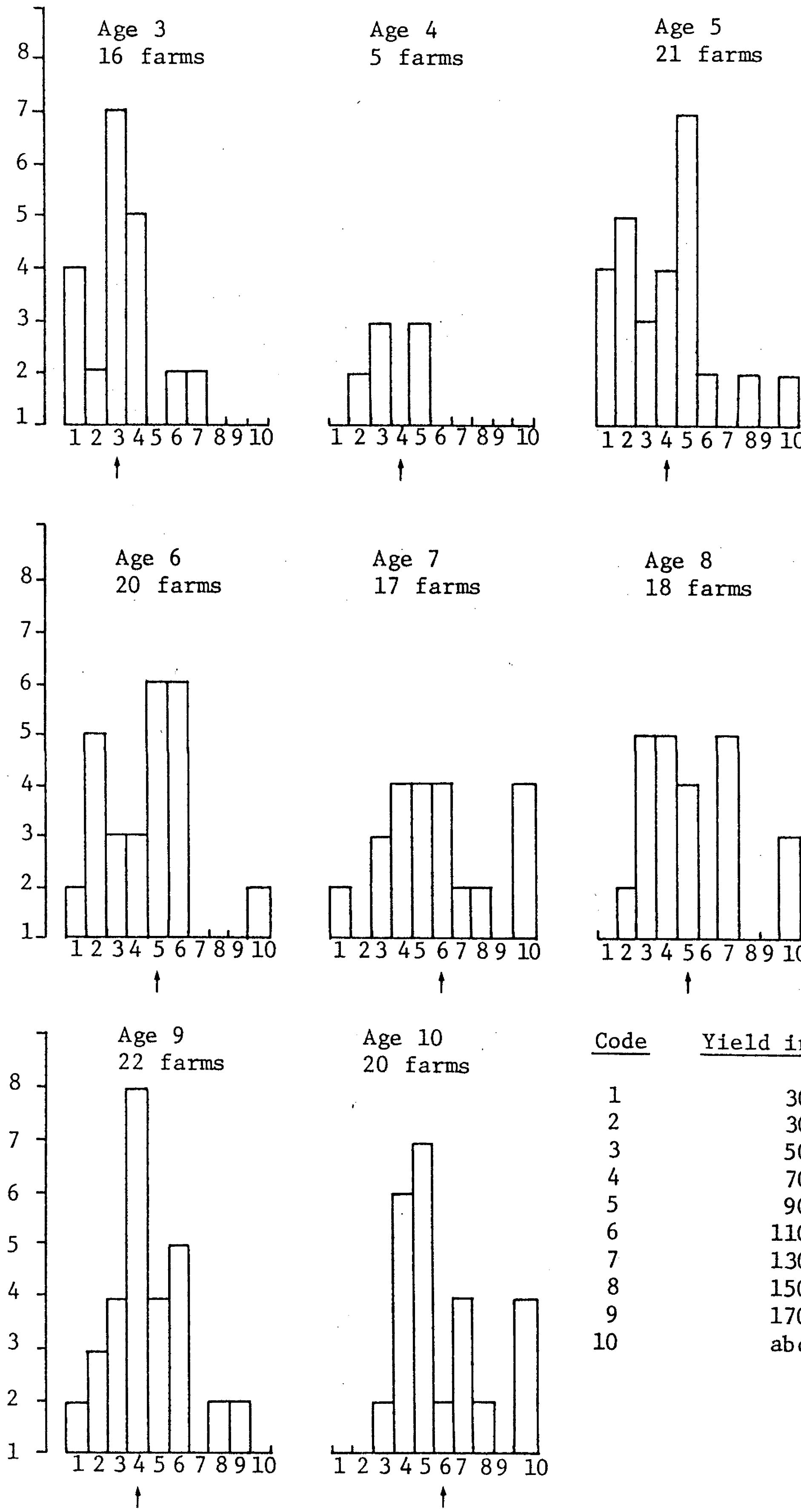
Tapping* age	RUBBER CLONE					
	PB86			Tjir 1		
	Mean yield	Coefficients of variations	No. of observations	Mean yield	Coefficients of variations	No. of observations
3	631 (312)[a]	49	16	792 (349)	44	7
4	718 (273)	38	5	703 (261)	37	15
5	790 (452)	57	21	821 (328)	40	10
6	922 (589)	64	20	781 (327)	42	16
7	1123 (512)	46	17	725 (249)	34	21
8	1050 (466)	44	18	845 (197)	23	17
9	873 (371)	42	22	779 (318)	41	17
10	1219 (494)	40	20	502 (300)	60	7
Total	938 (486)	52	139	756 (288)	38	110
	F value = 3.16			F value = 1.26		

a Figures in brackets denote standard deviations

* Commencement of tapping at six years after planting.

FIGURE 4.2A

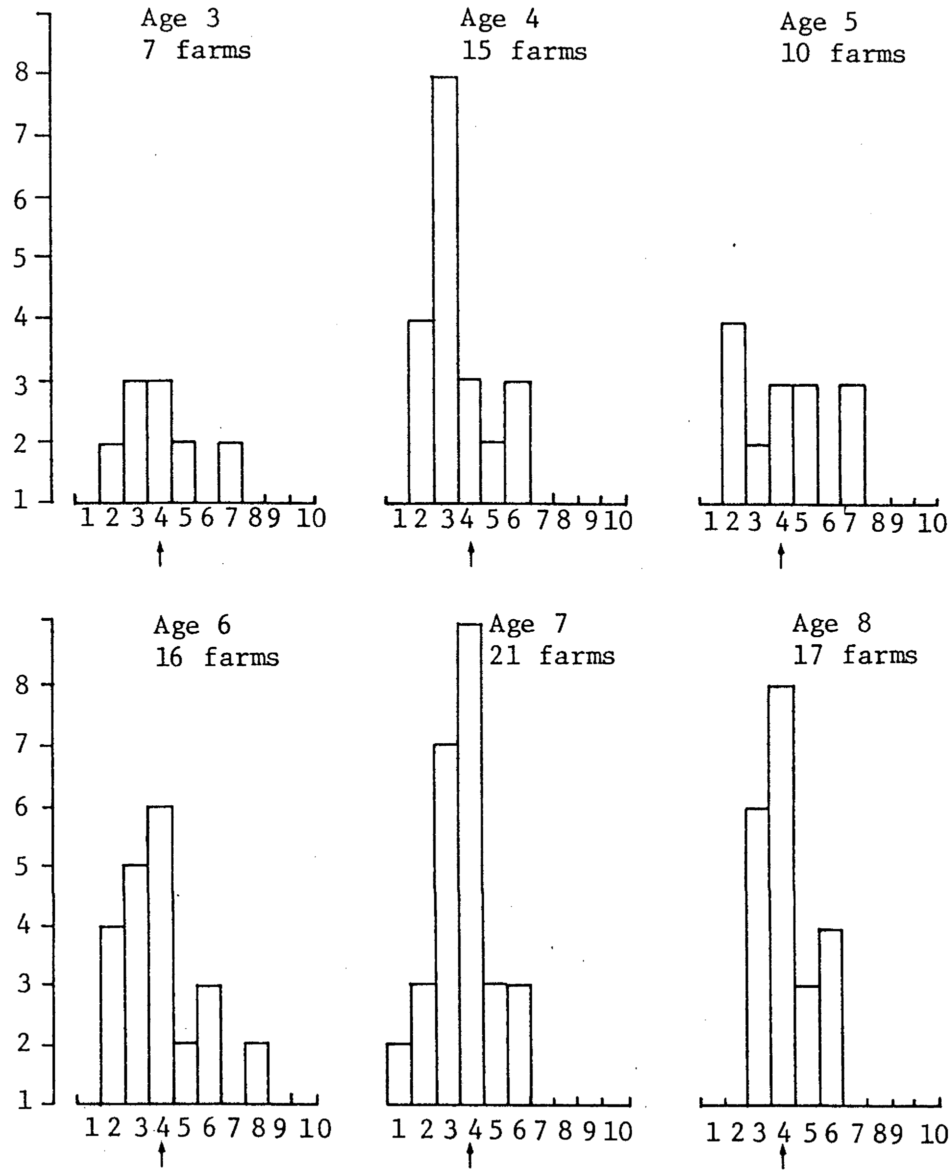
FREQUENCY DISTRIBUTION OF PB86 FARMS:
VARIATIONS OF YIELD WITHIN EACH AGE

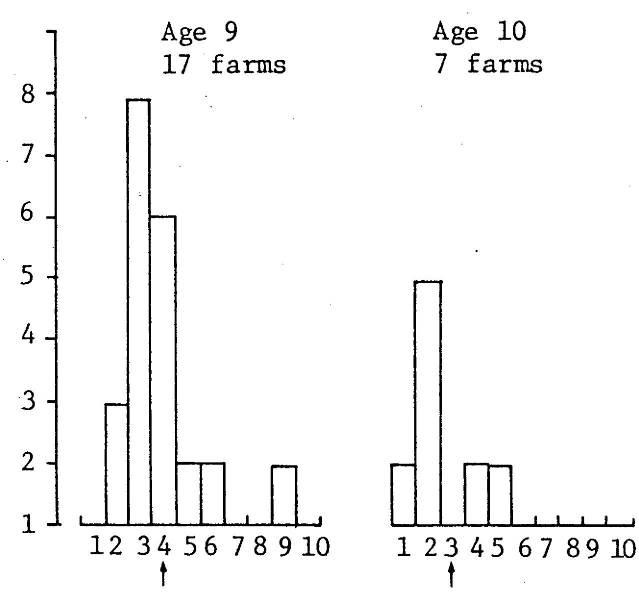


Code	Yield in lbs per acre
1	300 or less
2	301 to 500
3	501 to 700
4	701 to 900
5	901 to 1100
6	1101 to 1300
7	1301 to 1500
8	1501 to 1700
9	1701 to 1900
10	above 1900

FIGURE 4.2B

FREQUENCY DISTRIBUTION OF TJIR 1 FARMS
VARIATIONS OF YIELD WITHIN EACH AGE





Code	Yield in lbs per acre
1	300 or less
2	301 to 500
3	501 to 700
4	701 to 900
5	901 to 1100
6	1101 to 1300
7	1301 to 1500
8	1501 to 1700
9	1701 to 1900
10	above 1900

FIGURE 4.3A

MEAN YIELD OF PB86

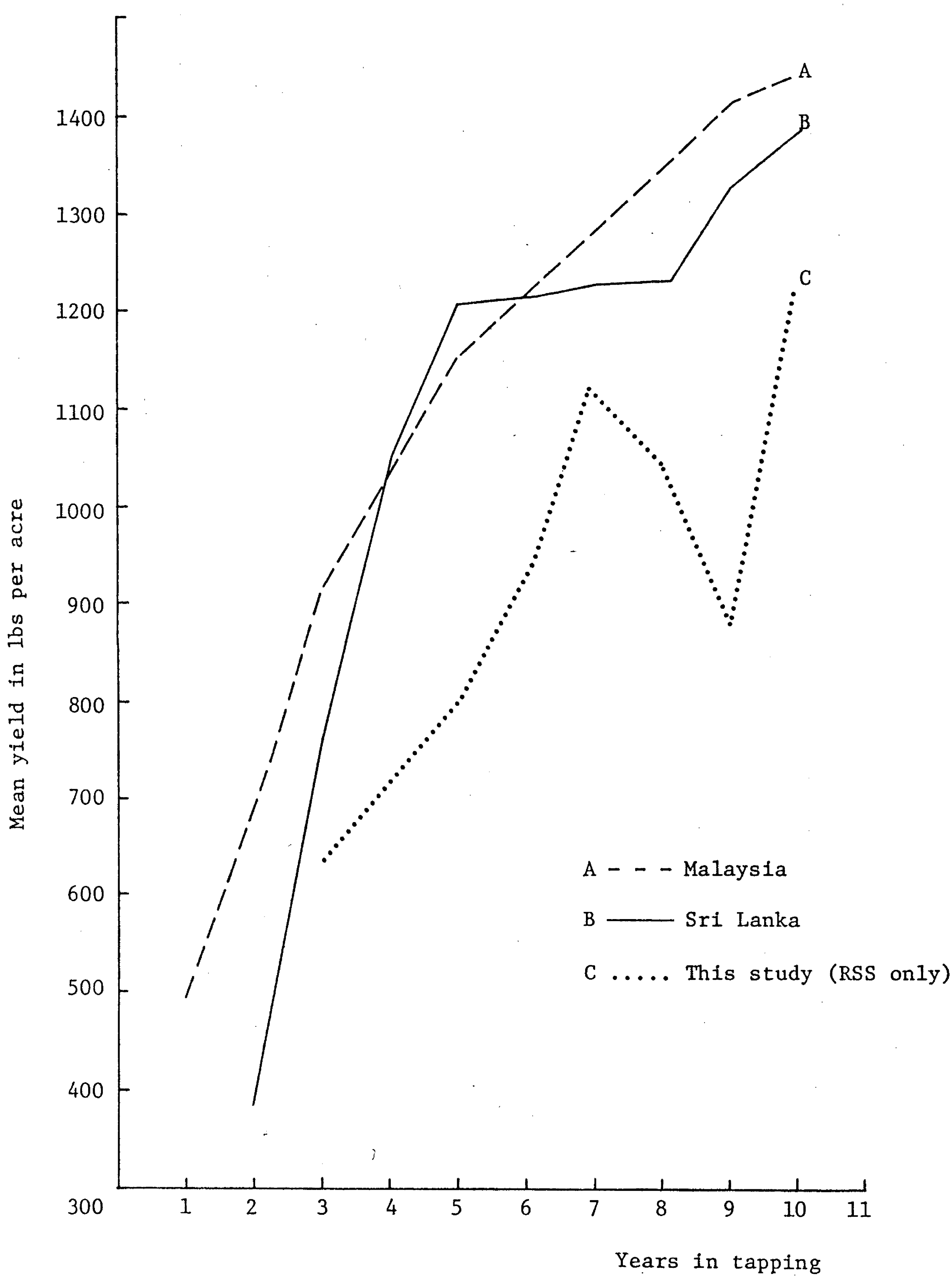
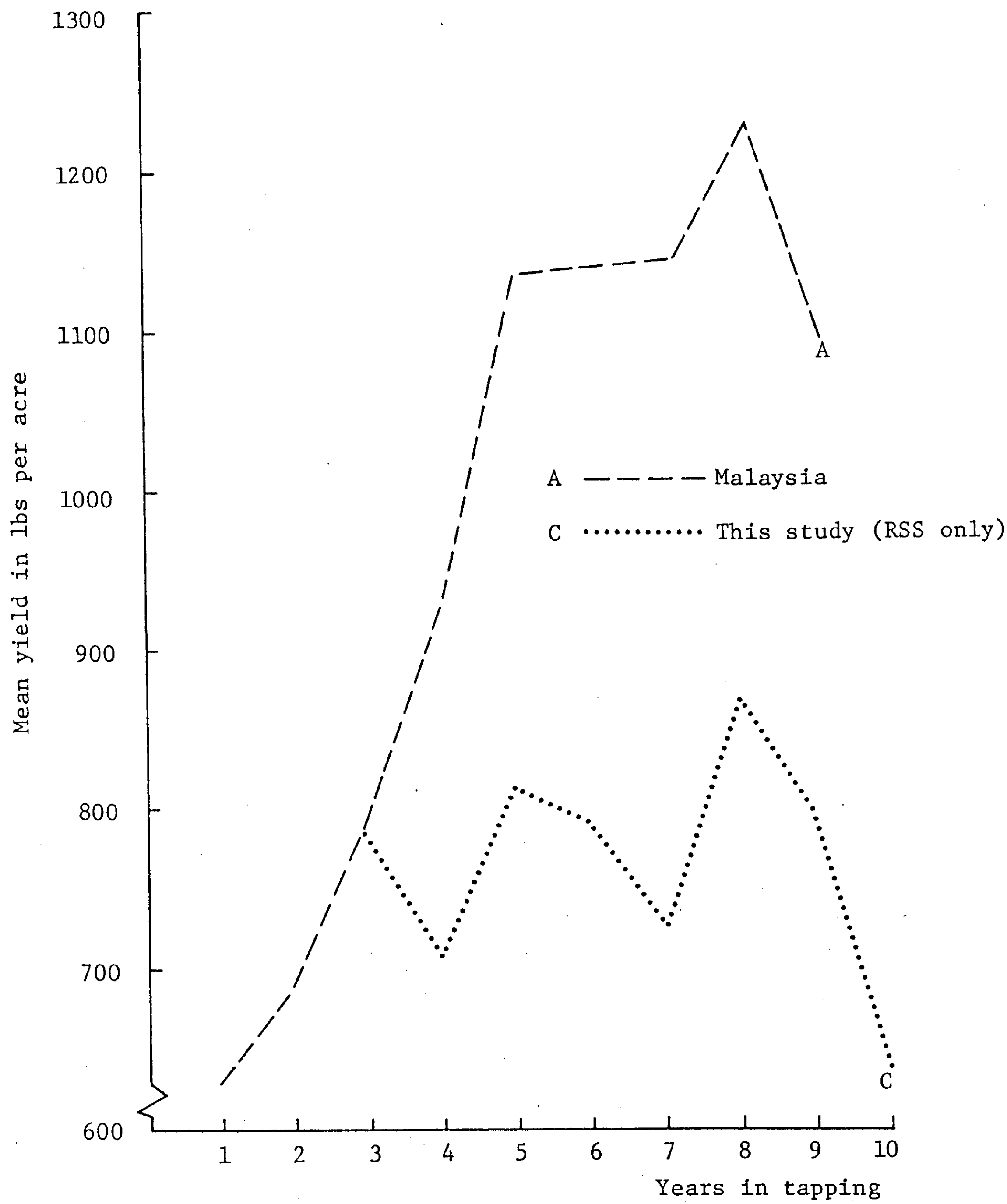


FIGURE 4.3B

MEAN YIELD OF TJIR 1



For PB86, the coefficient is significantly different from unity indicating that yield increases with age, but tends to flatten out as age advances.

For Tjir 1, the coefficients are not significant.

The very low R^2 values, even for PB86 where there is a significant relationship, indicate that the yield may not be strongly related to the age of the tree or other factors such as tapping frequency, planting density and management are obscuring the picture.

4.2.1.1.2 Yield per acre by planting density (Number of trees per acre)

Westgarth and Buttery (1965) observed that there is a positive relationship between number of trees per acre and yield per acre. However, if the density is too high, say over 350 trees in an acre, there is an adverse effect on yield due to late maturity of a high proportion of trees, poor girthing, high incidence of root diseases. In order to see the effect of different planting densities on yield, the farms were grouped into subpopulations according to the various density groups of the trees. The summary of the analysis of variance of yield by planting density for PB86 and Tjir farms is presented in Table 4.4.

It is clear that the range of planting density is very wide, ranging from below 90 trees to over 350 trees in an acre. PB86 has only one farm while Tjir has eleven farms with greater than 290 trees to an acre. About 54 per cent of PB86 farms have between 150 to about 180 trees in an acre, with the rest of the farms quite evenly spread out at both sides of the distribution; while the distribution of Tjir 1 farms is not so distinct. About 75 per cent of the Tjir farms are quite evenly spread out between 150 to 260 trees to an acre, indicating that Tjir farms tend to have comparatively more trees in an acre. This is quite a normal practice in both Sri Lanka and Malaysia.

TABLE 4.4

SUMMARY OF THE ANALYSIS OF VARIANCE: YIELD PER ACRE BY PLANTING DENSITY

Planting density	RUBBER CLONE					
	PB86			Tjir 1		
	Mean yield	Coefficients of variations	No. of observations	Mean yield	Coefficients of variations	No. of observations
Below 90	437 (398)[a]	91	4	302 (0)	0	1
90 to 109	408 (226)	55	3	511 (275)	54	2
110 to 129	467 (177)	38	7	893 (359)	40	2
130 to 149	1045 (437)	42	7	722 (240)	33	6
150 to 169	856 (411)	48	37	665 (262)	39	11
170 to 189	939 (317)	34	37	664 (226)	34	19
190 to 209	800 (308)	38	15	695 (273)	39	14
210 to 229	1329 (664)	50	3	728 (286)	39	16
230 to 249	959 (395)	41	7	948 (237)	25	11
250 to 269	1419 (803)	56	4	768 (188)	24	12
270 to 289	1534 (409)	27	4	727 (354)	48	4
290 to 309	2560[b] (0)	0	1	807 (55)	6	2
310 to 329	-			829 (228)	27	2
330 to 349	-			1210 (0)	0	1
Above 350	-			1053 (480)	45	7
Total	938 (477)	51	139	744 (311)	42	110
	F value = 5.87			F value = 1.85		

a Figures in brackets denote standard deviations.
b This value is a suspect.

FIGURE 4.4a

YIELD PER ACRE BY PLANTING DENSITY: CLONE PB86

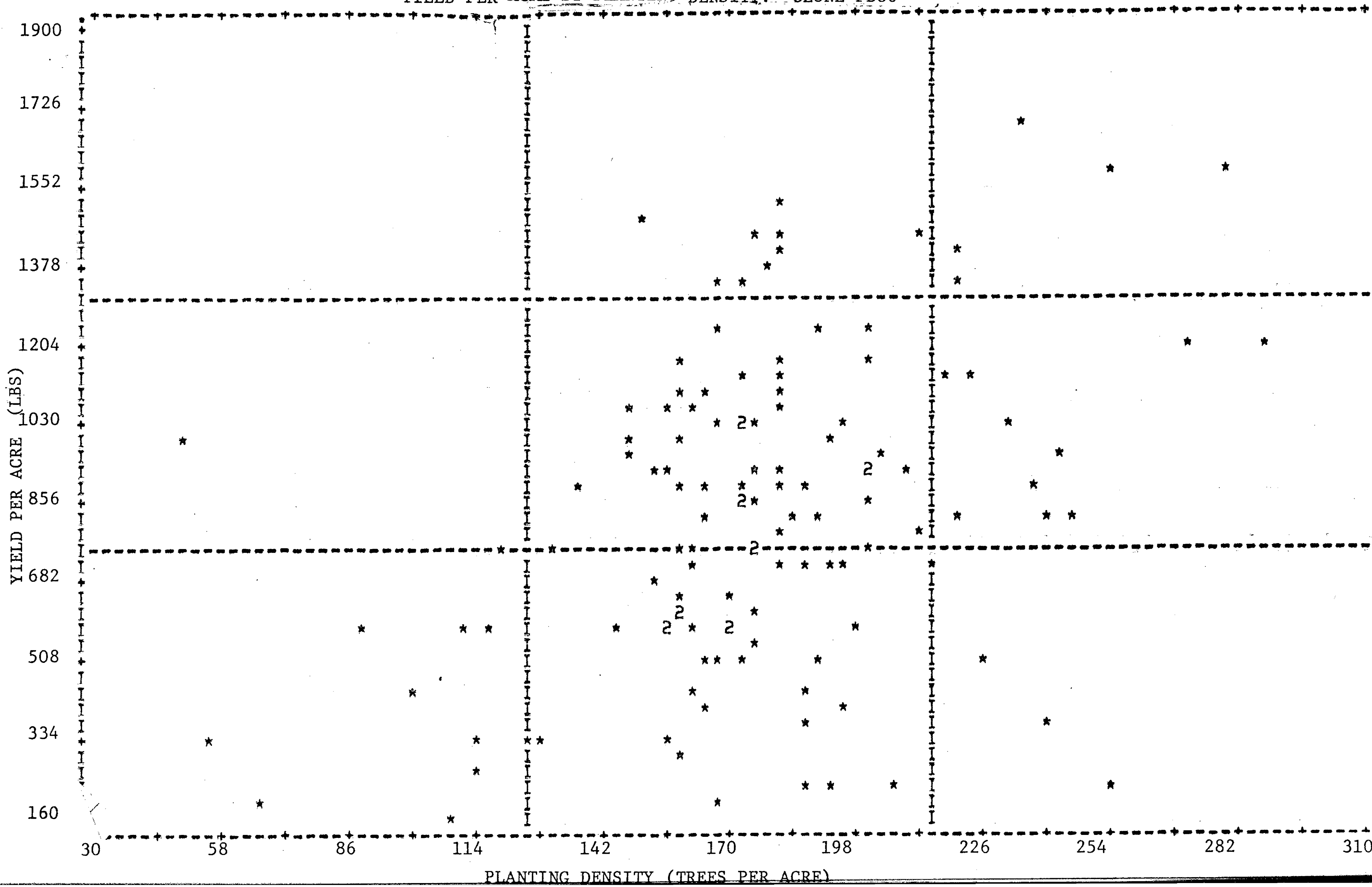
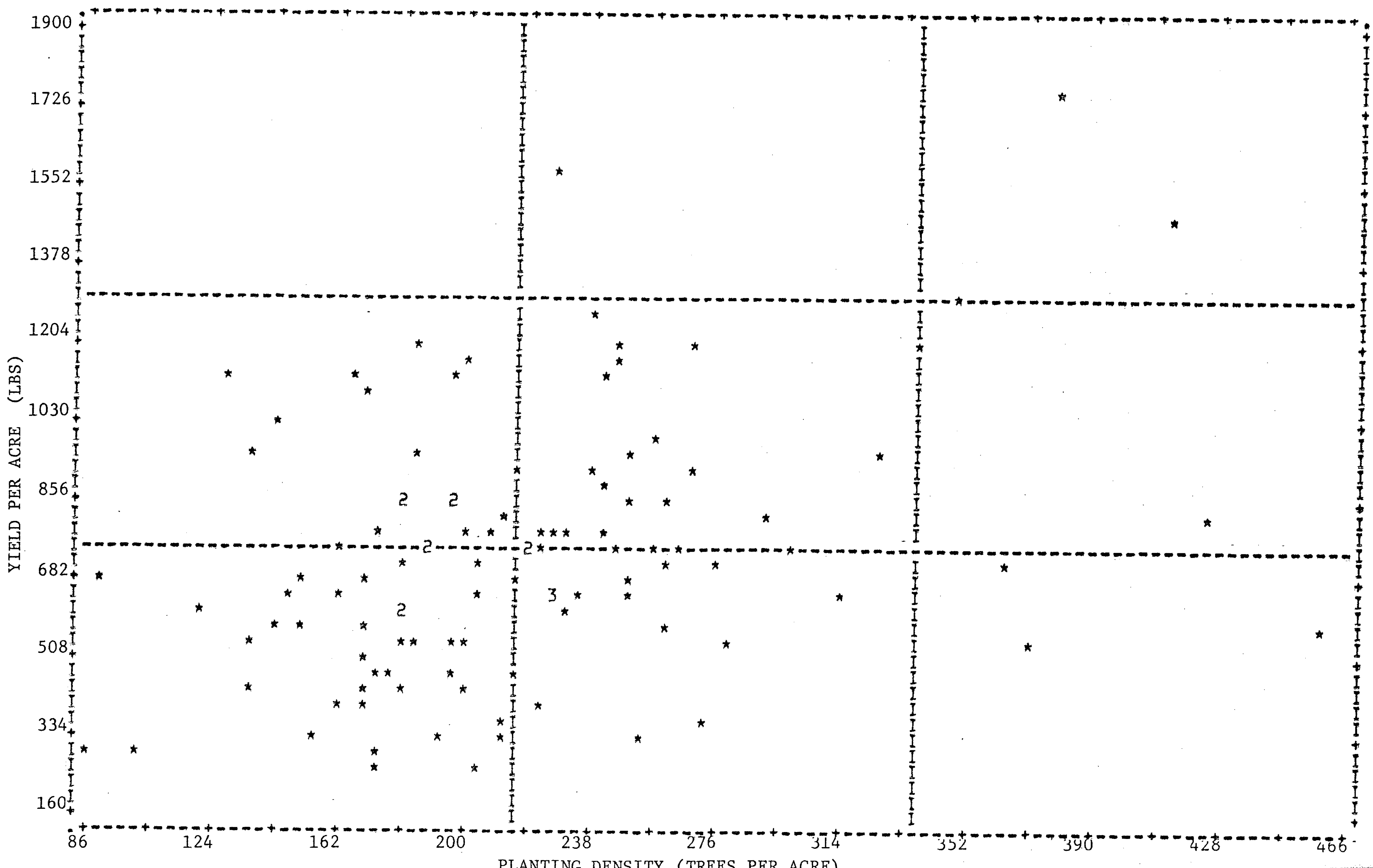


FIGURE 4.4b

YIELD PER ACRE BY PLANTING DENSITY: CLONE Tjir 1



In each case, the F value is significant, indicating that the means of the subpopulations are different from each other. The means reveal that farms with higher density of trees tend to have higher yield per acre. This positive relationship is illustrated in the scatter diagrams of Figure 4.4a and 4.4b which also display the wide dispersion of observations. The coefficients of variations indicate that smallest variations in yield are found in farms with 170 to 210 trees per acre for PB86; and 230 to 270 trees per acre for Tjir 1.

In order to relate the yield, Y, to planting density, X, a number of regressions of linear, log-linear and polynomial forms were fitted, and the best fitted forms are as follows:

Clone	Equation	R^2
PB86	$\ln Y = \ln 4.118 + 0.4997 \ln X$	0.13
	$(t = 4.4315)$	
Tjir 1	$\ln Y = \ln 4.042 + 0.471 \ln X$	0.13
	$(t = 3.986)$	

In both cases, the coefficients are positive and significantly different from unity, indicating that within the range of the sample, yield flattens out as density becomes higher.

The R^2 in both cases are very low, indicating that there are other important explanatory variables which have not been included in the regressions.

4.2.1.1.3 Yield per acre by the tapping frequency (Number of times trees are tapped in a year)

In a short run, the more frequently the trees are tapped, the higher will be the output. Trees do not accumulate latex over time, and rubber not extracted regularly is essentially lost production. However, excessive tapping causes wounding of the trees, leading to fungus attack, brown bast and dryness. A tapping frequency of 200 times a year is considered not excessive. The farms in the sample were divided into subpopulations according to their tapping frequency, as shown in Table 4.5.

It is clear that the range of tapping frequency is very wide, ranging from a minimum of below 70 to a maximum of over 300 times a year. However, in both cases, more than 85 per cent of the farms have tapping frequency of less than 150 times a year; about 50 per cent of the farms have tapping frequency between 110 to 150 times. Thus the tapping frequency of this sample of smallholders was considered to be low. This low frequency could be due to high rainfall in this area, and/or to the fact that the farmers were not full-time rubber tappers. Their other activities include non-rubber crops such as paddy, coconut, and working as labourers in the nearby rubber estates.

The F values shown in Table 4.5 are significant in both cases, indicating that in each case, the means of the subpopulation are different from each other. The means reveal that for PB86 yields increase as the tapping increases, although the relationship is not monotonic; there appears to be no obvious relationship for Tjir farms.

The large values of the standard deviation indicate wide variability of the yield within each subpopulation, and this is illustrated by the respective scatter diagrams (Figure 4.5a and 4.5b) which display the wide dispersion of the data. The coefficients of variations of yields do not differ between groups.

The means also reveal that, in most cases, for the same frequency group, yield from PB86 tends to be higher than that from Tjir; part of this could be due to the effects of other factors such as differences in age, distribution and planting density.

TABLE 4.5

SUMMARY OF THE ANALYSIS OF VARIANCE: YIELD PER ACRE BY TAPPING FREQUENCY

Tapping frequency	Rubber Clones					
	PB86			Tjir 1		
	Mean yield	Coefficients of variations	No. of observations	Mean yield	Coefficients of variations	No. of observations
Below 70	703 (365)[a]	52	14	748 (278)	37	14
70 - 89	576 (355)	62	18	649 (281)	43	12
90 - 109	708 (264)	37	22	742 (311)	42	17
110 - 129	1009 (330)	33	27	782 (326)	42	29
130 - 149	1141 (568)	50	42	762 (252	33	26
150 - 169	1144 (563)	49	7	783 (282)	36	10
170 - 189	1025 (289)	28	4	1147 (0)	0	1
190 - 209	1928 (0)	0	1	795 (0)	0	1
210 - 229	1122 (397)	35	2	-		-
290 - 309	2090 (0)	0	1	-		-
Above 310	1024 (0)	0	1	-		-
Total	938 (471)	50	139	756 (311)		110
	F value = 4.78			F value = 3.07		

a Figures in brackets denote standard deviations.

FIGURE 4.5a

YIELD PER ACRE BY TAPPING FREQUENCY: CLONE PB 86

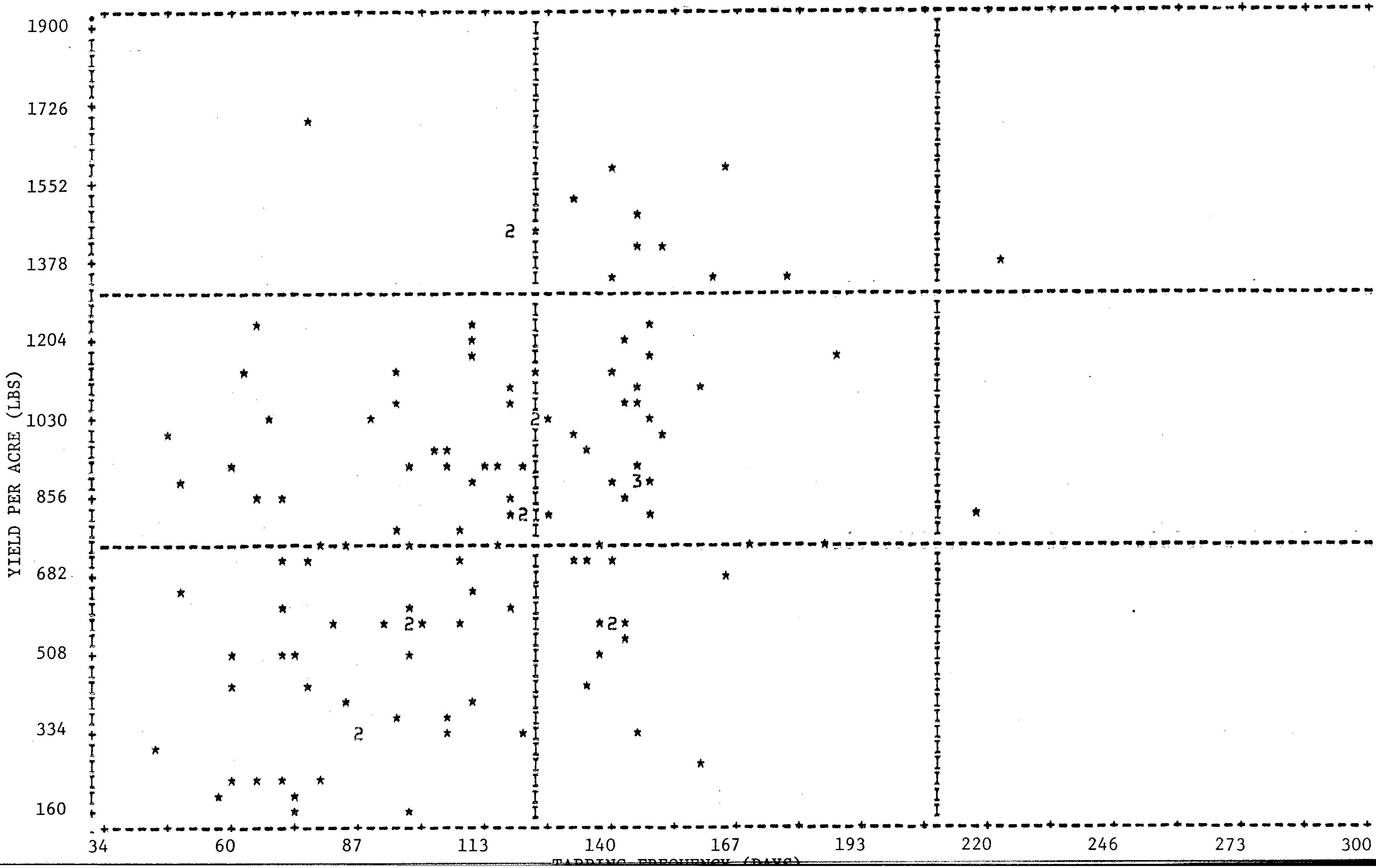
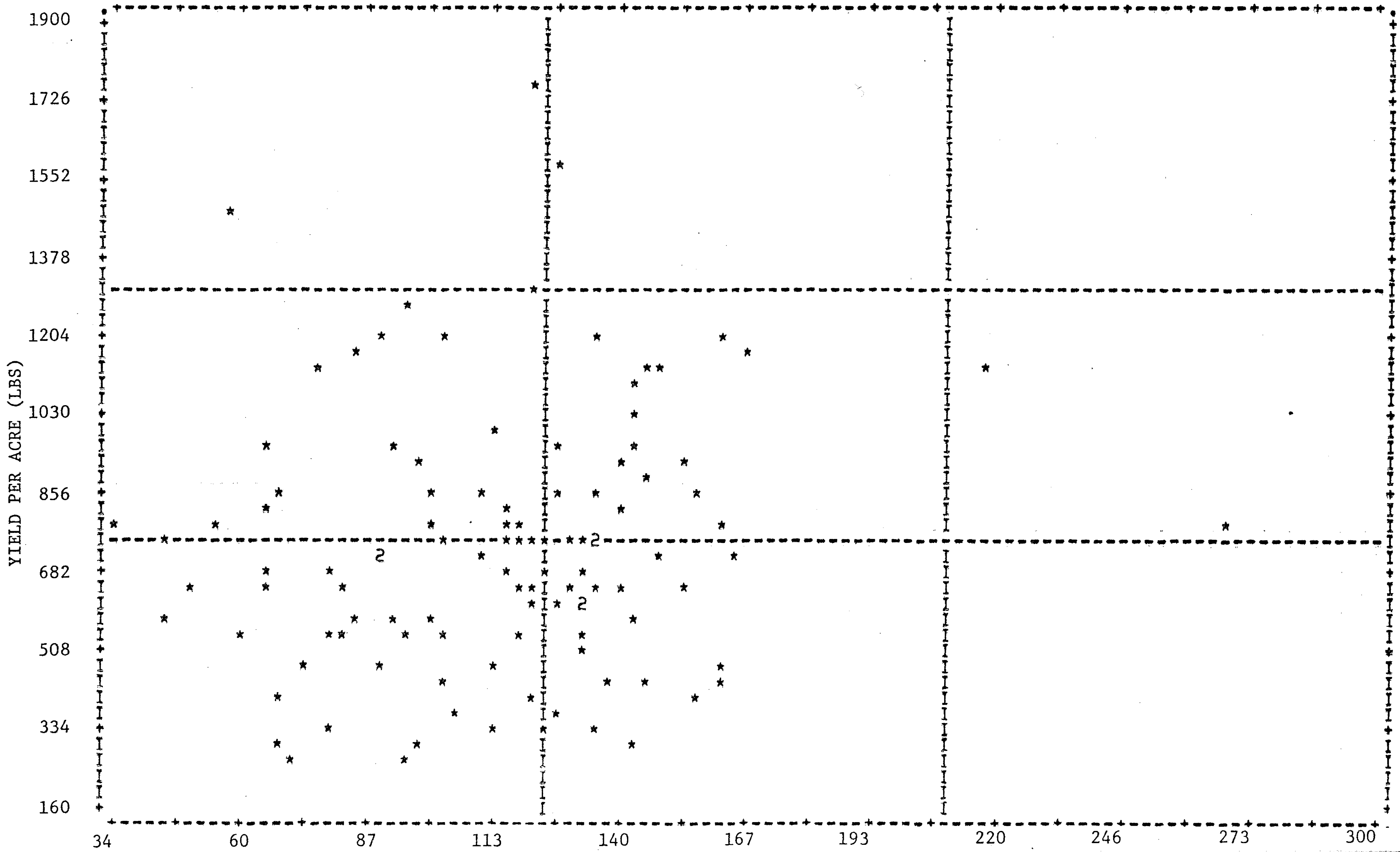


FIGURE 4.5b

YIELD PER ACRE BY TAPPING FREQUENCY: CLONE Tjir 1



A number of simple regression equations of yield per acre, Y, on tapping frequency, X, of linear, log-linear and polynomial forms were fitted in order to determine the general trends of the scatter of observations. The best fitted equations are as follows:

Clone	Equation	R^2
PB 86	$\ln Y = \ln 3.339 + 0.711 \ln X$ $(t = 5.926)$	0.20
Tjir 1	$\ln Y = \ln 6.007 + 0.117 \ln X$ $(t = 1.066)$	0.01

The equation for PB86 shows that the positive coefficient of the independent variable indicates that yield tends to increase with tapping frequency. A t-test reveals that the coefficient is significantly different from unity, indicating that the yield-tapping frequency relationship tends to flatten out as the frequency becomes higher.

The equation for Tjir 1 indicates that relationship between tapping frequency and yield is practically zero. It has been shown in the discussion on bivariate analysis that when the effect of planting density is removed, the relationship between tapping frquency and yield becomes significant. It is hoped that in the multiple regression in the next Chapter this relationship would be brought out clearly.

4.2.1.1.4 Yield per acre by Farm Size

The farms are divided into subpopulations according to different farm size group in order to determine whether different farm sizes have any significantly different yields. Summary of the analysis of variance for PB86 and Tjir farms is presented in Table 4.6.

The striking feature of the sampled group of farms is the large numbers of extremely small farms. More than 70 per cent of the PB86 farms and over 83 per cent of the Tjir farms were less than, or equal to, 2 acres in area. About 39 per cent of the PB86 farms and about 59 per cent of the

TABLE 4.6

SUMMARY OF THE ANALYSIS OF VARIANCE: YIELD PER ACRE BY FARM SIZE

Farm Size in Acres	Rubber Clones					
	PB86			Tjir 1		
	Mean yield	Coefficients of variations	No. of observations	Mean yield	Coefficients of variations	No. of observations
Below 1	795 (337)[a]	42	54	641 (272)	42	64
1.1 - 2	699 (343)	49	43	588 (220)	37	31
2.1 - 3	798 (412)	52	15	652 (305)	54	8
3.1 - 4	702 (380)	54	12	758 (263)	35	4
4.1 - 5	806 (367)	46	9	670 (0)	0	1
5.1 - 6	525 (39)	7	2	735 (85)	12	2
Above 6	1036 (279)	27	4	-		-
Total	762 (352)	46	139	633 (272)	42	110
	F value = 0.974			F value = 0.446		

a Figures in brackets denote standard deviations.

FIGURE 4.6a

YIELD PER ACRE BY FARM SIZE: CLONE PB 86

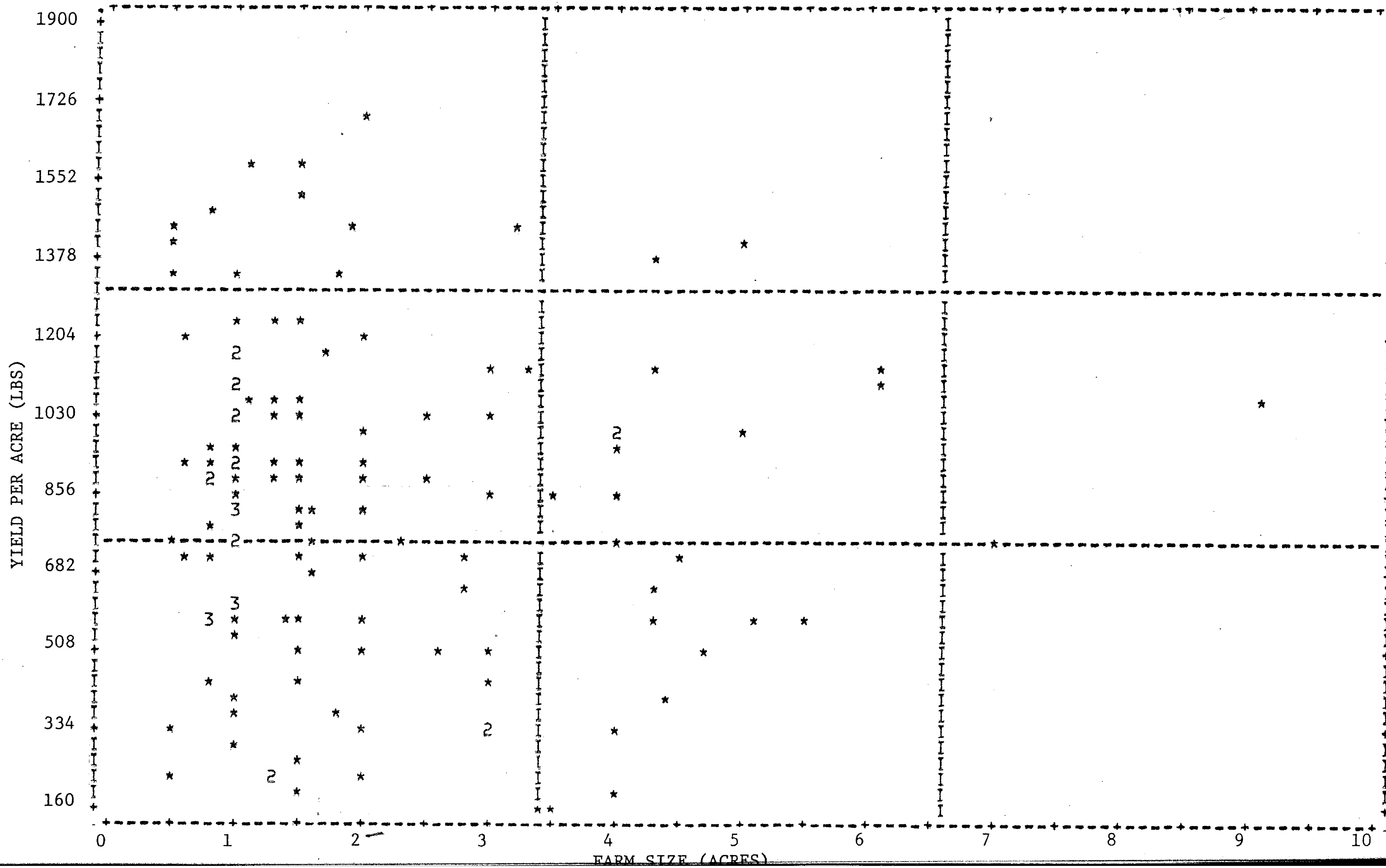
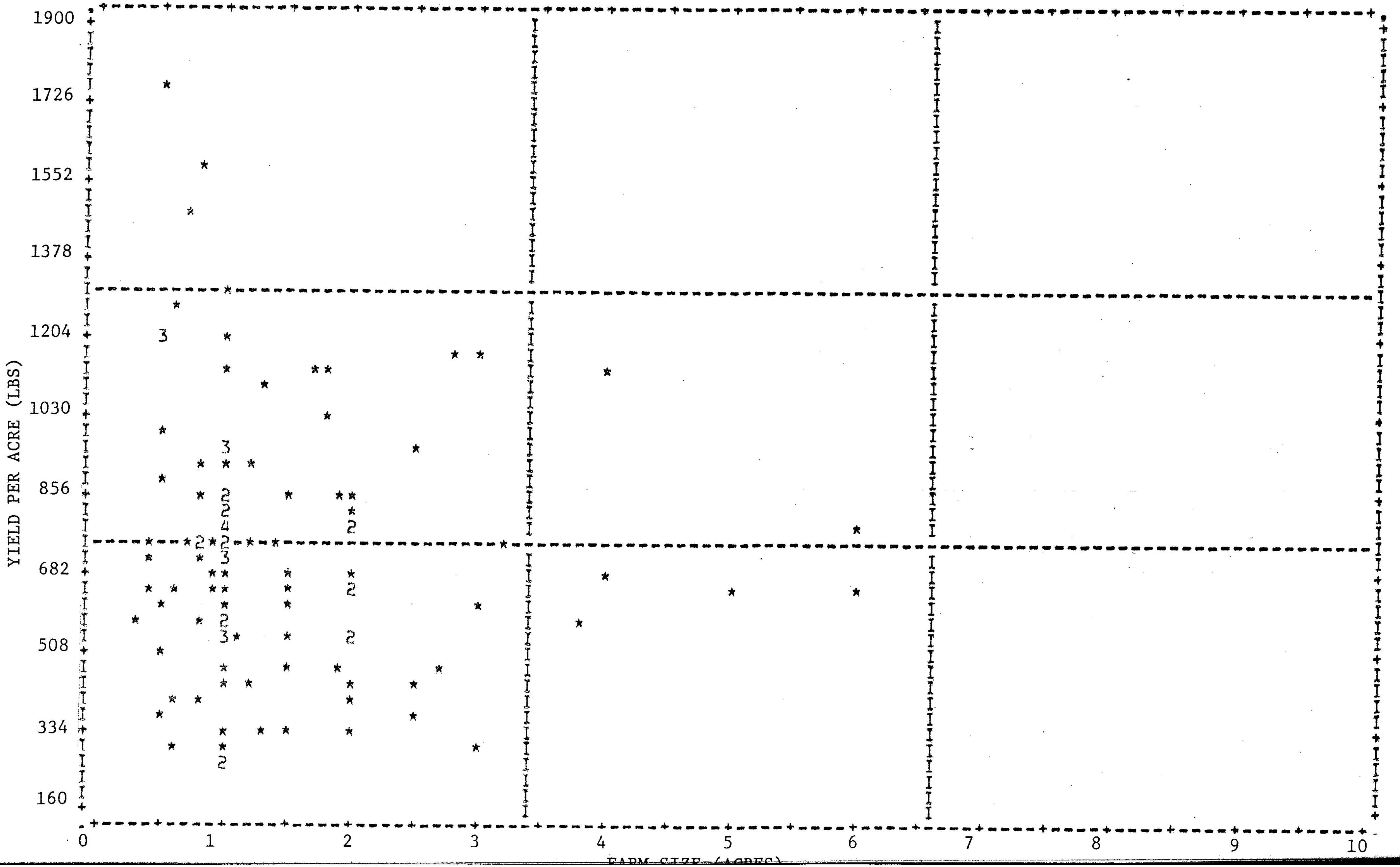


FIGURE 4.6b

YIELD PER ACRE BY FARM SIZE: CLONE Tjir 1



Tjir farms were less than, or equal to, 1 acre in area, which is the estimated national average area of rubber on smallholdings for Sri Lanka (De Silva, 1974). The evidence suggests that Tjir was more popular with the smaller farms. Barlow (1975) attributed this to the great importance placed by the small farms to higher yield of Tjir in the early period of tapping, and the greater resilience and shorter period of immaturity of Tjir.

There is no significant difference in the subpopulation means as confirmed by the non-significance of the F values. The simple correlation discussed earlier has revealed that the relationship between yield and farm size is practically zero. This is also revealed by the randomness in the scatter diagrams, Figure 4.6a and Figure 4.6b.

Results of the regression runs are as follows:

Clone	Equation	R^2
PB86	$Y = 1241.021 - 243.560X + 29.173X^2$ $(t = 1.216)\quad(t = 1.668)$	0.08
Tjir 1	$Y = 871.780 - 121.426X + 18.698X^2$ $(t = 1.511)\quad(t = 1.285)$	0.02

The extremely low values of R^2 in both cases, clearly show the complete lack of goodness of fit; indicating that, in this smallholder situation, yield is not related to farm size.

4.2.1.2 Summary

The above discussion takes into account, one at a time, the effect of tapping age, planting density, tapping frequency, and farm size on yield per acre of farms within the range of the sample. Simple regressions are fitted in each case and the results summarised below:

(i) Yields from PB86 farms are affected by age, but yields from Tjir farms tend to be independent of age effect.

(ii) Yields from both planting materials tend to increase with increasing planting density, but the yields flatten out as density becomes higher.

(iii) Tapping frequency affects yield in the PB86 farms, but yield from Tjir farms tends to show independence from the effect of tapping frequency.

(iv) Farm size has no effect on yield per acre for both clones of rubber.

However, since the above analysis is on bivariate basis, there are possible masking effects of one variable or group of variables on the other, thus suppressing the true relationship between variables.

In the next Chapter, we shall investigate relationship between variables within a multiple regression framework.

CHAPTER 5

EMPIRICAL PRODUCTION FUNCTION

5.1 Modified form of Cobb-Douglas function

In this study on rubber, which is a perennial crop, age is an important factor affecting output. Once the tree is planted, the manager can do nothing to influence age. The effect of age on output has been discussed earlier (see page 50).

One way to account for the effect of different age on output is to fit a separate function for each age group. Unfortunately, small sample size within each age group, varying from five farms to twenty-two farms, (Table 4.3), does not permit us to adopt this method. Hence, in order to take into account the effect on output due to differences in age of the rubber stand, dummy variables were employed to represent age. The dummy variable will assume the value of one for a particular age concerned, and zero otherwise.

Zero-one variables are employed here in the same context as those employed with quarterly observations in the analysis of "seasonal" variation. The observations can, from a technical point of view, be divided into separate classes (ages). However, the division is somewhat arbitrary. For example, the "true" age of the tree may run from the month of May of one year, to the next, while the constructed age from calendar year data runs from January to December.

In addition, yearly observations provide a lumpy picture, while the "true" changes are probably of a continuous nature. These problems do not preclude the use of dummy variables. However, they do suggest that care be exercised in interpreting such analysis as "true" age effects.

With the inclusion of dummy variables for age, equation 2.1 is rewritten as:

$$q_j = b_0 x_{1_j}^{b_1} \text{----} x_{i_j}^{b_i} \text{----} x_{n_j}^{b_n} e^{a_1 d_1 + \text{----} + a_f d_f} U_j \qquad .....(5.1)$$

where

e is log to the base e,

d_f is 1 or 0 dummy variable representing each age f

(f = 1, 2,----, g)

a_f is the parameter associated with the dummy variable of the respective age.

U_j is the error term.

In log linear form, this modified Cobb-Douglas function can be written as:

$$Q_j = b_0 + \sum_{i=1}^{m} b_i \, x \, i_j + \sum_{f=1}^{g} a_f d_f + U_j \qquad .....(5.2)$$

It has been decided in Chapter 4 that the variables to be included in the equation are:

x_1 the planting density,

x_2 farm size,

x_3 tapping frequency,

d_f the age of the rubber stand (dummy variable).

Assuming for the moment that the other variables are redundant, we could write the estimating equation for this study according to age as:

$$\left.\begin{array}{cl}
\underline{\text{Tapping Age}} & \underline{\text{Equation}} \\
1 & Q_1 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + a_1d_1 + U_1 \\
2 & Q_2 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + a_2d_2 + U_2 \\
3 & Q_3 = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + a_3d_3 + U_3 \\
\cdot & \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
\cdot & \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
\cdot & \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
\cdot & \cdot \quad \cdot \quad \cdot \quad \cdot \quad \cdot \\
g & Q_g = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + a_gd_g + U_g
\end{array}\right) \quad \ldots\ldots(5.3)$$

The assumption made here is that the production elasticities of planting density, farm size, and tapping frequency, are not associated with the age of the rubber stand, but rather that age affects the constant term, or the efficiency parameter. In other words, the effect of the age difference is to change the level (intercept) of the regression without changing the slope coefficients.

5.2 Test for Significant Difference in Clone Effect

It has been suggested from our discussion in Chapter 3 and the analysis of variance of yield by clone in Chapter 4, that the yielding capacity of PB86 and Tjir 1 are very different from each other. We now carry out a formal test for differences in clone effect.

First, we run a regression of output on the selected variables for the whole sample. We then divide the sample into two groups, based on the different clones. Therefore we obtain two estimates of the same relationship for two different clones of rubber. They are:

(a) PB86 as represented by the subscript

$$Q_\rho = b_{0_\rho} + b_{1_\rho} x_{1_\rho} = b_{2_\rho} x_{2_\rho} = b_{3_\rho} x_{3_\rho} + \sum_{f=3}^{10} a_{f\rho} d_{f\rho} + U_\rho$$

(b) Tjir 1 as represented by the subscript τ

$$Q_\tau = b_{0_\tau} + b_{1_\tau} x_{1_\tau} + b_{2_\tau} x_{2_\tau} + b_{3_\tau} x_{3_\tau} + \sum_{f=3}^{10} a_{f\tau} d_{f\tau} + U_\tau$$

Are the two estimated functions significantly different? Do the efficiency parameters differ between clones ($b_{0_\rho} \neq b_{0_\tau}$)? Does the coefficient for each factor input differ between clones ($b_{i\rho} \neq b_{i\tau}$)? Does the coefficient of the age effect differ ($a_{f\rho} \neq a_{f\tau}$)? Or is the difference not significant, so that it may be attributed to chance, in which case we may conclude that output from these two clones do not differ significantly in this sample of smallholders?

To answer these questions, we may perform the F test suggested by Chow (1960). We form the F ratio:

$$F^* = \frac{R_p - (R_a + R_b) \quad /K}{(R_a + R_b)/(N_a + N_b - 2K)} \qquad \text{.....(5.4)}$$

where

R_p is the Error Sum of Squares (ESS) of the "pooled" equation;

R_a is the ESS of PB86 equation;

R_b is the ESS of Tjir 1 equation;

K is the total number of yield variables, including the intercept;

N_a is the number of observations for PB86;

N_b is the number of observations for Tjir 1.

The null hypothesis is $b_{1\rho} = b_{1\tau}$ and $a_{f\rho} = a_{f\tau}$, that is, there is no difference in the coefficients obtained from the two samples.

We then compare the observed F* ratio with the tabulated value of $F_{0.05}$ with $v_1 = K$ and $v_2 = (N_a + N_b - 2K)$ degrees of freedom, which is the expected value for F if the null hypothesis were true.

5.2.1 Results of the Chow Test

The coefficients of ages 3 and 4 were found to be almost zero and t values were completely not significant; in subsequent regression analysis, only age 5 onwards will appear as separate variables. Any effects of ages 3 and 4 will be incorporated in the constant term. The other a_f associated with zero-one variables indicate the deviations of the other age intercepts from this base. The summary of the regression results of the pooled samples is presented in Table 5.1.

Table 5.1 also presents the summary of the results of regressions for each clone. The F values indicate that the overall regression coefficients are significant at 99% level of significance.

From the results of the above regressions, we can now test the null hypothesis that there is no difference in the coefficients obtained from the two different clones. We have:

$$R_p = 42.45$$
$$R_a = 12.12$$
$$R_b = 11.99$$
$$K = 10$$
$$N_a = 138$$
$$N_b = 110$$

Substituting the above values in the equation 5.4, we have:

$$F^* = \frac{42.45 - (12.12 + 11.99)/10}{(12.12 + 11.99)/(110 + 138 - 20)}$$

$$= 17.33$$

Tabulated value of $F_{0.01}$ with 10 and 229 degrees of freedom is 2.32. Therefore, we reject the null hypothesis, and accept that the two functions based on different clones do differ significantly.

TABLE 5.1

SUMMARY OF THE ESTIMATED COEFFICIENTS AND THE RELATED STATISTICS

INPUT	POOLED DATA		CLONE PB86		CLONE Tjir 1	
	Coefficient	t value	Coefficient	t value	Coefficient	t value
Planting density	0.5078 (0.0894)	5.680	0.6786 (0.0970)	6.996	0.4235 (0.1301)	3.255
Farm size	0.8935 (0.0425)	21.023	0.8268 (0.0419)	19.733	0.9086* (0.0623)	14.584
Tapping frequency	0.7390 (0.1238)	5.969	0.9367* (0.1177)	7.958	0.3911 (0.1863)	2.099
Age dummy year 5	0.1773 (0.0997)	1.778	0.1321** (0.1044)	1.265	0.1572** (0.1332)	1.180
6	0.2596 (0.0957)	2.713	0.3354 (0.1074)	3.123	0.1553** (0.1770)	1.327
7	0.2806 (0.0943)	2.976	0.3891 (0.1090)	3.570	0.0860** (1.1089)	0.710
8	0.3380 (0.0971)	3.481	0.2300 (0.1069)	2.152	0.2887 (0.1175)	2.457
9	0.2825 (0.0949)	2.977	0.2317 (0.1055)	2.196	0.2859 (0.1243)	2.300
10	0.4067 (0.1044)	3.895	0.4100 (0.1038)	3.950	-0.1978** (0.1649)	1.200
Constant	0.1343		-1.4976		2.2523	
R^2	0.72		0.83		0.76	
Regression SS	107.2987		58.5936		38.7848	
Error SS	42.4556		12.1203		11.9971	
F Ratio	67.1289		63.386		35.92	
No. of observations	248		138		110	

* Not significantly different from unity.
** Not significantly different from zero.

Figures in brackets denote Standard Deviation.

TABLE 5.2a

SIMPLE CORRELATION COEFFICIENTS BETWEEN SELECTED VARIABLES OF PB86

	Variables	1	2	3	4	5	6	7	8	9
1.	Planting density	1.00	-0.17	0.06	-0.03	-0.08	-0.04	0.09	0.06	0.08
2.	Farm size		1.00	0.05	-0.08	-0.10	0.09	0.06	0.11	-0.12
3.	Tapping frequency			1.00	-0.13	-0.10	0.04	0.13	0.76	0.02
4.	Dummy age 5				1.00	-0.17	-0.16	-0.16	-0.18	-0.17
5.	6					1.00	-0.15	-0.16	-0.18	-0.17
6.	7						1.00	-0.14	-0.16	-0.15
7.	8							1.00	-0.17	-0.16
8.	9								1.00	-0.18
9.	10									1.00

TABLE 5.2b

SIMPLE CORRELATION COEFFICIENTS BETWEEN SELECTED VARIABLES OF TJIR 1

	Variables	1	2	3	4	5	6	7	8	9
1.	Planting density	1.00	-0.29	-0.02	0.04	-0.02	0.11	-0.01	-0.20	-0.33
2.	Farm size		1.00	0.16	-0.10	-0.01	0.01	0.16	0.24	-0.02
3.	Tapping frequency			1.00	0.08	-0.01	-0.12	0.13	-0.14	0.08
4.	Dummy age 5				1.00	-0.13	-0.15	-0.13	-0.13	-0.08
5.	6					1.00	-0.20	-0.18	-0.18	-0.11
6.	7						1.00	-0.21	-0.21	-0.13
7.	8							1.00	-0.18	-0.11
8.	9								1.00	-0.11
9.	10									1.00

5.3 Multicollinearity

In the application of Least Squares, a crucial condition is that the explanatory variables are not perfectly correlated. When some of the explanatory variables in a relation are so highly correlated that it becomes difficult to measure their separate influences on the explained variable, we have the problem of multicollinearity, and the method of Least Squares breaks down. For cases where the explanatory variables are highly but not perfectly correlated, the variance of the estimator will be large, thus losing the significance or efficiency of the estimation Johnston 1963). Although multicollinearity is usually connected with time series, it is quite frequent in cross-section as well.

The simple correlation between the variables included in the production function indicates the degree of collinearity between them. Heady and Dillon (1961) have suggested that in agriculture, correlation coefficients greater than 0.8 are considered high. When the correlation is high for two or more factors, they should be combined and considered as one type of input. Tables 5.2a and 5.2b show the correlation coefficients of the variables in estimation of the production functions for PB86 and Tjir 1 respectively. In both cases, we notice that the problem of multicollinearity does not arise at all.

5.4 Average Production Function: Estimated Coefficients and the Related Statistics

The estimated coefficients and the related statistics have been summarised in Table 5.1.

The value of R^2 represents the amount of variation in output that can be explained by the independent variables operating jointly. The closer the R^2 value is to unity, the better the model explains the data. Table 5.1 shows that $R^2 = 0.83$ for PB86, indicating that 83 per cent of the variation in output in PB86 is explained by planting density, farm size, tapping frequency and various ages operating jointly. R^2 for Tjir is 0.76, indicating that 76 per cent of the variation in output in Tjir is explained by the inputs in the equation. The "unexplained" portion of variance in total product can be partly attributed to variations between farms in respect to techniques employed or management, soil differences and weather conditions. Part of the variance not "explained" by input of resources may also grow out of errors in reporting the original data (see Page 14).

The overall test uses the statistical inference procedures to test the null hypothesis that the multiple correlation is zero in the population from which the sample was drawn. The F value is the ratio of the regression mean squares to the residual mean squares. The F value is 63.386 for PB86 and 35.92 for Tjir; both are highly significant at all plausible levels of significance, indicating that it is unlikely that the sample was drawn from a population in which the input factors, as a whole, have no influence on the output.

The individual production coefficients were tested by a two-tail t-test. In the case of PB86, the coefficient of dummy variable for age 5 is not significantly different from zero. In the case of Tjir 1, the coefficients for dummy variables for ages 5, 6, 7 and 10 are not significant. The coefficients for tapping frequency for PB86 and farm size for Tjir 1 are not significantly different from unity. Their implications will be discussed later.

5.4.1 Production Elasticities

The production elasticity of each input indicates the expected percentage change in the output which will, on the average, result from a one per cent change in the input, with other input levels held constant.

In the following section, we shall discuss the details of practical implications of each of the production elasticities.

5.4.1.1 Production Elasticity of Tapping Frequency

The production elasticity of tapping frequency for PB86 was not significantly different from unity, indicating that, within the range of the sample, PB86 farms could be expected to double output if the tapping frequency was doubled, with other input levels held constant. In other words, constant marginal returns was indicated for tapping frequency in PB86 farms.

In the case of Tjir farms, the output could be expected to increase by only 39 per cent if the tapping frequency was doubled, indicating a diminishing marginal return.

Figure 5.1 shows the effect of tapping frequency on yield, with all other input levels of both clones (including age) being held constant at the level of Geometric mean of PB86. It is clear that with frequency above 70 days per year the curve for PB86 lies above that of Tjir, and the slope of PB86 curve is steeper than that of Tjir, indicating that for every per cent increase in tapping frequency, we could expect a higher output from PB86 than from Tjir 1. This tends to confirm the overall higher yielding capacity of PB86.

5.4.1.2 Production Elasticity of Planting Density

The production elasticity of planting density indicated that if the planting density was increased by one per cent, PB86 farms could be expected to increase output by about 0.68 per cent, while Tjir farms could increase output by about 0.42 per cent; indicating a decreasing marginal return in both cases.

Figure 5.2 shows the effect of planting density on yield, with all other inputs of both clones, including age, being held constant at the levels of Geometric mean of PB86. The curve for PB86 lies above that of Tjir, indicating that within the range of the sample output from PB86 could be expected to be higher than that from Tjir for every per cent increase in planting density.

FIGURE 5.1

EFFECT OF TAPPING FREQUENCY ON YIELD
WITH OTHER INPUT LEVELS HELD CONSTANT

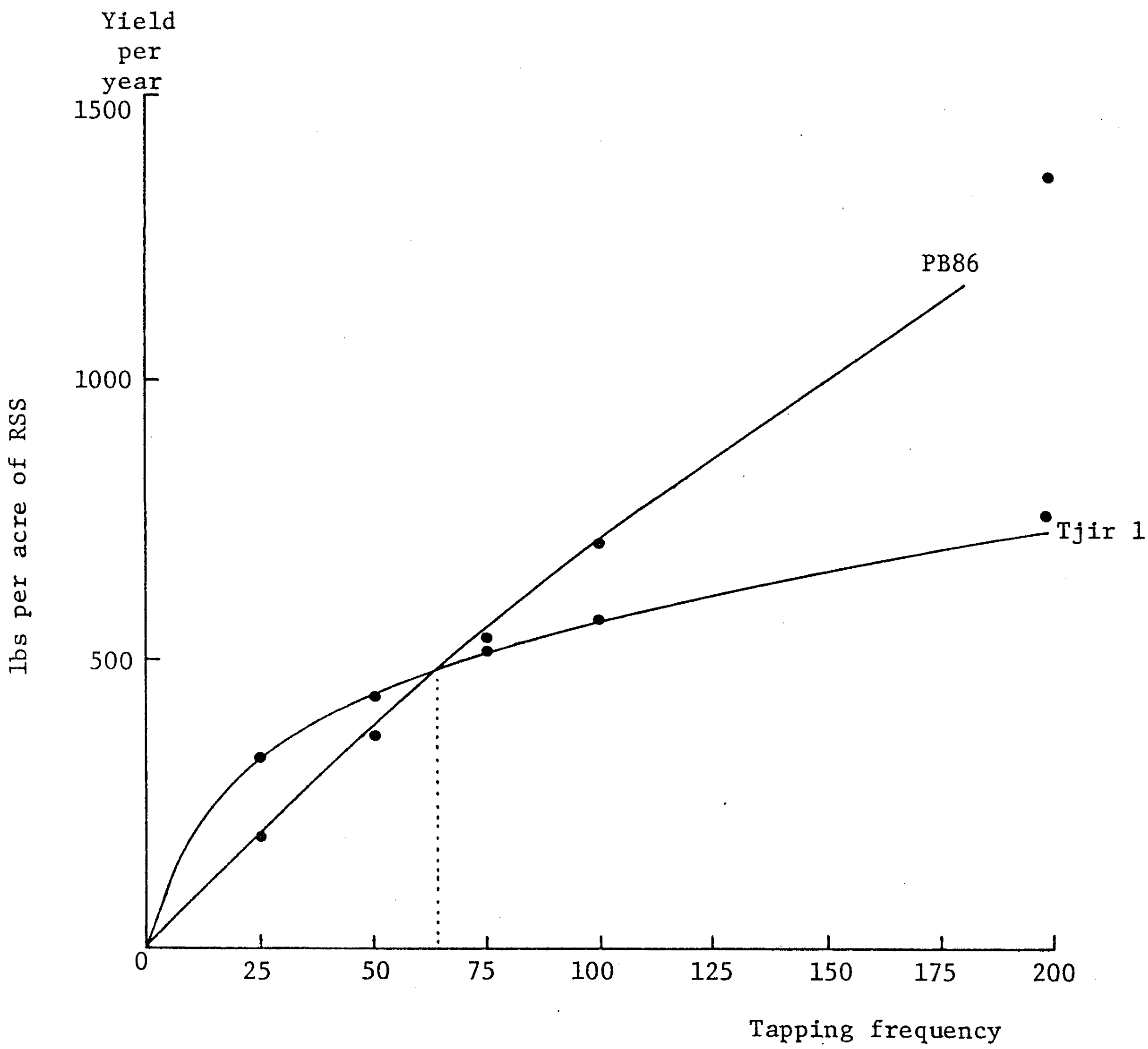
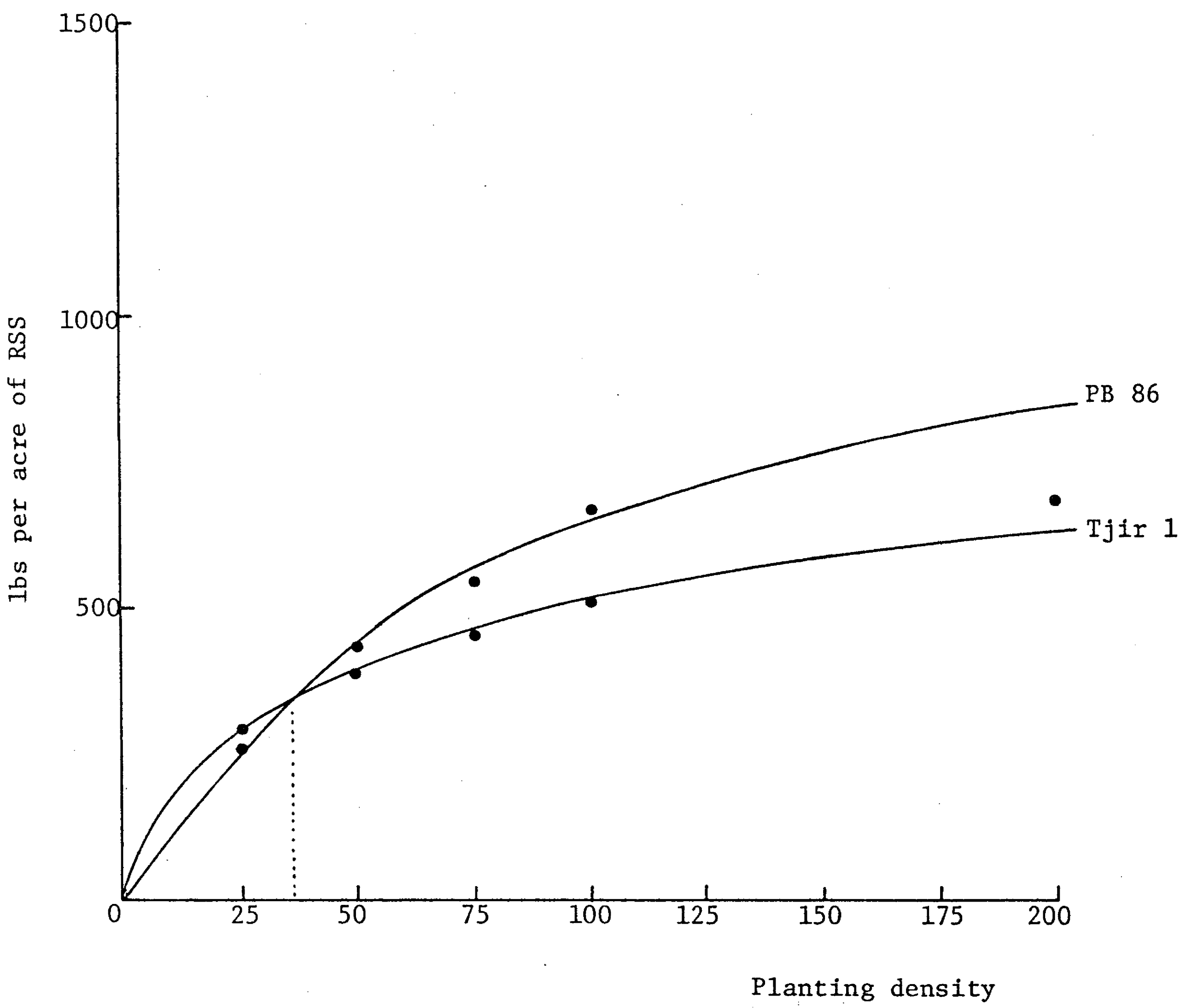


FIGURE 5.2

EFFECT OF PLANTING DENSITY ON YIELD
WITH OTHER INPUT LEVELS HELD CONSTANT



5.4.1.3 Production Elasticity of Farm Size

The production elasticity of farm size for Tjir farms is not significantly different from unity, indicating a constant marginal return, that is, output could be expected to increase by 100 per cent if the farm size could be doubled. In the case of PB86 farms, the output could be expected to increase by about 83 per cent if the farm size could be doubled, indicating a decreasing marginal return.

In general, in the Cobb-Douglas function, the sum of the production elasticities indicates the nature of returns to scale: if the sum of the exponents exceeds unity, there are increasing returns to scale; if it is less than one, decreasing returns to scale; while if the sum is equal to one, there are constant returns to scale.

However, in this modified form of Cobb-Douglas function in this present study, by virtue of the way the inputs have been defined, the concept of returns to size is more relevant. Since the production elasticity of farm size of Tjir farms is not significantly different from unity, the probability that Tjir farms exhibit constant returns to size cannot be rejected. The production elasticity of farm size of PB86 farms is significantly different from one, hence exhibiting a decreasing return to size. From the social point of view this tends to imply that under the smallholder conditions, there is no advantage in increasing the existing farm size.

5.4.1.4 Production Elasticities of Age Factors

Dummy variables have been employed to represent age factors in this study. The effects on yield by trees of ages 3 and 4 have been incorporated in the constant term of the equation. The effects of other ages, i.e. ages from 5 to 10, will appear as deviations of the age intercepts from this base, assuming that age of the trees is not related to other factors which may include farm efficiency.

For PB86, the antilog of the coefficient of age 6 dummy variable converts to 1.40, indicating that the output of rubber from a 6 year old stand is expected to be about 40 per cent greater than that from a 3 or 4 year old stand of the same clone. The output from other ages can be computed in a similar manner.

Using the coefficients estimated and the values of geometric means of each of the variables, the predicted yields per acre for different ages for each clone were calculated and presented in Table 5.3.

TABLE 5.3

PREDICTED YIELD IN LBS PER ACRE OF RSS

Clone	Years in Tapping							
	3	4	5	6	7	8	9	10
PB86	687	687	784	961	1014	865	866	1035
Tjir 1	622	622	728	726	678	830	828	510

Smooth curves could be drawn through these yield points as illustrated in Figure 5.3a or its alternative interpretations in Figures 5.3b, 5.3c, for Clone PB86 and Figure 5.4a or its alternative interpretations in Figures 5.4b, 5.4c, for Clone Tjir 1.

Figure 5.3a shows that the yield of PB86 first rises sharply and reaches a peak of about 1,000 lbs of RSS after 6 years of tapping. Thereafter, the yield declines to about 850 lbs at about 9th year, but picks up again after this decline.

Figure 5.4a shows that the yield of Tjir 1 rises sharply for the first 4 years and levels off between 5th and 6th years, rises again to a peak of about 900 lbs of RSS at about 9th year and thereafter drops sharply.

An alternative interpretation is illustrated in Figures 5.3b, and 5.4b. In both cases, the yield rises sharply for the first 5 years of tapping, reaches a peak on the 6th year, and then declines steadily thereafter.

The change in yield between 6 to 10 years could be due to change in tapping panel; it could be due to tapping on the first renewed bark; or it could even be due to a change in the tapping system. Unfortunately, the data do not show such a conclusion. Other alternatives are possible.

There is a possibility that declining yields for the comparatively older trees could be the accumulated effects of plant mortality or reduction in tapping frequency. However, Tables 5.4a and 5.4b reveal that in this sample, the mean of planting density and tapping frequency for both clones do not differ significantly for different ages (F values are not significant). Hence, declining yield may not be due to these effects.

Another alternative bypothesis is that technology was vintage specific. The farms with younger trees may have "better" planting materials in the sense that there is some constant level of technical progress embodied in the relevant vintage. Another way by which the younger stand could be "better" is that the farmers who plant later might have learnt from the mistakes of the farmers who have planted earlier or have access to information which was not available earlier. Consequently, we may have for every farm or group of farms for every year, or group of years, a separate yield curve and the curves are pivoted by the age effect. The younger trees have higher yield curve than the older ones. Thus, instead of a single production function, there exists a family of production functions depicting various efficiency levels, as illustrated in Figures 5.3c and Figures 5.4c. They may be more representative of the true situation than in Figures 5.3a, 5.3b or Figures 5.4a, 5.4b.

FIGURE 5.3A

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: PB 86 (BUDGRAFTED)

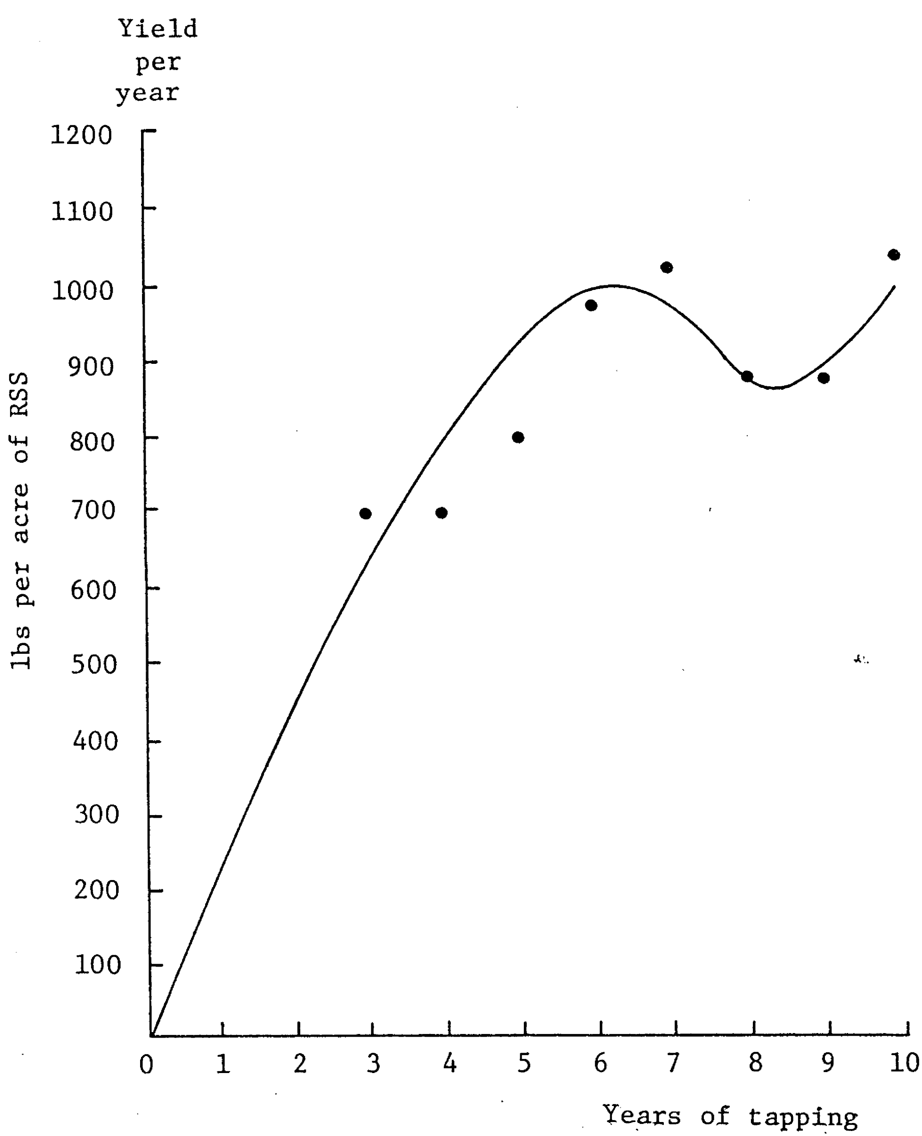


FIGURE 5.3B

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: PB 86 (BUDGRAFTED)

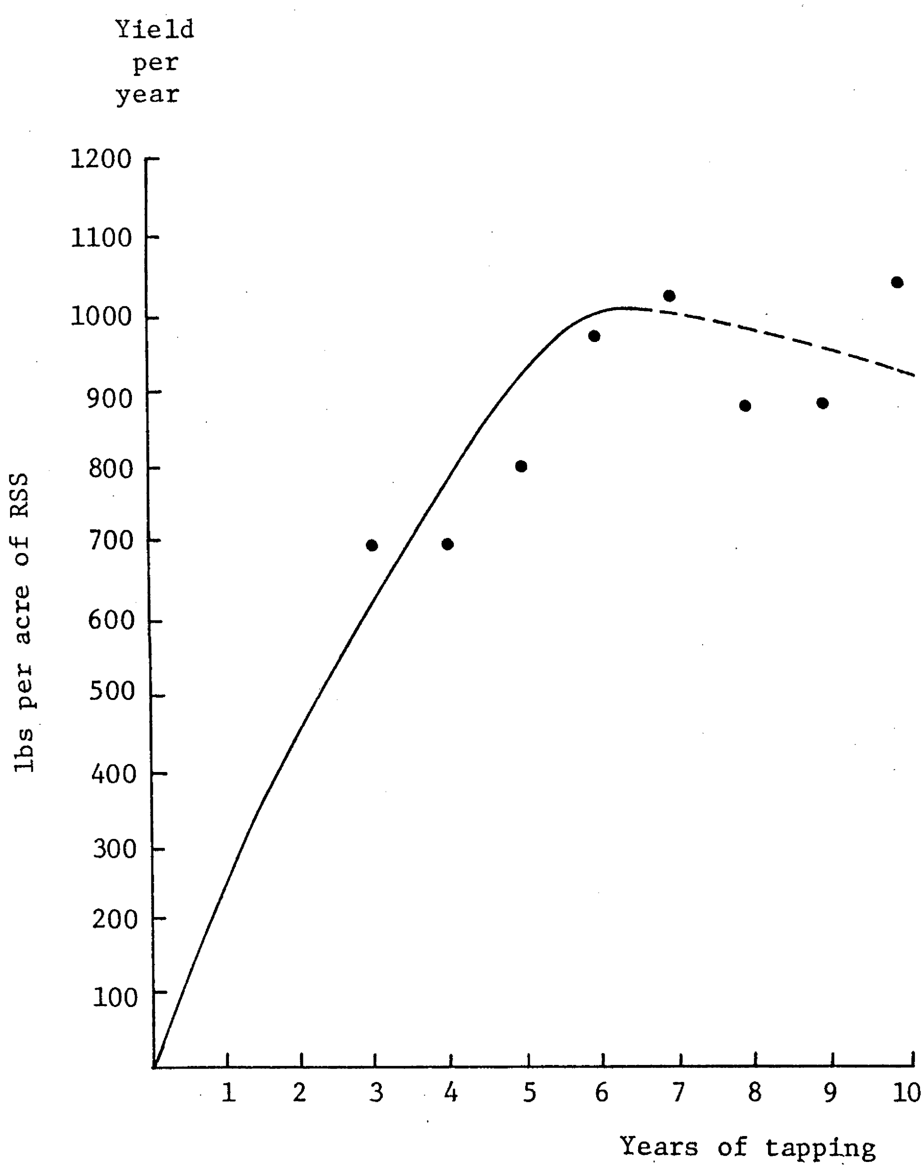


FIGURE 5.3C

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: PB 86 (BUDGRAFTED)

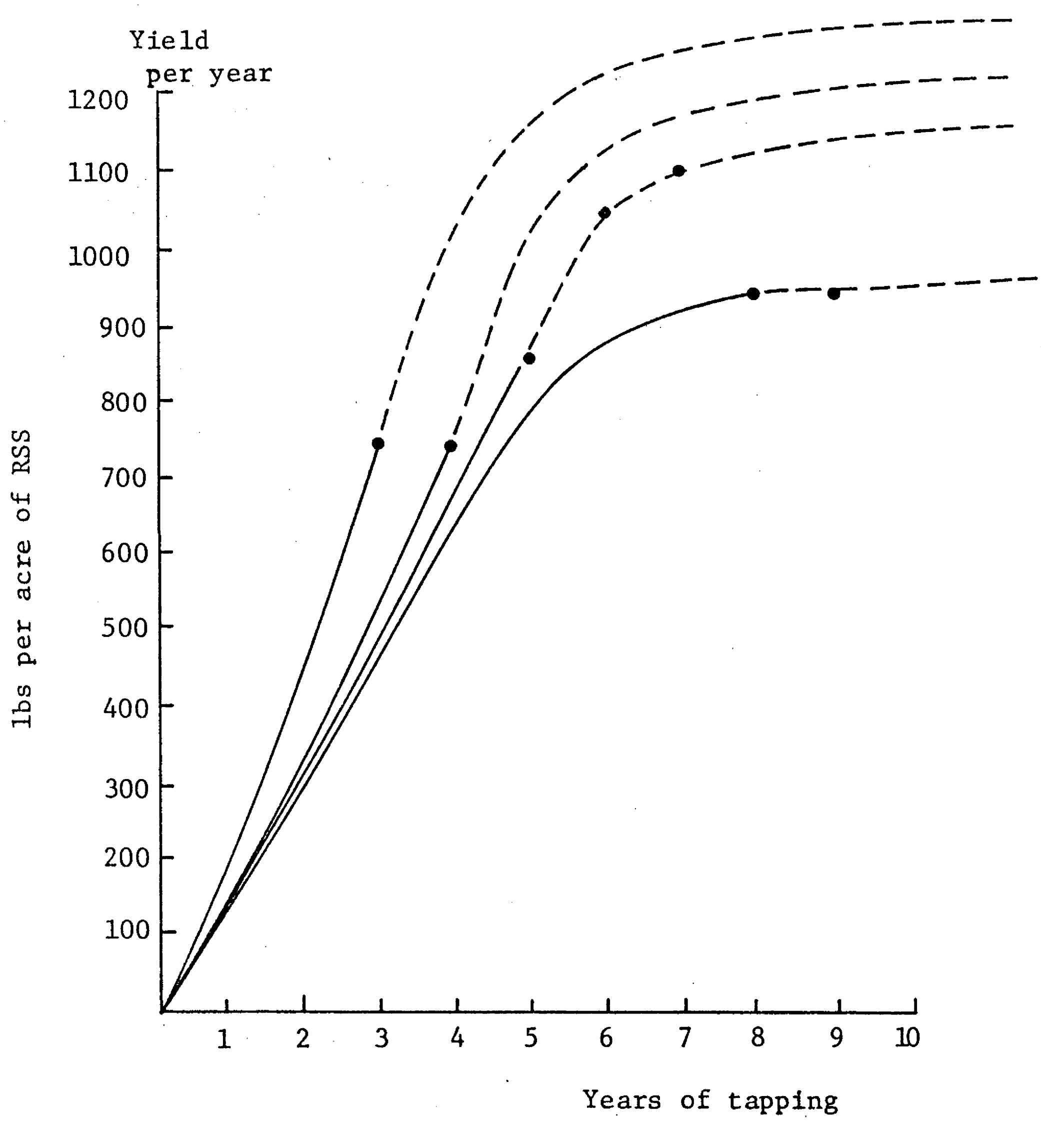


FIGURE 5.4A

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: Tjir 1 (C.S.)

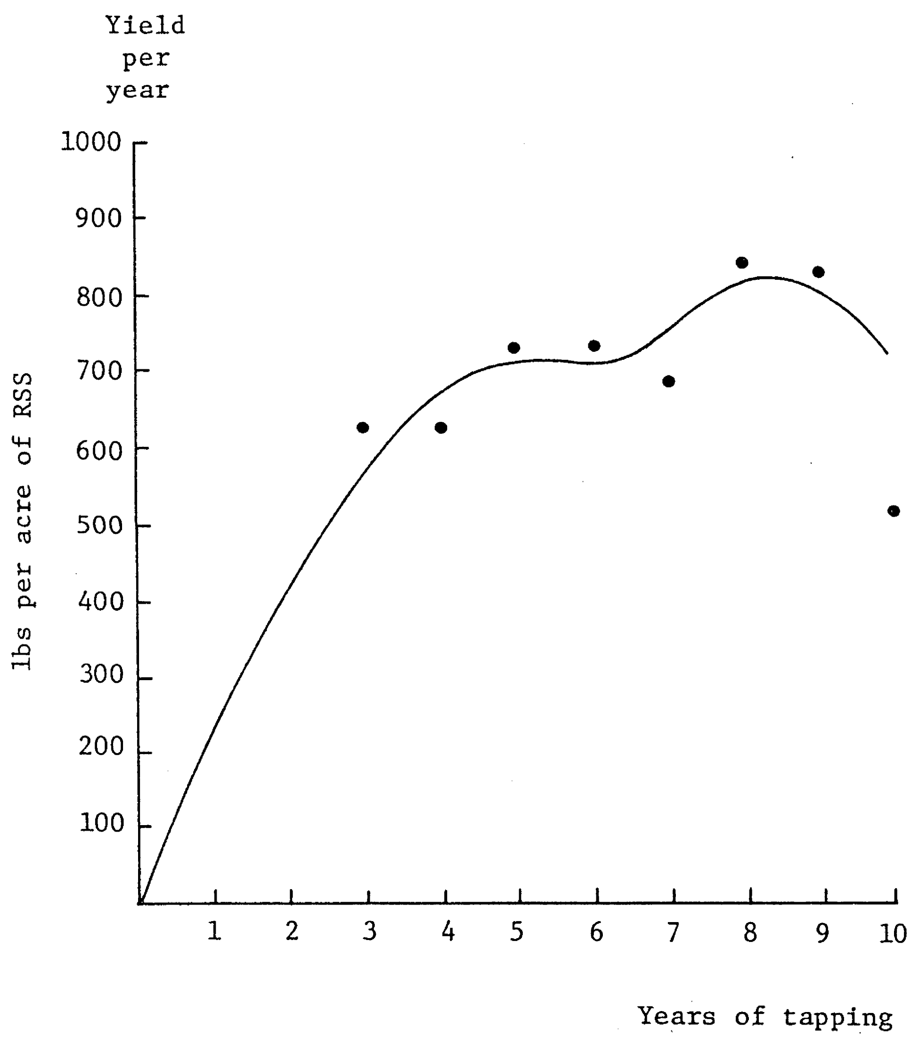


FIGURE 5.4A

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: Tjir 1 (C.S.)

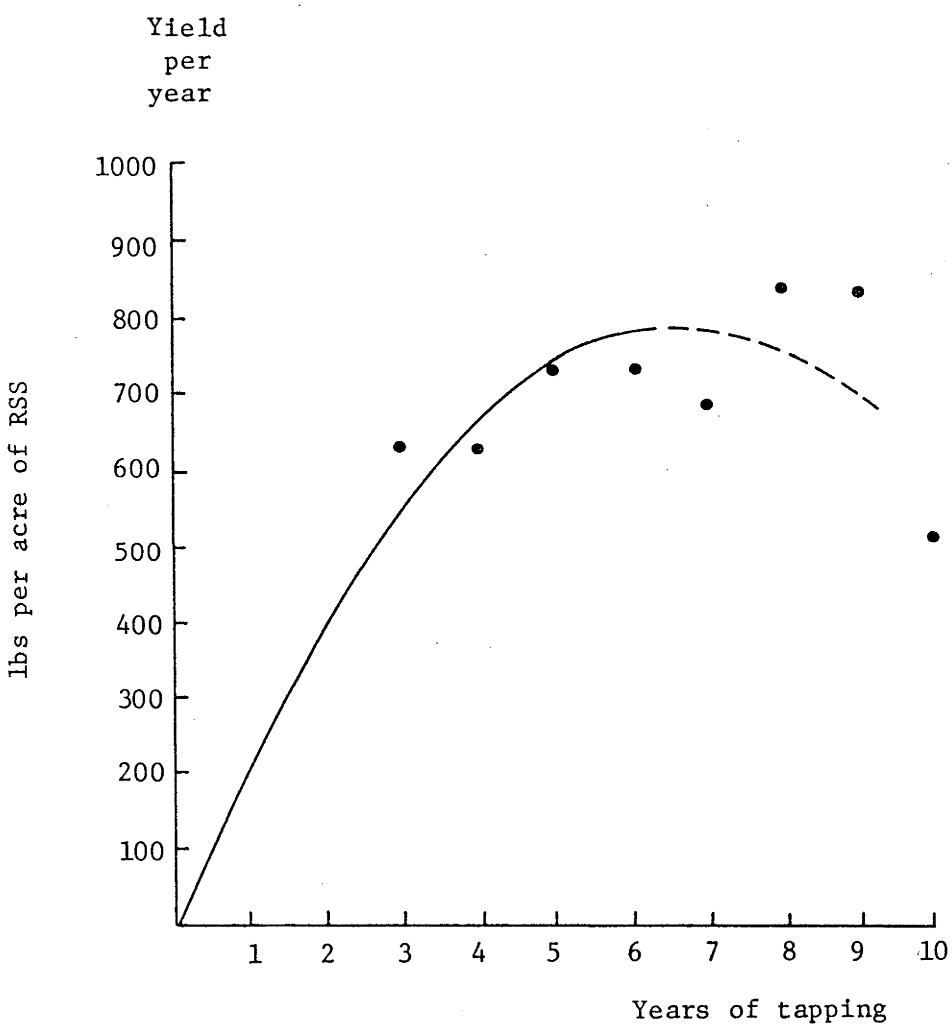


FIGURE 5.4C

ALTERNATIVE INTERPRETATION OF RUBBER YIELD
AND THEIR PATHS OVER TIME

CLONE: Tjir 1 (C.S.)

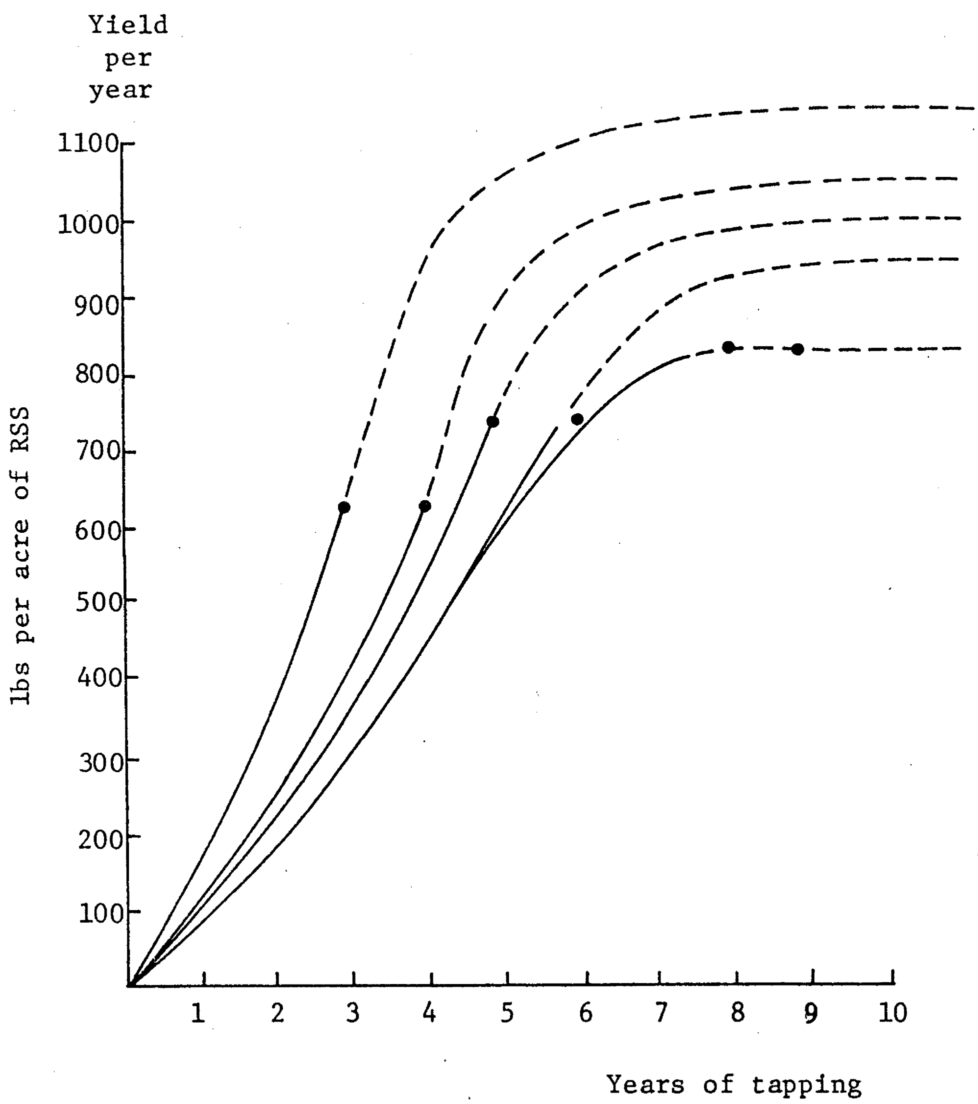


TABLE 5.4a

MEAN OF PLANTING DENSITY AND TAPPING FREQUENCY ACCORDING TO TAPPING AGE: CLONE PB86

Tapping age	Planting density		Tapping frequency		Number of Observations
(years)	Mean	Coefficient of variation	Mean	Coefficient of variation	
3	167 (45)	27	138 (29)	21	16
4	177 (34)	19	139 (29)	21	5
5	174 (50)	29	133 (33)	25	21
6	173 (55)	32	136 (37)	27	20
7	172 (49)	28	146 (40)	27	17
8	188 (41)	22	153 (32)	21	18
9	182 (30)	16	146 (22)	15	22
10	187 (40)	21	142 (21)	15	20
Total	178 (43)	24	142 (31)	22	139
	F value 0.514		F value 0.832		

TABLE 5.4b

MEAN OF PLANTING DENSITY AND TAPPING FREQUENCY ACCORDING TO TAPPING AGE: CLONE TJIR 1

Tapping age (years)	Planting density		Tapping frequency		Number of Observations
	Mean	Coefficient of variation	Mean	Coefficient of variation	
3	279 (96)	34	152 (31)	20	7
4	246 (82)	33	137 (23)	17	15
5	222 (57)	26	146 (17)	11	10
6	211 (41)	19	141 (25)	18	16
7	232 (68)	29	134 (22)	16	21
8	212 (40)	19	149 (29)	19	17
9	188 (58)	31	133 (28)	21	17
10	190 (43)	23	148 (23)	16	7
Total	218 (66)	30	141 (25)	18	110
	F value 2.458		F value 1.274		

5.5 Frontier Production Function

The next stage is to examine frontier production function which was estimated from the same functional form as the average production function discussed above.

Table 5.5 presents the coefficients of the production functions estimated by these two methods. LP_{a1}, LP_{a2} and LP_{b1}, LP_{b2} report the results of fitting the linear form of the Cobb-Douglas function using the linear programming model outlined in Chapter 2. They are frontier production functions. OLS_a and OLS_b are the average estimates in respect of Clone PB86 and Clone Tjir 1 which are presented in this table for the purpose of comparison.

LP_{a1} presents the results of fitting a deterministic frontier function to the same data set as used in OLS_a for Clone PB86. With the exception of coefficients for tapping frequency and dummy variables for age 5 and 10, the rest of the coefficients are very different from those in OLS_a.

The 100 per cent "efficient" observations were noted; there are as many "efficient" farms as there are factors of production with $\hat{B}_i > 0$.

The efficient farms could have been measured as efficient because of error of observations or other problems. Timmer (1970) suggested that in order to overcome possible bias due to data problems, some of the efficient farms might be discarded, and the rest of the observations used to determine the frontier.

Accordingly, the first 5 per cent of the most efficient farms were removed from LP_{a1} and the probabilistic frontier estimated. The results are given by LP_{a2}. All the coefficients are, with minor exception, remarkably similar to the coefficients of LP_{a1}; indicating that the coefficients seem to have stabilised.

TABLE 5.5

COEFFICIENTS OF PRODUCTION FUNCTIONS ESTIMATED BY ORDINARY LEAST SQUARES AND LINEAR PROGRAMMING METHODS

Clone	Method	VARIABLES									
		Constant	X1	X2	X3	D5	D6	D7	D8	D9	D10
PB86	OLSa	-1.4976	0.6786	0.8268	0.9367	0.1321	0.3354	0.3891	0.2300	0.2317	0.4100
	LPa1	0.0006	0.4300	0.7805	0.9777	0.1214	0.6522	0.7449	0.5841	0.3830	0.4593
	LPa2	0.1872	0.4117	0.8093	0.9409	0.1610	0.6465	0.3791	0.3446	0.4159	0.4481
Tjir 1	OLSb	2.2525	0.4235	0.9086	0.3911	0.1572	0.1553	0.0860	0.2887	0.2859	-0.1978
	LPb1	1.2061	0.4196	0.7905	0.7223	0.0853	0.2205	0.0013	0.2024	0.2408	0.0034
	LPb2	1.2566	0.4261	0.8109	0.6910	0.0062	0.2663	-	0.2255	0.2188	-

OLS = Ordinary Least Squares
LP = Linear Programming
X1 = Planting Density
X2 = Land
X3 = Tapping Frequenty
D5, D6, ... D10 = Age 5, 6, ... 10 (dummy variables)

For each age group, there is an average and a frontier function. Comparing the average function, OLS_a, with the frontier function, LP_{a1}, for all ages, there is a fall of 37 per cent in planting density coefficient, a fall of 6 per cent in farm size coefficient, but a rise of 4 per cent in tapping frequency coefficient.

The effect of ages 3 and 4 are included in the intercept. The antilog of the intercept for the frontier function is 1.0006 as compared to that of the average function which is 0.2337.

The coefficient of the frontier function for age 5 shows a fall of 8 per cent. There is a rise of 95 per cent, 91 per cent, 150 per cent, 65 per cent and 12 per cent over the coefficient of the average function for ages 6, 7, 8, 9 and 10 respectively.

Brown (1966) divided technological change into two types, namely, neutral and non-neutral change. "A neutral change alters the production function but does not affect the marginal rate of substitution. A non-neutral change does affect the marginal rate of substitution." In accordance with this definition, the difference in technology between the average and the frontier functions for Clone PB86 is non-neutral since the production elasticities appeared to have been affected differently.*

LP_{b1} presents the results of a deterministic frontier function estimated from the same data set as used in OLS_b, for Clone Tjir 1. LP_{b2} is the probablistic frontier estimated by removing 5 per cent of the most efficient farms from LP_{b1}. With minor exceptions, the coefficients

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* There are no formal tests of significance with which this assertion can be checked.

for LP_{b2} are remarkably similar to those of LP_{b1}, indicating that stabilisation of the coefficients seems to have occurred.

When compared to the average function, OLS_b, the frontier function, LP_{b1}, indicates almost no change in the coefficient of planting density, a fall of 13 per cent in the farm size coefficient, and a rise of 85 per cent in the tapping frequency coefficient for all ages. The coefficients for different ages are affected differently. The difference in technological change between the average and the frontier for Tjir 1 also appears to be non-neutral, similar to that of the Clone PB86.

CHAPTER 6

TECHNICAL EFFICIENCY AND MARGINAL PRODUCTIVITY

6.1 Technical Efficiency

Production function could enable one to judge one farm's performance relative to that of another when different factor amounts and proportions are used. Two different vectors of technical efficiency for each rubber Clone are generated from the production function results of Table 5.5. The technical efficiency ratings of the average or the frontier functions are the ratios of the actual output to the calculated average output or calculated frontier output respectively (equation 2.17). They are reported in Appendix Table 1, along with rankings of each vector. The farm with the highest efficiency rating was assigned rank 1; tied efficiencies were assigned the average of the tied ranks.

Setting the farms with the average efficiency level equal to 1, the efficiency ratings for average production function for rubber clone Tjir 1 farms, reveal that out of 110 farms, 55 per cent of the farms had an efficiency level above the average, while the remaining 45 per cent had an efficiency level below the average.

The average efficiency ratings varied from a minimum of 0.43 to a maximum of 1.69. The maximum efficiency rating indicates that, given a similar set of inputs, the best Tjir 1 farm could produce 69 per cent higher output of rubber than the average farm, while the minimum efficiency rating suggests that the worst farm was producing only 43 per cent of the average output.

The most efficient farms had efficient levels of 1 in the frontier rating, and 5 farms were found to have operated at the frontier for Tjir 1.

About 25 per cent of the farms had a measured technical efficiency within 25 per cent of the frontier; about 71 per cent of the farms were operating within 50 per cent of the frontier.

The least efficient farm (Farm No. 46) had efficiency level of only 0.24, which suggests that given the same level of inputs, the most efficient farm could produce 76 per cent more output of rubber than the least efficient farm.

On examining the rubber Clone PB86, and setting the average efficiency rating to unity, the average ratings reveal that out of 138 farms, only 46 per cent of the farms had efficiency level above the average, while the remaining 54 per cent were below the average.

The efficiency ratings varied from a minimum of 0.30 to a maximum of 1.62. These values indicate that the best PB86 farms could produce 62 per cent more output of rubber than the average farm, while the worst farm was producing 70 per cent less output than an average farm.

The frontier efficiency ratings for PB86 reveal that 9 farms were operating at the frontier. 20 per cent of the farms had a measured technical efficiency within 25 per cent of the frontier, and about 60 per cent of the farms were operating within 50 per cent of the frontier.

The least efficient farm (Farm No. 138) had an efficiency level of only 0.13. Therefore, for a given set of inputs, the least efficient PB86 farm produced 87 per cent less output than the most efficient farm.

Since the farms in the sample also had other crops besides rubber (Table 1.4), there was a possibility that the presence of these non-rubber crops, such as paddy, tea, coconut, could affect the measured technical efficiency. Those farms within 25 per cent of the least efficient farm were examined, but there was no indication that these farms had any substantial areas of non-rubber crops. Nevertheless, in the absence of further information on these non-rubber crops, it was not possible to conclude that the presence of non-rubber crops had no influence on the measured rechnical efficiency.

There was also no evidence to indicate that those farms at the lower end or the upper end of the efficiency scale were related to farm size.

The results suggest that there exists a wide range of technical efficiency at the farm level. Could this big difference in efficiency be due to soil quality? Or is it due to differences in farm management practices, in which case diverting resources towards extension services would be urgently needed? Or is it that the measured differences were not related to either the physical or management factors, but mainly due to errors of measurement in the variables used for the production function analysis? The set of technical efficiency generated may be sensitive to slight changes in specification and subject to a wide range of uncertainty. It is obvious that errors due to misspecification of several input variables, and possibly the output variable as well, could not be ruled out. Given the data, a somewhat low degree of confidence should be placed on all the ratings, and further research is needed to clarify the true meaning of these "efficiency indices" as applied to the rubber smallholders.

6.1.1 Comparison of the Efficiency Ratings from the Average and the Frontier Production Functions

The use of two different methods to generate estimates of technical efficiency invites comparison to see if any relationship exists between these two efficiency vectors.

The correlation coefficient between the average and the frontier ratings for PB86 was found to be 0.93, and that for Tjir 1 was 0.96, both being highly significant at all plausible levels of significance. Therefore the null hypothesis of zero correlation between these two sets of efficiency indices is rejected in favour of the alternative hypothesis that there exists a relationship between the two.

The frontier ratings were plotted against the average ratings for the Clone PB86 and Clone Tjir 1 separately, and the scatter diagrams were presented in Figure 6.1a and 6.1b respectively. Both figures clearly illustrate the existence of a very strong linear relationship between the average and the frontier rankings. The evidence clearly demonstrates that the farms which are efficient as compared to the average farm, are also efficient relative to the best farms. Thus, within the range of this sample, the results suggest that one could come to a similar conclusion on the technical efficiency ranking of the farms irrespective of whether the ratings were calculated relative to the average or to the frontier production function. Similar conclusions were obtained by Sharma (1974) in his study of the technical efficiency of paddy and wheat farmers of Nepal.

6.2 Marginal Returns to Factors of Production

The marginal produce of an input indicates the quantity that would be added to the output by the last unit of that input. Under the assumption of perfect markets, the marginal productivity of a factor and its opportunity cost could indicate the allocative efficiency of farms in the district.

Tables 6.1a (for PB86) and 6.1b (for Tjir 1) present the estimates of geometric means, production elasticities and marginal productivities for the input factors according to different age of the rubber stand. With the exception of age 10, the marginal productivities of different years for each factor are relatively stable. The following discussion relates to the average farm in the area.

Consider the rubber stand of age 3. The marginal productivity of planting density indicated an additional increase of 4.2 lb to the PB86 output and 1.4 lb to the Tjir 1 output for one additional tree in an acre.

FIGURE 6.1a

EFFICIENCY RATINGS OF CLONE PB86 FARMS

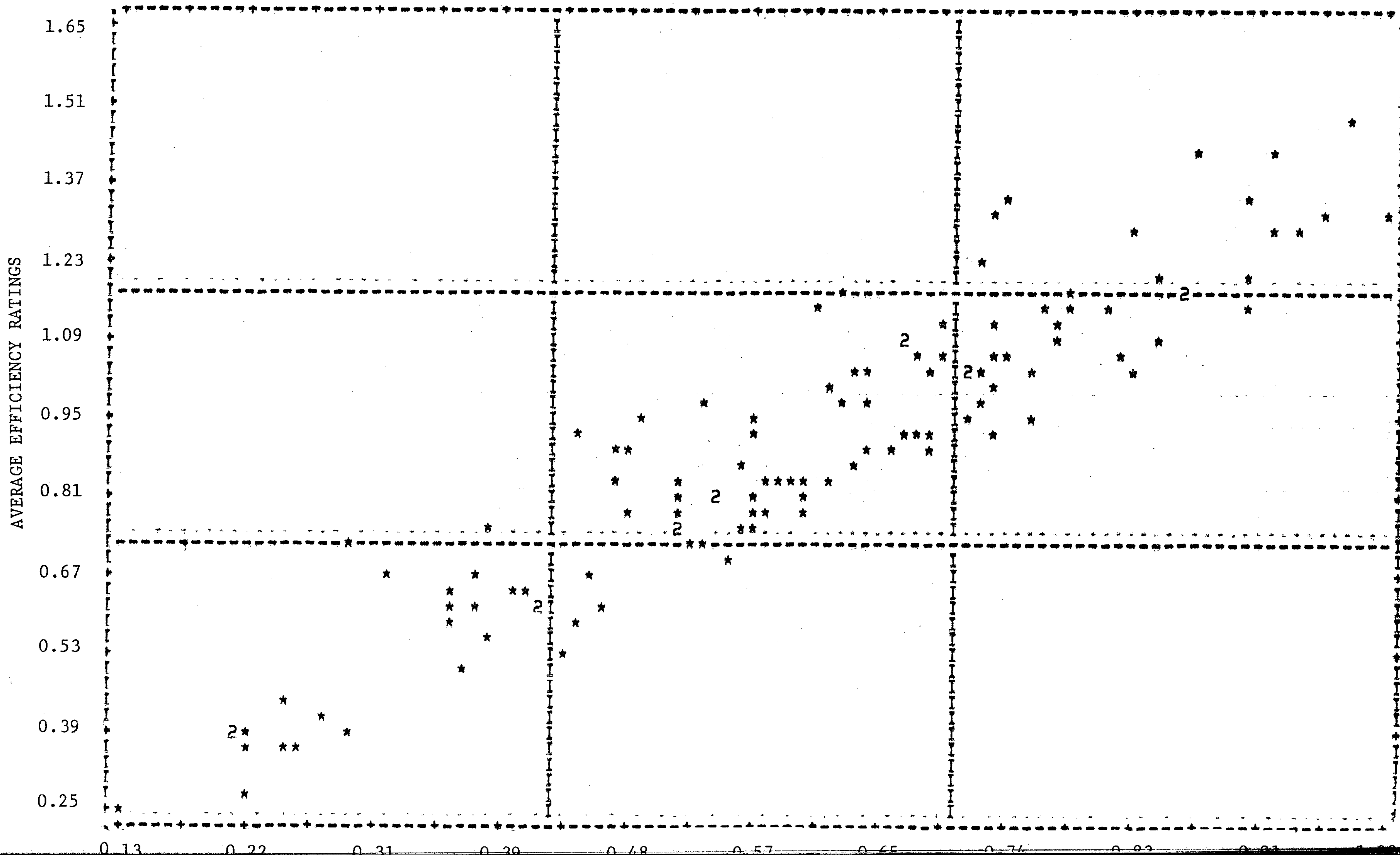


FIGURE 6.1b

EFFICIENCY RATINGS OF CLONE Tjir 1 FARMS

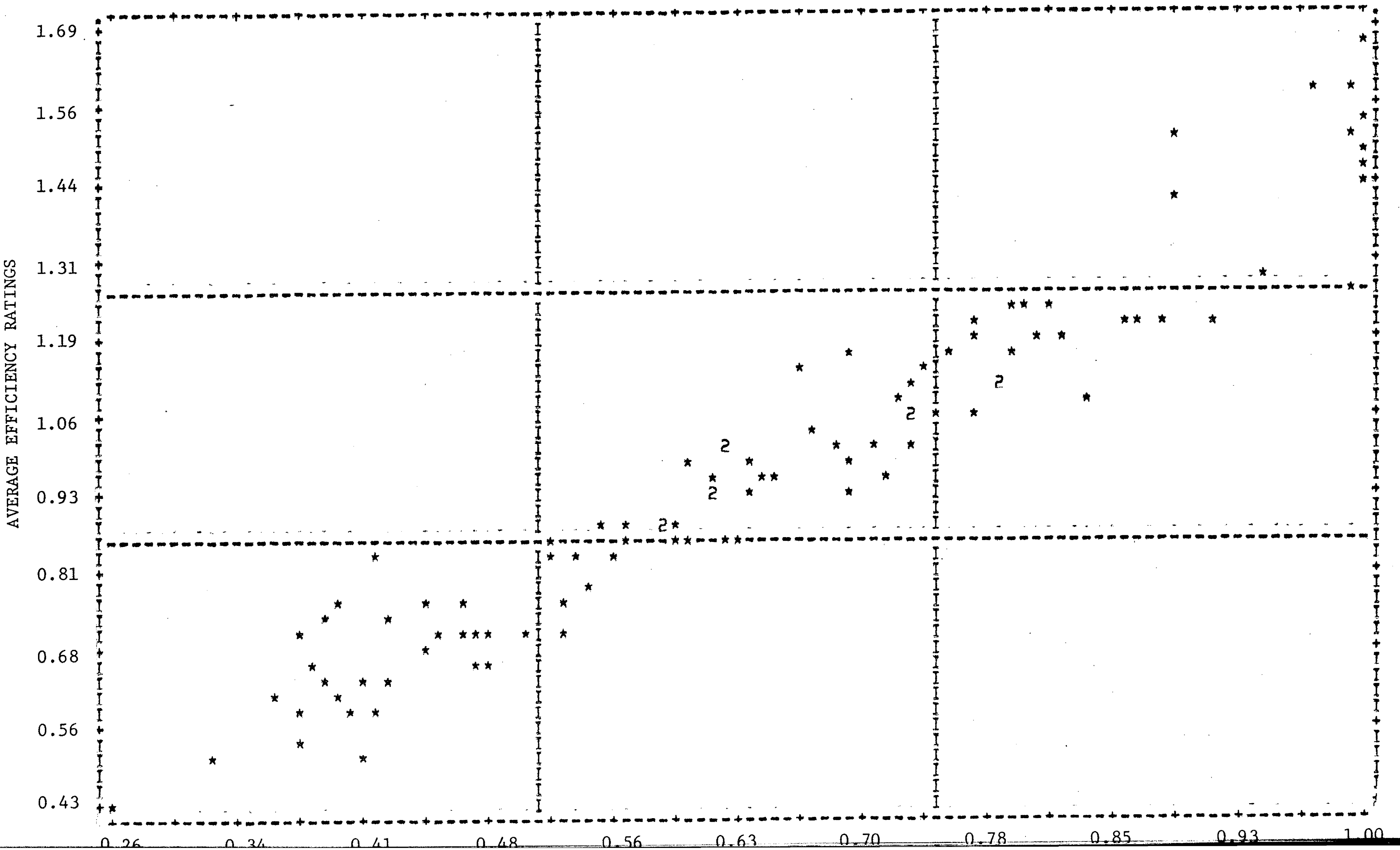


TABLE 6.1a

GEOMETRIC MEANS, PRODUCTION ELASTICITIES AND MARGINAL PRODUCTIVITIES OF SELECTED INPUTS FOR DIFFERENT AGES: RUBBER CLONE: PB86

	Planting density (X_1) (Trees per acre)	Farm size (X_2) (Acres)	Tapping frequency (X_3) (Days per year)
Geometric mean	172	1.56	140
Estimated elasticity	0.6786	0.8268	0.9367
Marginal product			
Age 3	4.249	570.810	7.206
4	4.249	570.810	7.206
5	4.849	651.370	8.223
6	5.942	798.180	10.076
7	6.269	842.170	10.639
8	5.350	718.680	9.073
9	5.358	719.740	9.086
10	6.403	860.190	10.859

	TAPPING AGE							
	3	4	5	6	7	8	9	10
Estimated level of output $\hat{Q}$ lbs	1077	1077	1229	1506	1589	1356	1358	1623
Marginal product of age		0	152	277	83	-233	2	265

MP_{ia} Marginal Productivity of the i^{th} factor at age a (a = 3, 4, ..., 10)

$$MP_{ia} = b_i \frac{\hat{Q}a}{X_i}$$

b_i Estimated production elasticity of the i^{th} factor.

$\hat{Q}_a$ Estimated level of output at age a when each input is held at its geometric mean.

TABLE 6.1b

GEOMETRIC MEANS, PRODUCTION ELASTICITIES AND MARGINAL PRODUCTIVITIES OF SELECTED INPUTS FOR DIFFERENT AGES: RUBBER CLONE: TJIR 1

	Planting density (X_1) (Trees per acre)	Farm size (X_2) (Acres)	Tapping frequency (X_3) (Days per year)
Geometric mean	210	1.20	140
Estimated elasticity	0.4235	0.9086	0.3911
Marginal product			
Age 3	1.504	564.846	2.084
4	1.504	564.846	2.084
5	1.761	661.008	2.439
6	1.759	660.249	2.436
7	1.639	615.577	2.271
8	2.009	754.138	2.782
9	2.003	751.867	2.774
10	1.234	463.386	1.710

	TAPPING AGE							
	3	4	5	6	7	8	9	10
Estimated level of output $\hat{Q}$ lbs	746	746	873	872	813	996	993	612
Marginal product of age		0	127	-1	-59	183	-3	-381

The rubber stand of other ages also indicated this relatively higher marginal productivity of PB86. Optimal density recommended by Rubber Research Institute of Sri Lanka is between 140-160 trees per acre; the average PB86 holding of 1.56 acres in this study had 172 trees per acre, and the average Tjir 1 holding of 1.20 acres had 210 trees per acre. In view of the relatively higher marginal returns per tree per acre for PB86, the case for still higher optimal densities for this clone should not be rejected.

The marginal productivity for farm size or land indicated that for one acre increase in farm size, there could be an increase of 571 lbs to PB86 output, and 565 lbs to the Tjir 1 output; this could indicate that for the first 9 years of tapping, on the average, the marginal returns to land for both the clones of rubber do not seem to differ significantly. Unfortunately, the analysis could not include much older trees. Nevertheless, the marginal productivity in year 10 indicates that the returns to land for these two clones could be vastly different from each other in the subsequent years.

As regards tapping frequency, an increase of one tapping day would contribute about 7.2 lbs at the margin to the output of PB86. Assuming that the price of rubber was Rs.1.00 per lb, the opportunity cost of tapping labour for PB86 farms would be Rs.7.20. The degree of misallocation of labour input is indicated by comparing the marginal return with its wage rate. Assuming that the average wage rate for one labour day in the area was Rs.5.00, then the opportunity cost of tapping labour for PB86 farm was higher than the wage rate; indicating the under utilization of labour inputs for this clone of rubber farms. The marginal productivity was higher for the older stand of rubber, hence the opportunity cost of tapping labour was even higher for those farms.

Similarly, the marginal return to tapping labour for Tjir 1 farms was estimated to be about 2.1 lbs, which was Rs.2.1 at Rs.1.00 per lb. If the wage rate for one labour day was Rs.5.00, then the opportunity cost of a tapping day for Tjir 1 farms was well below the wage rate. The marginal productivity of tapping frequency seemed to be quite stable for different age of the rubber stand. Hence, at rubber price of Rs.1.00 a lb it did not pay for the average Tjir 1 farmer to keep on tapping his own trees. He should, perhaps, hire out his labour to PB86 farms.

The average tapping frequency of both types of farms were the same - 140 days per year. Weather conditions could perhaps be the limiting factor for increasing the tapping days. Low tapping frequency could partly be explained by the ralatively low price of rubber in that year. However, if alternative employment was not readily available, the low price of rubber could actually induce the farmer to tap more rubber in order to make up for its low value. An alternative hypothesis is that the farmers in PB86 farms might have over-reacted to the conservative approach to exploitation of rubber trees, as reported by Barlow (1970).

The marginal productivity of age is the difference of the output between one age and the next one. The figures in Table 6.1a and 6.1b both provide lumpy pictures, while the true changes were probably of a continuous nature. The lumpy picture tends to support the hypothesis that for every group of farms for every year, there was actually a separate yield curve (see Chapter 5).

The marginal productivity of each input factor for each individual farm was computed and the results presented in Appendix Table 2.

For PB86 farms, there was a very wide range of marginal returns for farm size (land) between individual farms - a minimum of about 132 lbs to a maximum of about 1600 lbs. The distribution of marginal productivity of land is presented graphically in Figure 6.2a(i) which reveals that 50 per cent of the farms had marginal productivity of below 750 lbs and 75 per cent below 900 lbs. Within the range of the sample, there was no significant relationship between farm size and the marginal returns to the land as illustrated in Figure 6.3a.

In the case of Tjir 1 farms, the range of marginal returns for land was between 250 lbs to 1200 lbs, and Figure 6.2b(i) reveals that 50 per cent of the farms had marginal productivity below 700 lbs and 75 per cent below 800 lbs. Figure 6.3b shows that within the range of the sample, there was no significant relationship between the farm size of Tjir 1 and the marginal returns to the land.

The return at the margin to an additional tapping day per year for PB86 showed a wide variation from about 1 lb to about 30 lbs. Figure 6.2a(ii) reveals that 50 per cent of the farms had marginal returns of less than 9 lbs and 75 per cent had marginal returns of less than 15 lbs.

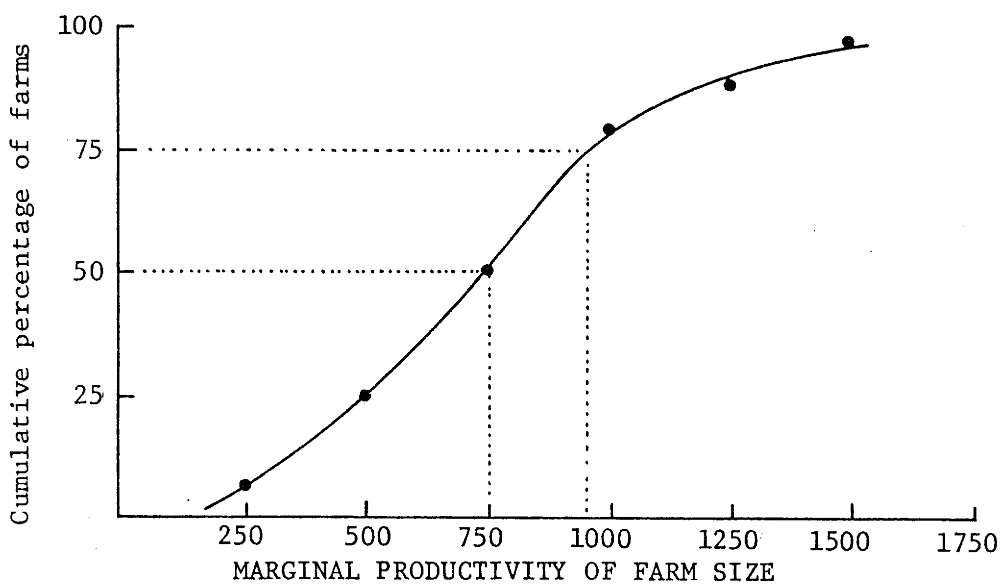
Under the assumption of perfect markets, the equilibrium point for maximum efficiency in labour-use occurs when the marginal value product of the labour is equal to its wage rate. The distance of marginal value product (MVP) from the wage line reveals the extent of inefficiency in utilization of labour. Over utilization of labour occurs in those farms which have MVP of labour below the wage line, and under utilization in those farms above the wage line.

Assuming that price of rubber was Rs.1.00 per lb and the average wage rate was Rs.5.00 per day, Figure 6.4a indicates the extent of allocative inefficiency of tapping labour use for each of the PB86 farms. About 30 per cent of the farms had MVP of labour below the wage line, indicating over utilization of labour; 70 per cent above the wage line, indicating under utilization of labour.

FIGURE 6.2A

CLONE PB86
MARGINAL PRODUCTIVITY

(i)



(ii)

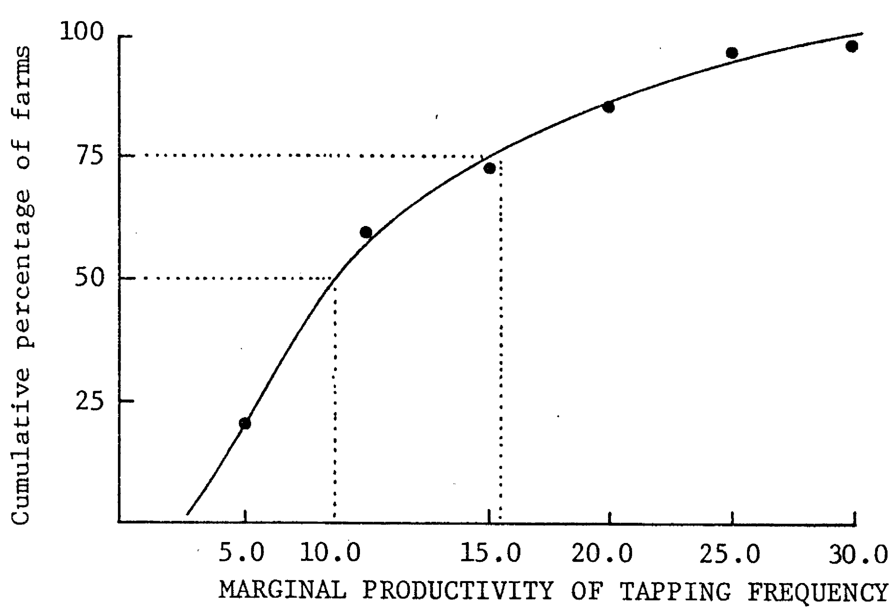


FIGURE 6.2B

CLONE TJIR 1
MARGINAL PRODUCTIVITY

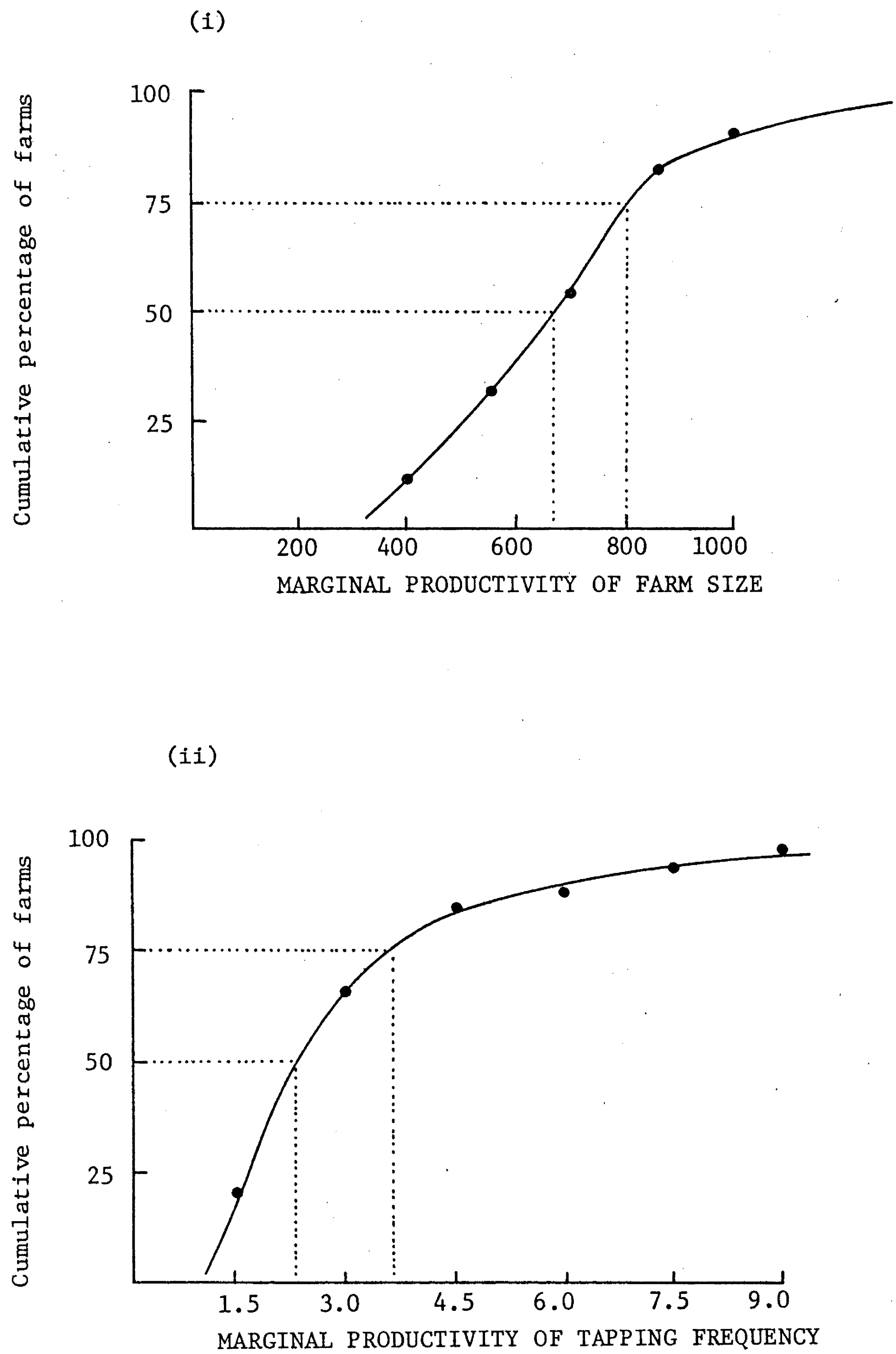


FIGURE 6.3a

MARGINAL PRODUCTIVITY OF LAND IN RELATION TO AREA: CLONE PB86

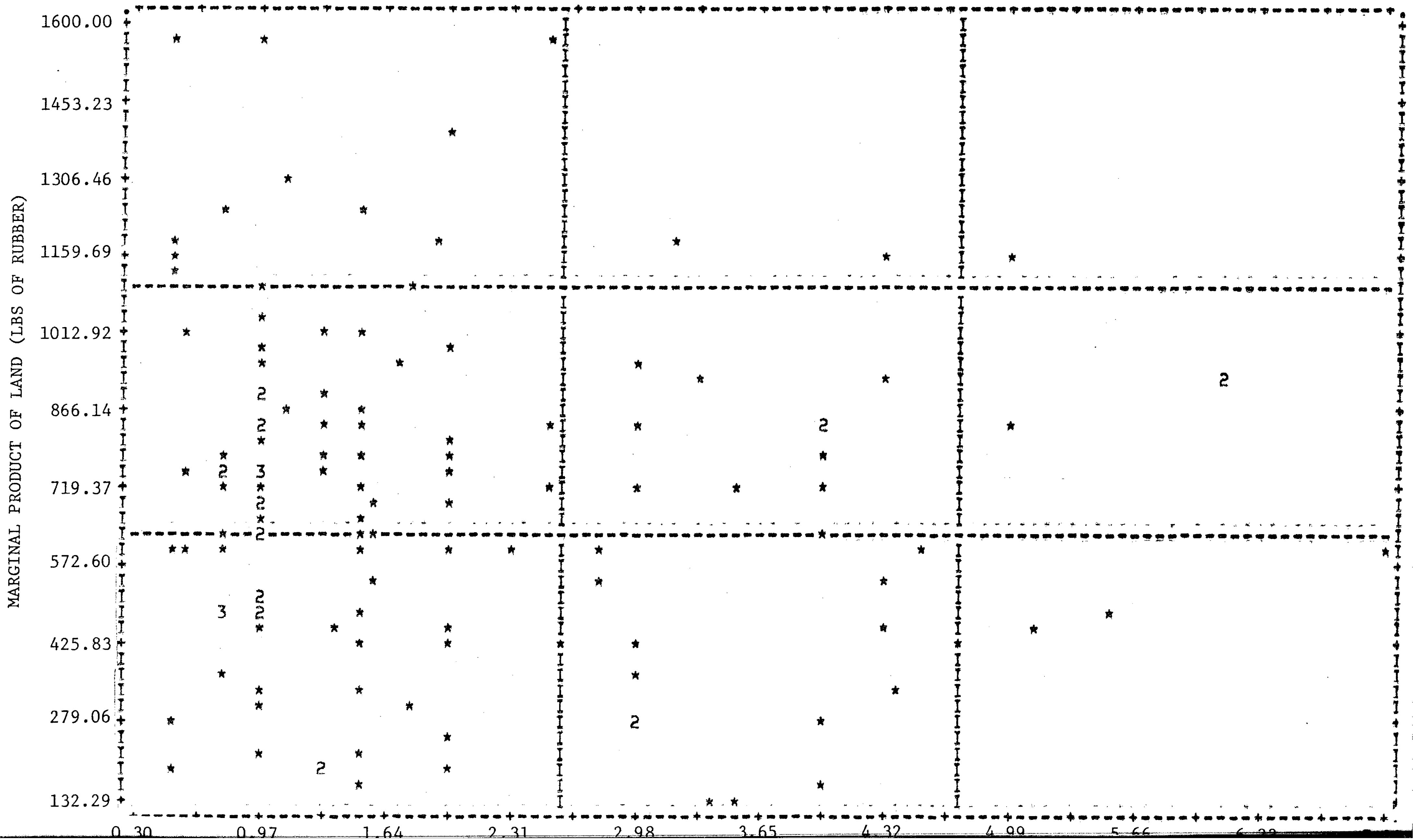


FIGURE 6.3b

MARGINAL PRODUCTIVITY OF LAND IN RELATION TO AREA: CLONE Tjir 1

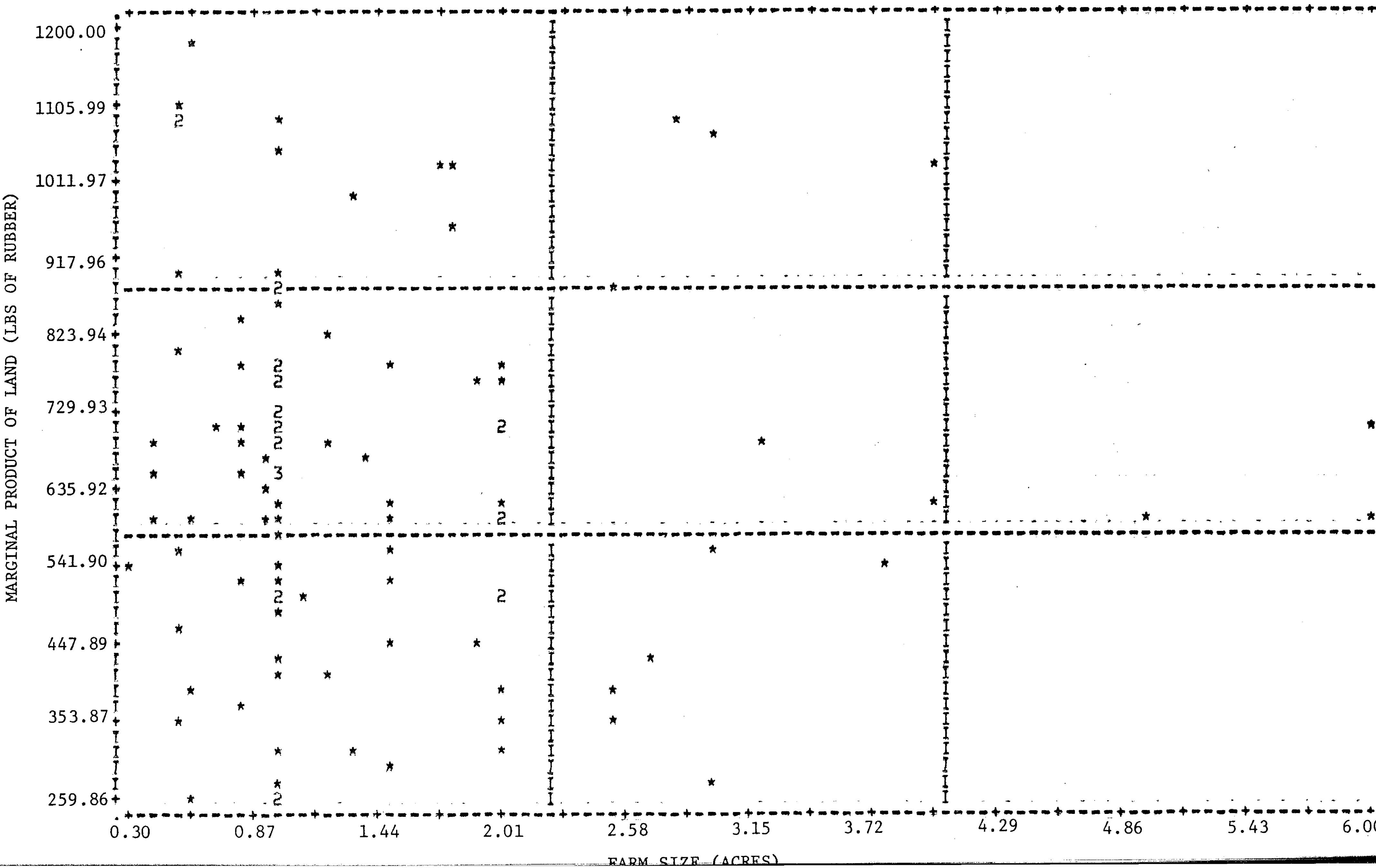


FIGURE 6.4a

MARGINAL VALUE PRODUCT OF TAPPING DAYS IN RELATION TO AREA: CLONE PB86

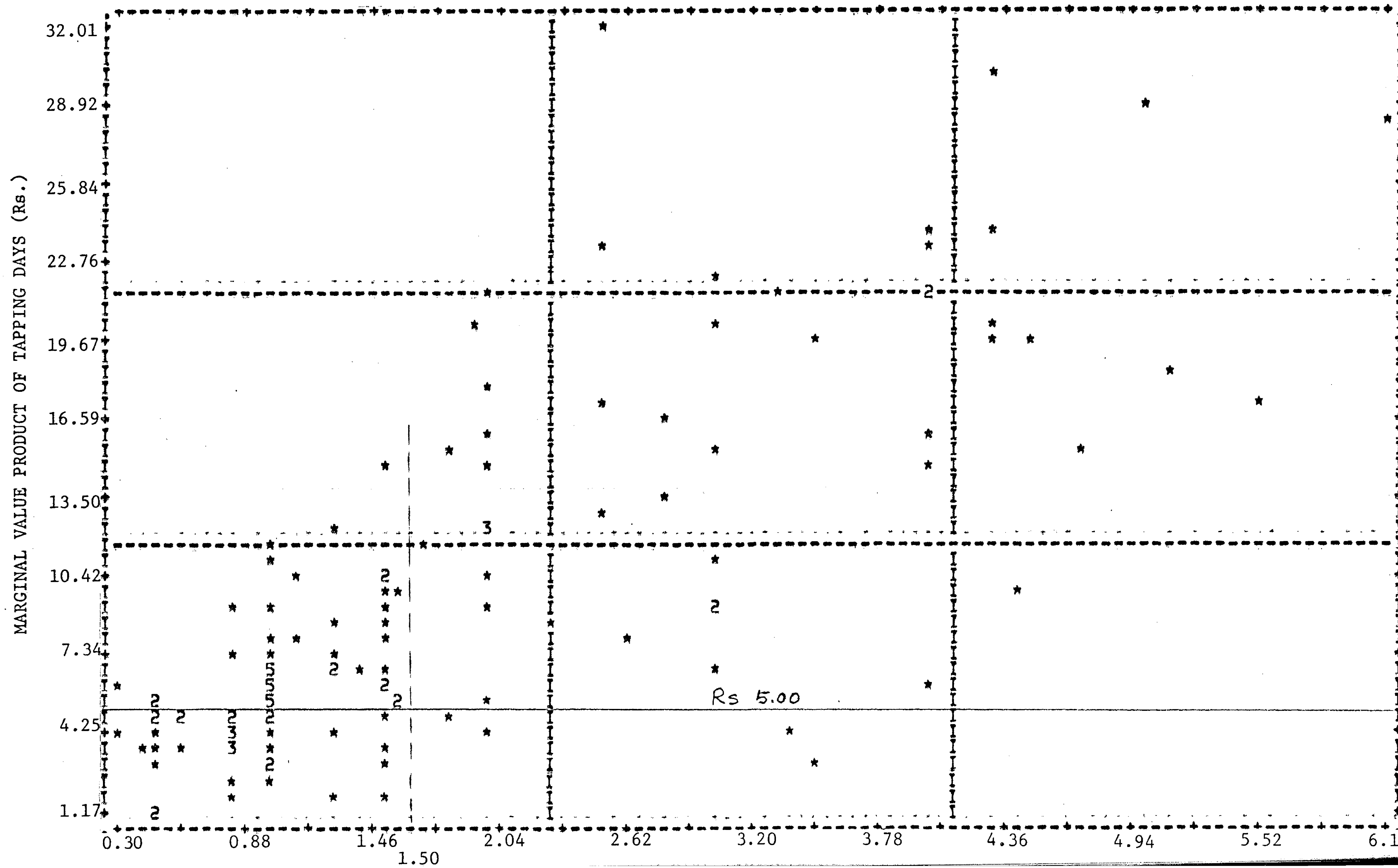


FIGURE 6.4b

MARGINAL VALUE PRODUCT OF TAPPING DAYS IN RELATION TO AREA: CLONE Tjir 1

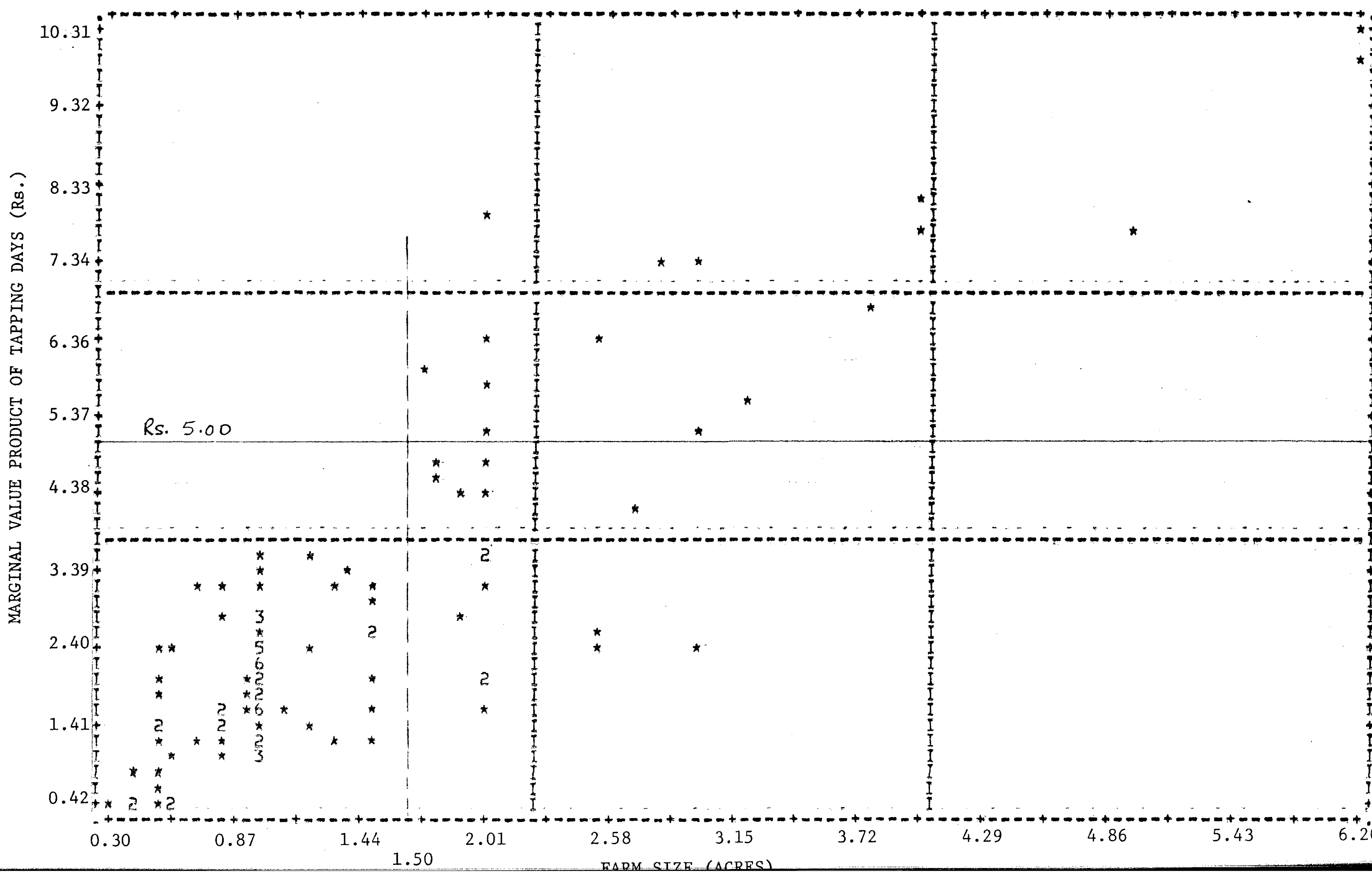


Figure 6.4a also reveals that for PB86 farms, nearly all the farms which had area above the average size* had under used the labour input; while among those farms which were below average size, only about 55 per cent had under used this input. Over utilization of tapping labour occurred only in the smaller farms.

In the case of Tjir 1 farms, the return at the margin to an additional tapping day ranged from 9.4 lbs to about 10 lbs. Figure 6.2b(ii) reveals that 50 per cent of the farms had marginal return of less than 2.5 lbs and 75 per cent of the farms had less than 4.0 lbs.

Assuming that Tjir 1 farms had the same rubber price and wage rate as the PB86 farms, Figure 6.4b indicates the extent of allocative inefficiency of tapping labour for each of the Tjir 1 farms. Only 13 per cent of the farms had MVP above the wage line, indicating under utilization of tapping labour; and all these farms had area above the average size. Hence 87 per cent of the Tjir 1 farms had the problem of over utilization of tapping labour and the majority of these farms were below the average size.

If all the farms had similar wage rates, then these results reveal that for PB86 farms, the majority of the smaller farms had over used the tapping labour and nearly all the larger farms had under utilized this input; for Tjir 1 farms, all the smaller farms and about 50 per cent of the larger farms had over used the tapping labour, and under utilization of tapping labour occurred only in the larger farms.

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* Average size of farm was 1.50 acres.

However, whether these different rates of utilization represent allocative inefficiencies cannot be fully resolved without more adequate data on relative factor prices.

Though the structure of ownership was not fully recorded, it was believed that the smaller farms were owner-occupied and operated, and the larger farms were held by absentee landlords Barlow (1975). These larger farms were tapped by waged-worker or by share-cropper. If this was the case, then under utilization of tapping labour for the larger farms might be a result of tapping-labour shortage or the unattractive nature of the share arrangement or wage-payment by the landlords.

CHAPTER 7

SUMMARY AND CONCLUSIONS

The main purpose of this study has been to estimate farm factor productivity using the Cobb-Douglas production function and working with cross-section input-output data from a 1971/72 survey of small rubber holdings in the Agalawatta district of Sri Lanka. Of the twelve factors of production believed to affect output of rubber, only four factors, namely, planting density, farm size or land, tapping frequency, and tapping age of the trees were retained in the final estimating equations. Zero-one dummy variables were employed to represent different ages of the rubber stand. Due to limitations in the data, farms between tapping ages of 3 to 10 years old only were considered. Functions were estimated for clone PB86 and clone Tjir 1, separately.

For each rubber clone, the Cobb-Douglas production function was estimated by two different techniques, namely, the Ordinary Least Squares method which estimates the average production function for the sampled farms and the Linear Programming method which estimates the "best" or the frontier function. The analysis was carried out under the assumption that the same functional form applied to all the farms.

In the specification of the variables, various possible sources of error were encountered. There were no data on the total output of dry rubber, thus only the weight of RSS was considered. No account was taken for the difference between the total number of mature rubber trees and the number of trees currently in production. The labour input for tapping was considered as the number of tapping days per annum which could represent an over-estimation of the average usage, particularly as larger holdings often had two or more tasks. Quality differences in labour such as age, sex, educational level or working experience could not be considered due to lack of data. Management bias could not be overcome because information relating to managerial ability over a period of years was not available. Similarly, tree age differences within holdings were not available so a common age for all trees on a holding was used. Tree age, of course, varied between holdings.

As a first step in the analysis, simple correlation and simple regression methods were employed with a view to establishing relationships between each of the specific factors and yield, measured as the total quantity of sheet and scrap per acre. The results indicated that yield for the clone PB86 was related to age, planting density, and tapping frequency, whereas for the clone Tjir 1, yield was related to planting density only. Farm size had no significant influence on the yields of both clones.

Within the framework of multiple regression analysis, the production coefficients of the estimated average function were statistically significant for both clones. The R^2 values were high (approx 0.8) and the F ratios were significant at conventional levels of significance.

The production elasticity of tapping frequency for PB86 farms indicated constant marginal returns, and that for Tjir farms indicated diminishing returns. The production elasticity of planting density indicated decreasing marginal returns for both rubber clones. The production elasticity for farm size or land indicated that the probability of Tjir farms exhibiting a constant return to size could not be rejected, while the PB86 farms had decreasing returns to size.

The estimated coefficients were used to predict output for each clone. For both clones, the results strongly suggest that for every farm or group of farms for every year or group of years, there is a separate yield curve. Instead of a single production function, there exists a family of functions depicting various efficiency levels.

For both clones, the estimated coefficients of the frontier function appeared to be different from those of the average function, indicating that the frontier had shifted non-neutrally upward from the average function.

For each clone, two different vectors of technical efficiency were generated from the estimated average and the frontier production functions. For a given set of inputs, the best Tjir 1 farm could produce 69 per cent higher output of rubber than the average farm, while the worst farm could produce only 43 per cent of the output of the average farm. For PB86 farms, the best farm could produce 62 per cent higher output than an average farm while the worst farm was producing 70 per cent less output than an average farm.

Since the farms in the sample also had other crops such as paddy, tea and coconut besides rubber, there was a possibility that the presence of these non-rubber crops could affect the measured technical efficiency. Without information on soil differences, management, and inputs to non-rubber crops, it was not possible to conclude if the differences in technical efficiency were due to these factors or due to errors of measurement in the variables used for the production function analysis.

The correlation coefficients between the average and the frontier efficiency ratings were 0.93 for PB86 and 0.96 for Tjir 1. The null hypothesis of no correlation between these two ratings was therefore rejected. Figure 6.1b, showing average ratings plotted against the frontier ratings, revealed a very strong linear relationship between the two ratings. This result suggests that, within the range of this sample, it is irrelevant whether the efficiency ratings were calculated relative to the average or the frontier function.

On the average, the planting density of PB86 farms showed a relatively higher marginal productivity per acre than that of the Tjir 1 farms. The optimal density recommended by the Rubber Research Institute of Sri Lanka is between 140 and 160 high-yield variety trees per acre; the average PB86 holding had 172 trees per acre and the average Tjir 1 holding had 210 trees per acre. In view of the relatively higher marginal returns per tree per acre for PB86, the case for still higher optimal densities for this clone should not be rejected.

For the first nine years of tapping, on the average, the marginal returns to land for both the rubber clones did not seem to differ significantly.

The degree of misallocation of a unit of labour is indicated by comparing the marginal return with its wage rate. For PB86 farms, about 70 per cent of the farms exhibited labour under-utilization and this occurred in all those farms which were above the average size. For Tjir 1 farms, only 13 per cent of the farms had underused labour and all these farms were above the average size. Hence, under-utilization of labour was a problem on the larger farms, perhaps lending weight to the argument that other forms of cultivation on these farms compete with rubber for labour.

The average tapping frequency of both types of farms were the same - 140 days per year. There was a possibility that the low tapping frequency for PB86 farms might have been due to the over-reaction of these farmers to the conservative approach to exploitation of rubber trees.

Since the larger farms were probably tapped by wage workers or share-croppers, the under-utilization of tapping labour could be a result of a shortage of tapping labour or an unattractive nature of the share-arrangement or wage-payment by the landlords, quite apart from the demands of other crops.

The fact that there were substantial areas of non-rubber crops on the surveyed farms means that it is important not to misinterpret the observed factor productivities of rubber in isolation from the "whole farm" situation. Selecting one crop from within a mixed crop environment makes for partial analysis. The interactive effects of crops, seasons, and management decisions cannot be assessed from partial data. The observed input levels may not be indicative or provide a satisfactory explanation of the single crop situation. However, in this survey, although 179 out of 289 farmers had some area of other crops, no significant interactive effects could be isolated from the data gathered for rubber production. Further attention should be directed to quantifying this problem, particularly to gain a more accurate basis from which to offer crop-specific advice.

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APPENDIX TABLE I

TECHNICAL EFFICIENCY RATINGS AND RANKING

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
1	1.16	37	0.58	62	0.78	100.5	0.53	76
2	1.60	6	0.98	10	0.78	100.5	0.53	76
3	0.76	83.5	0.36	97	0.39	128	0.27	125.5
4	0.74	87	0.34	103	0.87	81.5	0.51	80
5	1.18	35	0.69	40	1.17	39	0.82	21.5
6	1.25	23.5	0.71	37	1.35	19.5	1.00	5
7	0.52	108	0.28	109	1.11	46.5	0.75	28
8	1.12	40.5	0.66	44	0.72	106.5	0.48	89.5
9	0.64	100	0.39	90	0.87	81.5	0.58	61.5
10	1.03	49.5	0.53	72.5	1.30	27	0.90	18
11	0.61	102.5	0.34	103	1.37	16	0.92	16.5
12	1.56	10	0.86	20	1.19	34.5	0.73	30.5
13	0.73	89	0.42	87.5	0.80	95	0.53	76
14	0.98	58	0.52	76	1.22	32.5	0.77	25.5
15	1.69	1	1.00	3	0.60	119	0.42	103.5

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
16	0.89	67.5	0.45	83	1.34	21	0.72	33.5
17	1.44	18	0.91	14.5	0.97	67.5	0.69	40
18	1.59	8	0.88	18.5	1.54	7	1.00	5
19	1.21	30.5	0.81	25.5	0.94	72.5	0.66	46
20	0.76	83.5	0.47	81	0.51	123	0.36	115.5
21	0.65	99	0.34	103	1.26	30	0.94	14.5
22	0.94	63.5	0.56	63.5	1.43	12	1.00	5
23	1.11	42	0.62	55	0.38	130	0.23	130.5
24	0.86	75	0.54	67.5	1.47	9	1.00	5
25	0.60	104	0.37	95	0.36	135	0.24	129
26	0.68	96.5	0.44	85	1.32	23.5	0.97	11
27	1.41	20	0.85	22	1.31	26	0.89	19
28	1.22	28.5	0.71	37	0.95	70.5	0.72	33.5
29	0.67	98	0.41	89	1.08	49.5	0.70	39
30	1.07	44	0.59	60	0.79	97	0.57	63.5
31	1.67	3	1.00	3	1.07	52	0.73	30.5
32	1.23	26.5	0.74	32	0.96	69	0.54	74
33	1.01	53.5	0.53	72.5	1.05	55.5	0.65	49

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
34	1.06	46	0.67	42.5	1.03	60.5	0.68	42.5
35	0.70	95	0.38	92	0.86	84	0.56	67
36	0.84	78.5	0.44	85	0.84	88	0.56	67
37	1.66	4	0.89	17	1.16	41.5	0.74	29
38	1.23	26.5	0.65	46.5	0.58	121	0.38	111
39	1.68	2	1.00	3	1.18	36.5	0.83	20
40	1.04	48	0.61	57.5	0.81	93.5	0.56	67
41	1.18	35	0.59	60	1.19	34.5	0.96	12
42	1.18	35	0.71	37	0.95	70.5	0.52	78.5
43	0.63	101	0.35	99	0.45	124	0.23	130.5
44	0.72	92.5	0.35	99	0.38	131	0.20	135
45	0.98	58	0.53	72.5	1.18	36.5	0.59	59.5
46	0.43	110	0.24	110	0.62	116.5	0.32	121
47	0.87	72.5	0.54	67.5	0.93	75	0.41	106.5
48	1.53	12	0.85	22	0.41	126	0.19	137
49	1.22	28.5	0.81	25.5	1.17	39	0.56	67
50	1.12	40.5	0.72	34.5	0.98	66	0.49	86
51	1.25	23.5	0.88	18.5	1.61	2	1.00	5

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
52	0.58	106	0.37	95	0.68	108.5	0.33	120
53	1.06	46	0.75	29	0.75	102.5	0.35	118.5
54	1.20	32.5	0.74	32	1.36	17.5	0.68	42.5
55	0.98	58	0.65	46.5	0.91	79	0.44	98
56	0.90	66	0.53	72.5	0.39	129	0.20	135
57	1.20	32.5	0.72	34.5	0.74	104.5	0.27	125.5
58	0.86	75	0.54	67.5	0.90	80	0.43	100.5
59	0.78	81	0.53	72.5	0.97	67.5	0.44	98
60	1.51	14	0.90	16	0.78	100.5	0.36	115.5
61	1.14	38	0.67	42.5	0.68	108.5	0.22	132
62	0.51	109	0.38	92	1.45	10	0.62	55
63	0.72	92.5	0.44	85	0.91	79	0.45	94.5
64	1.63	5	0.99	7.5	0.72	106.5	0.36	115.5
65	1.47	17	1.00	3	1.22	32.5	0.59	59.5
66	1.21	30.5	0.77	27	1.32	23.5	0.65	49
67	1.00	55	0.64	50.5	0.94	72.5	0.43	100.5
68	0.53	107	0.33	106.5	1.05	55.5	0.49	86
69	1.03	49.5	0.65	46.5	1.62	1	1.00	5

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
70	1.43	19	0.92	13	1.27	29	0.64	52.5
71	0.88	70	0.55	65	0.91	79	0.42	103.5
72	0.88	70	0.50	78.5	0.93	75	0.42	103.5
73	1.59	8	0.99	7.5	0.55	122	0.28	124
74	0.85	77	0.48	80	1.13	44.5	0.55	70.5
75	0.89	67.5	0.53	72.5	0.75	102.5	0.38	111
76	0.88	70	0.54	67.5	1.50	8	0.71	37
77	0.84	78.5	0.56	63.5	0.99	64	0.47	91.5
78	1.24	25	0.69	40	0.85	86	0.44	98
79	0.73	89	0.42	87.5	1.43	12	0.65	49
80	0.77	82	0.51	77	1.60	4	1.00	5
81	0.87	72.5	0.64	50.5	1.07	52	0.49	86
82	1.13	39	0.75	29	1.16	41.5	0.56	67
83	1.02	51.5	0.74	32	0.66	111	0.30	123
84	0.93	65	0.59	60	1.03	60.5	0.50	82
85	0.97	60	0.75	29	0.39	15	0.71	37
86	1.50	15	0.97	11	0.62	116.5	0.31	122
87	0.86	75	0.62	55	0.64	112.5	0.26	127

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
88	0.72	92.5	0.50	78.5	0.78	100.5	0.38	111
89	0.94	63.5	0.62	55	0.99	64	0.47	91.5
90	1.48	16	0.96	12	0.81	93.5	0.38	111
91	0.61	102.5	0.35	99	0.64	112.5	0.39	109
92	0.73	89	0.46	82	1.04	59	0.61	56
93	0.95	62	0.64	50.5	1.60	4	0.99	10
94	0.99	56	0.63	53	0.86	84	0.43	86
95	1.01	53.5	0.65	46.5	0.62	116.5	0.36	115.5
96	1.27	22	0.99	7.5	1.09	48	0.65	49
97	0.59	105	0.33	106.5	0.79	97	0.45	94.5
98	1.09	43	0.69	40	0.82	91	0.50	82
99	1.53	12	0.83	24	1.60	4	0.95	13
100	1.30	21	0.91	14.5	1.11	46.5	0.63	54
101	1.53	12	0.99	7.5	1.58	6	1.00	5
102	1.06	46	0.64	50.5	0.40	127	0.21	133
103	0.96	61	0.61	57.5	0.59	120	0.35	118.5
104	0.68	96.5	0.34	103	1.04	59	0.60	57.5
105	0.83	80	0.34	103	0.43	125	0.26	127

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
106	0.75	85.5	0.30	108	0.82	91	0.49	86
107	1.59	8	1.00	3	1.23	31	0.71	37
108	0.75	85.5	0.38	92	1.43	12	0.82	21.5
109	1.02	51.5	0.85	22	0.79	97	0.50	82
110	0.72	92.5	0.37	95	1.13	44.5	0.68	42.5
111					1.02	62	0.60	57.5
112					0.67	110	0.41	106.5
113					1.41	14	1.00	5
114					0.82	91	0.54	73
115					1.28	28	0.76	27
116					0.62	116.5	0.38	111
117					1.17	39	0.77	25.5
118					0.63	114	0.42	103.5
119					0.86	84	0.57	63.5
120					0.99	64	0.67	45
121					1.05	55.5	0.64	52.5
122					1.35	19.5	0.92	16.5
123					0.84	88	0.52	78.5

Appendix Table I (continued) -

Farm No.	Clone Tjir 1				Clone PB86			
	Average function		Frontier function		Average function		Frontier function	
	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank	Efficiency Rating	Rank
124					1.36	17.5	0.81	23
125					1.10	47	0.72	33.5
126					1.05	55.5	0.65	49
127					1.32	23.5	0.94	14.5
128					1.15	43	0.78	24
129					0.92	77	0.58	61.5
130					1.08	49.5	0.72	33.5
131					0.74	104.5	0.48	89.5
132					0.37	132	0.20	135
133					0.84	88	0.45	94.5
134					1.32	23.5	0.68	42.5
135					1.04	59	0.54	73
136					0.93	75	0.45	94.5
137					1.07	52	0.55	70.5
138					0.30	138	0.13	138

APPENDIX TABLE II

MARGINAL PRODUCTIVITY OF INPUT FACTORS BY INDIVIDUAL FARMS

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
1	4.73	297.92	9.21	1.18	849.54	1.54
2	5.44	427.71	8.45	1.07	1156.41	3.22
3	3.40	172.18	6.14	0.36	606.49	0.62
4	3.66	491.12	3.19	0.34	665.55	0.60
5	9.98	489.97	19.77	1.41	537.21	1.65
6	11.46	949.07	21.77	1.71	662.37	2.11
7	2.11	1132.72	3.67	0.31	359.81	0.54
8	2.18	465.49	3.71	1.23	603.71	1.96
9	4.21	615.69	6.23	1.96	354.72	2.41
10	12.32	552.22	20.85	0.88	711.30	1.34
11	1.63	618.72	4.95	1.57	372.53	1.77
12	9,97	624.41	9.14	0.76	1069.44	1.97
13	3.87	505.45	5.37	0.83	374.80	1.02
14	1.63	628.37	3.33	0.73	605.73	1.16
15	2.61	330.26	5.26	2.77	1099.41	2.82

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
16	2.25	496.08	4.32	0.59	577.87	0.85
17	11.94	483.92	18.64	1.12	787.07	2.98
18	5.50	793.73	8.99	2.22	882.25	2.60
19	4.00	865.59	7.04	5.70	550.66	6.82
20	1.81	206.29	5.70	1.32	522.44	3.23
21	4.29	1318.37	10.81	0.17	548.19	0.59
22	21.57	840.86	29.40	1.19	493.37	1.78
23	2.48	228.19	2.31	0.80	699.62	0.95
24	3.05	1507.06	5.59	1.69	603.31	2.76
25	0.46	216.62	1.29	1.88	403.42	2.02
26	20.47	623.52	35.63	2.82	406.32	2.67
27	6.12	861.52	10.61	1.60	1195.99	3.55
28	1.74	1021.09	5.10	0.83	915.87	1.56
29	8.64	302.81	15.25	1.32	422.50	1.46
30	2.62	759.83	5.66	0.80	823.19	1.22
31	1.28	249.69	6.28	1.40	1155.73	2.47
32	3.67	503.31	2.96	3.09	797.14	3.10

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
33	3.52	737.92	4.31	1.48	696.90	2.11
34	4.98	765.11	7.09	1.17	626.03	3.29
35	2.71	528.32	4.75	1.05	440.67	1.48
36	5.13	689.00	6.50	1.23	600.58	1.76
37	2.42	770.30	4.12	5.24	1033.28	4.76
38	5.40	282.49	6.76	1.88	799.57	2.51
39	4.87	792.09	10.59	2.39	902.40	3.29
40	5.91	390.25	11.24	1.75	688.59	3.58
41	20.59	846.64	24.59	1.86	862.26	2.21
42	6.12	1006.63	16.06	2.95	728.70	5.23
43	1.03	200.34	4.68	1.32	288.03	1.09
44	1.07	314.18	3.45	0.65	474.29	0.72
45	4.39	436.96	15.00	1.60	705.68	2.51
46	2.36	691.20	5.51	0.84	305.29	1.36
47	4.77	484.27	6.74	2.20	571.81	2.17
48	1.75	350.56	2.82	5.83	899.56	7.49
49	8.50	971.25	12.07	1.44	739.60	2.87

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
50	6.86	752.80	12.73	1.54	667/82	2.26
51	2.81	1575.13	6.36	9.97	722.64	8.26
52	4.00	974.79	5.18	1.25	322.90	1.23
53	3.19	764.79	4.12	4.41	567.27	5.23
54	5.83	1029.05	12.84	1.49	797.75	2.54
55	7.58	1034.05	8.65	1.70	776.85	4.78
56	2.43	367.09	4.10	1.09	697.80	1.85
57	8.27	276.98	4.27	1.72	773.22	2.22
58	3.28	647.38	6.16	1.19	510.63	1.72
59	3.56	800.96	5.15	1.88	458.60	2.84
60	4.04	860.69	5.80	2.02	975.34	2.89
61	12.30	132.29	4.32	1.29	900.42	2.47
62	4.50	1100.83	5.44	0.59	259.86	1.36
63	13.58	728.20	21.71	0.93	508.82	1.70
64	11.65	617.34	20.05	0.95	626.87	2.14
65	13.73	966.25	22.49	1.66	889.52	3.65
66	2.99	728.41	11.30	2.25	580.59	1.95

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
67	4.07	853.26	7.00	1.14	670.55	2.35
68	2.67	521.71	7.78	0.72	322.55	1.08
69	21.01	1338.72	32.00	1.79	518.81	1.74
70	14.86	1593.74	23.39	7.65	900.12	7.53
71	3.64	777.19	6.88	1.23	768.67	2.45
72	5.47	1121.14	6.68	1.41	708.71	1.45
73	2.38	439.86	7.05	9.55	979.93	8.27
74	7.53	555.73	16.95	1.53	734.15	1.78
75	10.66	649.45	16.44	1.21	713.25	1.73
76	9.53	1118.48	15.52	1.29	683.47	2.01
77	5.08	479.54	10.65	2.71	625.57	3.71
78	3.71	695.03	10.24	1.07	985.39	1.60
79	2.73	1197.21	5.34	0.95	668.95	1.39
80	18.11	1206.87	34.00	1.96	523.96	2.64
81	6.12	900.58	7.89	7.54	613.91	9.97
82	23.01	1159.83	24.35	1.98	841.21	3.68
83	4.85	568.42	5.63	6.97	630.79	7.76

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
84	2.10	1015.01	4.08	1.48	715.98	2.39
85	4.87	1589.93	11.85	2.53	611.49	5.78
86	11.43	498.78	17.27	5.69	960.09	4.86
87	2.45	374.13	2.33	2.64	516.54	4.40
88	5.17	606.04	9.41	3.19	446.89	4.22
89	8.82	739.82	13.26	1.72	551.52	2.35
90	2.53	769.96	4.75	7.61	890.79	6.48
91	9.18	448.23	15.49	1.84	456.72	1.67
92	4.51	658.68	9.73	1.45	421.59	1.65
93	26.23	943.09	46.89	8.76	608.76	7.79
94	2.38	508.48	5.65	5.57	700.19	5.74
95	4.84	644.39	5.81	2.89	619.66	3.22
96	7.07	784.22	12.88	3.21	715.09	8.09
97	3.04	682.11	5.26	0.95	531.53	1.36
98	2.74	808.61	6.59	3.48	778.05	4.39
99	8.66	1265.56	15.04	0.99	975.10	2.42
100	4.16	913.61	7.29	4.05	793.21	6.38

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
101	9.87	1413.83	22.09	4.23	995.11	6.03
102	0.96	291.03	1.17	1.93	726.88	2.44
103	6.13	429.38	9.24	3.84	606.94	3.60
104	4.29	1046.73	7.23	0.71	265.31	1.09
105	6.31	339.55	10.07	0.69	398.27	0.61
106	2.04	660.41	5.07	0.88	274.09	0.42
107	18.86	847.47	21.95	3.58	990.46	3.37
108	4.51	989.68	9.50	1.56	322.09	2.01
109	6.47	608.88	13.89	2.95	641.07	1.71
110	12.34	736.32	20.27	2.35	290.75	2.57
111	10.38	720.69	15.91			
112	2.12	505.38	4.02			
113	7.46	1009.24	9.59			
114	2.99	765.62	7.23			
115	4.03	639.12	8.32			
116	2.44	603.56	3.77			
117	27.98	903.85	33.98			

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
118	2.61	699.47	5.66			
119	6.06	698.23	12.46			
120	9.03	859.21	17.63			
121	2.69	1182.32	4.62			
122	8.76	1192.98	20.30			
123	4.54	913.61	6.16			
124	5.47	1250.53	7.81			
125	12.58	851.60	20.38			
126	4.92	882.42	8.33			
127	22.01	1180.17	25.56			
128	1.74	1526.12	4.70			
129	6.08	888.53	9.93			
130	2.61	1589.10	5.96			
131	4.89	741.91	8.26			
132	0.83	196.52	2.28			
133	3.56	189.06	3.12			
134	7.05	828.87	18.23			

Appendix Table II (continued) -

Farm No.	RUBBER CLONE					
	Clone PB86: Marginal Productivity of			Clone Tjir 1: Marginal Productivity of		
	Planting Density	Farm Size/Land	Tapping Frequency	Planting Density	Farm Size/Land	Tapping Frequency
135	15.39	953.32	30.35			
136	18.29	925.61	28.56			
137	12.84	796.21	23.89			
138	3.59	134.18	3.17			