IMPLICATION OF ALTERNATIVE REPLANTING

STRATEGIES FOR THE AREA AND

PRODUCTION OF RUBBER IN SRI LANKA

A SIMULATION PLANNING MODEL

by

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D E C L A R A T I O N

Except where otherwise indicated, this sub-thesis is my own work.

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ABSTRACT

The rubber industry in Sri Lanka plays a vital role as the second major foreign exchange earner. The government is greatly concerned with the need to raise rubber production. Since there is little land available to expand production yield from existing areas could be raised by replanting with high yielding clones and by using more inputs. The present official replanting scheme operates with an implied optimum target of a 33 years replacement cycle. But in practice the rubber farmers operate a number of replacement cycles.

This study attempts to analyse the strategies underlying the different replanting cycle and their implications for future area and production. Among those strategies five have been selected for investigation. The data collected by the Rubber Industry Master Plan Study of Sri Lanka on age-specific area provides the basis for the study. Further, data collected on physical conditions of the rubber plantation and the farmers expressed intention to replant provide a better understanding of real situation.

By using the simulation approach it has been possible to forecast the area figures under five strategies investigated. In order to estimate production figures from the estimated rubber mature area some yield curves have been used. The accuracy of the area, production estimation, yield curves, and the model are tested by the validation procedure. As a result there is confirmation that the strategy based on farmers' intention to replant is closer to reality than the other alternatives

On the basis of the results, certain conclusions are drawn which would be useful in planning and policy formulation in the rubber industry. The direction in which further studies should be made is also indicated.

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CHAPTER 1

INTRODUCTION

Sri Lanka has a population of about 14.2 million, increasing at 1.7 per cent annually (Central Bank of Ceylon, 1978). The gross national product in 1978 at current factor cost prices has been estimated at Rs.40,098 million, reflecting a per capita income of Rs.2827 (U.S. dollars 182). The economy grew by 8.2 per cent[1] in 1978 and this was more than twice the annual growth during the previous decade. The share of agriculture in gross national product was 26.2 per cent in 1978. Agricultural exports, mainly of perennial crops, provide more than seventy per cent of total export earnings, while the annual crops are mostly consumed locally. Tea is the largest foreign exchange earner, followed by rubber and coconut. The gross earnings from industrial exports, comprising mainly garments, ceramics, graphite

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1 GNP at constant (1970) factor cost prices.

Table 1.1

Composition of Exports 1974-78

Commodity	Value in Rupees (Million)				
	1974	1975	1976	1977	1978
1. Tea	1360	1392	2100	3503	6401
2. Rubber	738	654	890	931	2021
3. Coconut	397	397	382	335	972
4. Minor Agricultural Crops*	267	202	279	452	902
5. Industrial exports*	492	498	761	919	1891
6. Gems	109	180	261	298	531
7. Other Exports	109	70	142	200	488
TOTAL EXPORTS	3492	3933	4815	6638	13206

Commodity	Percentage of Total Exports				
	1974	1975	1976	1977	1978
1. Tea	38.4	35.4	43.6	52.8	48.5
2. Rubber	21.1	16.6	18.5	14.0	15.3
3. Coconut	11.4	10.1	7.9	5.1	7.4
4. Minor Agricultural Crops*	7.6	5.1	6.0	6.8	6.8
5. Industrial Exports*	14.1	12.7	15.8	13.8	14.3
6. Gems	3.1	4.6	5.4	4.5	4.0
7. Other exports	3.1	1.8	2.9	3.0	3.7
TOTAL EXPORTS	100.0	100.0	100.0	100.0	100.0

* selected items

Source: Central Bank of Ceylon, 1978, Table 11.3, Page 242.

and glycerine, together contribute less than the earnings from rubber. The development programmes have been financed mainly from export crop earnings.

In the Sri Lankan economy the rubber industry plays a vital role as the second major foreign exchange earner, accounting for about 15 per cent of foreign exchange earnings. Its importance is shown in Table 1.1(above).

Approximately 200,000 workers, 5 per cent of Sri Lanka's total labor force, are directly employed in the rubber industry. The well-being of these workers and their families, as well as a further 150,000 families of smallholders who own plots of rubber of less than ten acres (4.05 hectares), is directly linked with the development of the rubber industry.

1.1 Area under Rubber

Rubber is grown in Sri Lanka in wet zone land of low and medium elevation, mainly in the districts of Kalutara, Kegalle, Ratnapura, Colombo and Galle. The area under rubber at present registered with the Rubber Controller under the Rubber Control Act[2] is 263,000 hectares.

However the total rubber area in nine main rubber growing districts as estimated by the aerial photographic analysis of the Rubber Industry Master Plan Study (1979)[3] is 210465 hectares ± 4 per cent. This figure is well below that previously mentioned under the Rubber Control Act but it is close to the estimations provided by the Agricultural Census (1972/73) and Agricultural Productivity Committee Survey (1973), with figures of 205,800 Ha. and 290800 Ha. respectively. The total rubber area, estimated from photographic analysis by the Rubber Industry Master Plan Study, is broken down by districts and given in Table 1.2.

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2 The Rubber Control Department of Sri Lanka administers the Rubber Control Act, No.11 of 1956, and the Rubber Replanting Subsidy Act, No.36 of 1953. Under the Rubber Control Act, the Department is responsible for the collection of statistics of acreage, production, consumption and exports of rubber; for the issue of permits for the planting of new areas in rubber and the replanting of worn-out rubber areas; for the issue of licences to rubber dealers; and for the performance of any other duties in furtherance of the interests of the rubber industry. The administrative report of the Rubber Controller deals with the activities of the Department under the Rubber Control Act and the operation of the Rubber Replanting Subsidy Scheme, under the Rubber Replanting Subsidy Act.

3 The government of Sri Lanka with the assistance of the U.K. government has set up a Master Plan for future development of the rubber industry. The recommendations of the study were submitted by September 1979.

Table 1.2

Total Rubber Area

DISTRICTS	ESTIMATED RUBBER AREA (Ha)	PERCENTAGE OF TOTAL
Kalutara	42,400	20.3
Kegalle	61,400	29.4
Ratnapura	38,100	18.3
Colombo	31,400	15.0
Galle	15,700	7.5
Matara	7,600	3.6
Kurnegate	5,900	2.8
Matale	2,800	1.3
Kandy	3,400	1.6
TOTAL	208,700	100.0

Source: Report on the Rubber Industry Master Plan Study - Volume V. Economic Studies - September 1979 - Page (ii) of the Summary.

The area under rubber is classified by the Rubber Controller into small holdings below 10 acres (4.05 Ha.), medium holdings of 10 to 100 acres (40.5 Ha.) and large estates of over 100 acres. However the Land Reform Laws of 1972 and 1975 vested over 71630 Ha. in the Land Reform Commission, limiting private individuals to a maximum of 50 acres (20.25 Ha.). As a result of this, about 75 per cent of the total land is in private holdings below 20.25 Ha., of which 95 per cent, representing 30 per cent of the area, are below 4.05 Ha. while the majority are below 0.81 Ha. (2 acres).

It has been estimated that significantly large areas of marginal land have been withdrawn from rubber production during the past two decades. Due to the high prices of rubber in the immediate post war period, some of the rubber plantations were exploited very intensively. On the other hand, rubber areas were abandoned in the following period of lower prices. Herath (1975) has commented that the performance of the rubber industry in the recent past has been unsatisfactory, mainly caused by a fall in prices. Further he emphasized that the response of rubber producers to the high prices during the Korean War period and also the price-output relationship for 1971, 1972 and 1973 indicate that there is a positive response. The Draft Report of the Smallholder Rubber Replanting Project of Sri Lanka (FAO-World Bank 1979) has identified some reasons for the withdrawal of land from rubber production; the uncertainty surrounding land reform, the general disincentive effects on producers of high levels of export duties and cesses[4] and the inadequacies of government supporting institutions are all significant constraints.

Additionally plantation areas have been abandoned because of high elevation, steepness, inadequate rainfall, water logging, crop diversification and urban development.

1.2 Rubber Production and Processing

The total rubber production of Sri Lanka rose from about 97,000 tons of rubber in the mid 1950's to over 140,000 tons in 1967, representing an increase in the share of world natural rubber (NR) production from 5.0 per cent to 5.6 per cent. In the period 1972-1974 production had increased only marginally to 142,400 tons which was only 4.3 per cent of world NR production. Since then production in Sri Lanka has stagnated, while that of other competitors has continued to rise. As a result the 1978 Sri Lanka output of 156,000 tons was barely 4 per cent of world production. As there is only little land available for new planting, any further rises in production must come mainly through increasing the yield from existing areas; this could be achieved by replanting the over-age rubber areas with high yielding clones and by using increased amounts of fertilizer and other inputs (FAO-World Bank, 1979).

In Sri Lanka raw rubber is processed into Ribbed Smoked Sheet (RSS), latex crepe, sole crepe, scrap crepe, concentrated latex and technically specified rubber. It is estimated that the 95 per cent of RSS comes from small holdings below 4.05 Ha. Both the latex crepe and sole crepe are processed by large estates, now

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4 The total, some 50 per cent of f.o.b. value, is diverted to government as export duty and cesses. Corresponding figures for other rubber producing countries range from 27 per cent for Malaysia to 13 per cent for Indonesia.

almost exclusively in the hands of the State. 'Crepe' is special purpose rubber which commands a higher price premium over the Ribbed Smoked Sheets. Sri Lanka's latex crepe is universally considered as a high quality rubber, having consistently obtained a premium over similar types of rubber produced in other countries (Rubber Controller, 1974).

1.3 Rubber Replanting and Government Replanting Policies

Replanting of rubber is a major investment of the industry especially for smallholders. In addition to the finance required for this investment, there is also loss of income during the immature period of the new cycle. Although intercropping can bring additional income during this period, it is not practised on any great scale. This perhaps is largely due to lack of capital for initial investment in intercrops, coupled with factors such as uncertainty of markets, prices of the produce and prevention of theft. There has also not been any active encouragement of intercropping and demonstrations have not been widespread. Replanting payments do provide for the supply of most inputs, but they do not cover the total cost of the immature period and foregone income. The subsidy scheme which provides the replanting payments was started in 1953. This was introduced with a view to accelerating the replanting of Sri Lanka's worn out rubber area. At the beginning the scheme was financed by the cess collected on exports of sheet rubber. Subsequently, the cess has been levied from other types of rubber as well (crepe rubber, scrap rubber, etc.) and credited to the 'subsidy fund' for its operation. Since 1967, in terms of the Rubber Replanting Subsidy (Amendment) Act No.3, the Treasury of Sri Lanka makes contributions from the consolidated fund to the Rubber Replanting Subsidy Fund.

In order to qualify for assistance for replanting under the above scheme, the instructions on uprooting and clearing of old trees, soil conservation, fencing, budded stumps, weeding, cover crop, manuring, etc. must be observed. If these requirements are in order, the replanting subsidies are released in seven instalments over the five year period after planting.

The subsidy paid to farmers for replanting from the inception of the scheme is given in Table 1.3.

Table 1.3

Grant Paid under Rubber Subsidy Scheme (rupees/acre)

Since the Year	Smallholdings	Medium Holdings	Estates
1953	1000	900	700
1963	1200	1100	1000
1967	1500	1500	1400
1975	2000	2000	2000
1977	3000	3000	2000
1979	4000	4000	4000

Source: Department of Rubber Control, Sri Lanka.

As a result of the success of the replanting subsidy programme, during the first five years the target of 75,000 acres (30350 Ha.) was exceeded and about 93,978 acres (38030 Ha.) were planted (Rubber Controller, 1974; p.85). A similar trend in replanting was achieved in the second five year period and a further 93,702 acres (37,920 Ha.) were planted. However since 1963, the rate of replanting has fallen to extremely unsatisfactory levels, in spite of an increase in the subsidy rate. At present it is well below the target of 6070 Ha. a year. Table 1.4 gives details of progress under the scheme since its inauguration in 1953.

The rubber replanting subsidy scheme is operated with the aim of achieving a replanting cycle of 33 years. This brings about 3 per cent of the total area under rubber into replanting annually. In recent years this target has not been achieved even with the inducement of a rise in the subsidy. On the assumption that each age

Table 1.4

Area Replanted 1945-1978 (Ha.)

Year	Total Area	Replanted Area Total	S.H	M.H	Est.	New Planted Area	Replanted Area as a Percentage of Total Area
1945	267126	38	na	na	na	1104	0.02
1946	267025	666	na	na	na	613	0.25
1947	266794	857	na	na	na	183	0.33
1948	266538	592	na	na	na	119	0.23
1949	265226	890	na	na	na	232	0.34
1950	265273	1565	na	na	na	272	0.59
1951	265385	1387	na	na	na	570	0.53
1952	265943	1700	na	na	na	553	0.64
1953	266165	2348	188	400	1780	348	0.89
1954	266886	7472	1588	2075	3809	619	2.80
1955	267605	8464	2270	2484	3710	502	3.17
1956	266902	9953	2740	2839	4374	174	3.73
1956	267500	9809	2757	3029	4024	1130	3.67
1958	269184	8355	2650	2357	3348	935	3.11
1959	270517	7503	3150	1848	2504	813	2.78
1960	270829	7244	2911	1837	2495	786	2.68
1961	271591	7565	3106	1674	2807	572	2.79
1962	229684	7269	2831	1413	3004	277	3.17
1963	229952	6442	2489	1090	2863	268	2.81
1964	230123	5487	1985	1559	1942	171	2.39
1965	230384	5061	1956	1284	1821	260	2.20
1966	230540	4689	1960	863	1866	157	2.04
1967	230413	4083	1337	858	1888	55	1.78
1968	230448	5155	1734	953	2470	237	2.24
1969	230228	4892	1665	707	2520	126	2.13
1970	230178	4145	1430	691	2023	112	1.80
1971	229953	3431	1207	553	1672	238	1.50
1972	229655	3539	951	448	2139	180	1.55
1973	228673	2946	930	374	1641	186	1.29
1974	228100	2865	986	338	1540	34	1.26
1975	227730	3230	1128	520	1582	142	1.42
1976	227074	2550	1132	317	1102	56	1.12
1977	226660	2617	1196	313	1107	45	1.15
1978	226400	3225	1415	320	1490	378	1.42

Source: Department of Rubber Control, Sri Lanka.
Central Bank of Ceylon, 1978.

Table 1.5

Over Age Rubber ('000 hectares)

	Holding Size			
	Smallholders	Medium Size	Large Estates	Total
Rubber Area	69.2(31)	52.6(23)	104.5(46)	226.3(100)
Replanted since 1953	45.7(66)	30.8(58)	60.7(58)	137.2(61)
Overdue for Replanting	25.3(34)	21.9(42)	43.7(42)	89.1(39)

Source: Department of Rubber Controller - Sri Lanka, 1977.
Percentage values are given in parenthesis.

of tree has a 3 per cent representation in the total rubber area, then the 0 to 7 immature age group should represent 24 per cent of the total replanted rubber area. However the actual figure is very much lower, about 10 per cent among each size group. This suggests an ageing national rubber plantation. In fact the remaining life of rubber trees calculated by the Rubber Industry Master Plan Study of Sri Lanka, shows that 44 per cent of trees have between 0 and 9 years' life remaining (Rubber Industry Master Plan Study, 1979; p.7). The registers of the Rubber Controller show that there are about 89070 Ha. (220,000 acres) of overage rubber, representing about 40 per cent of the crop area, which have to be replanted in the near future as summarized in Table 1.5 (above). The historical reasons for the accumulation of this 'backlog' is discussed in detail in Chapters 2 and 3.

In order to remedy this situation the government of Sri Lanka, in collaboration with the FAO/World Bank cooperative programme, studied the feasibility of implementing a smallholder rubber replanting project (FAO-World Bank, 1979). For the first phase of the project the development of supporting institutions would be the most important initial objective. This would prepare the way for a rapid subsequent acceleration of replanting. Project replanting targets are modest for the first two years, but rise sharply thereafter. The first phase of the project is to be limited to two revenue districts (Kalutara and Ratnapura), due to the infrastructural facilities. These two districts contain 40 per cent of the total rubber area of Sri Lanka and an estimated 24290 Ha.of smallholdings which are already over age. With the necessary inducement and institutional support a replanting target of 9720 Ha.is considered possible over a period of five years.

The project also plans for intercropping, especially during the period of immaturity, wherever it is suitable. Based on the present replanting rate of this area of some 570 Ha. per annum [5] this project would achieve a net gain of 6880 Ha. It is estimated that the project would benefit an estimated 12000 smallholders, many of them with income below the poverty line of Rs 3600/- per annum. It also has the advantage of creating employment for about 2800 persons in farms and 120 in supporting services. The estimated economic rate of return is 22 per cent. It has been decided to implement this project in the beginning of 1981.

The declining rate of replanting has been facilitated by several factors such as fluctuation of prices, uncertainty of land reforms, and the effects on producers of high level of export duties and taxes. It is to be noted that the rubber plantations were very intensively exploited during the period of high prices, which is explained in detail in Chapter Three. But this had adverse effects on the production cycle in subsequent years. As a result of these factors, there are now a number of replanting cycles operating, although the standard cycle is 33 years. Therefore the future of the rubber industry is dependent on the behaviour of such strategies.

1.4 Objectives of the Study

The objective of this study is an examination of rubber replacement strategies, using a simulation approach. First, emphasis has been placed on gaining a clear understanding of the alternative replacement strategies currently in use. Factors such as the farmers' intention towards replanting, intensity of exploitation, pricing and size of rubber holdings are examined in relation to the choice of replanting strategy to be utilized. Second, a simulation approach is used to make an inventory projection for rubber areas which incorporates these factors into the data collected by the Rubber Industry Master Plan Study of Sri Lanka. Finally, yield curves are examined for rubber on smallholdings and on large holdings, based on the replanting policies under study. By applying the age specific yield curves to the age specific area, different projections are also made of expected production levels.

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[5] This is based on the figures estimated by the project team.

CHAPTER 2

FACTORS AFFECTING THE ALTERNATIVE REPLANTING STRATEGIES OF RUBBER

The area under rubber is governed by the rubber replanting policies. This is to a large extent a reflection of the economic decisions taken by the thousands of farm households. The long term investment decision of rubber replanting cannot be separated from a multitude of other decisions, both short-term and long-term, made by farmers. The decision to replant a particular rubber stand, plant up a new area or choose another crop takes place in the normal course of attempting to maximize some form of a multi-period utility function. The variables in such a function include non-economic and economic factors. Therefore the farmer's decision cannot be adequately assessed without an appreciation of the major factors involved in reaching it.

It is useful to discuss briefly the theory of replacement before detailing the behaviour of such factors. The principles of optimal assets replacement are most clearly stated by Perrin (1972). The assets should be replaced when the expected returns from the present assets begin to fall below the highest annuity that can be obtained from its replacement by the best 'challenger'. This principle has been applied to rubber in Sri Lanka by Jayasuriya (1973) and Etherington and Jayasuriya (1976) and to rubber in Malaysia by Etherington (1977). The deterministic model developed by Etherington (1977) provides a ready and clear explanation of the theory in brief.

For a single cycle of the assets the present value of the stream of earnings can be expressed as

$$C(0,s,1) = \int_0^s R(t)e^{-pt}\,dt + M(s)e^{-ps} \qquad (2.1)$$

Where

C (0,s,1)	=	present value of the stream of residual earnings from a challenger to be initiated in year 0 and replaced by age 's' by a challenger.
R (t)	=	net earnings. This is negative in the case of rubber during its immaturity.
M (s)	=	Salvage value (timber of rubber)
p	=	discount rate.

In the case of rubber, which has a series of identical cycles, the problem is to ascertain the replacement date which maximizes the value of the entire income stream.

The stream could be expressed as:

$$C(0,s,\infty) = C(0,s,1) + e^{-ps}\,C(0,s,1) + e^{-p2s}\,C(0,s,1) + \ldots \qquad (2.2)$$

The reduced form of this gives the expression for the present value of a perpetual annuity received in every 's' years, as shown in equation (2.3).

$$C(0,s,\infty) = \frac{1}{1-e^{-ps}} C(0,s,1) \tag{2.3}$$

The following first order condition gives the maximized value for equation 2.3, with respect to the replacement date 's'.

$$\{R(s)+M'(s)\}e^{-ps} = \{\int_0^s R(t)e^{-pt}dt+M(s)\} \frac{p}{e^{pt}-1} \tag{2.4.1}$$

Where M'(s) = first derivative of the salvage function

The above equation states the general principle of replacement, that the discounted marginal returns must equal the annuity formed from the discounted total flow of earnings from the assets plus the salvage value. Further this could be written by using 'r', the discrete interest rate.

$$\{R(s)+\Delta M(s)\}(1+r)^{-s} = \{\sum_0^s R(t)(1+r)^{-t}+M(s)\} \frac{r}{(1+r)^{s}-1} \tag{2.4.2}$$

This equation states that the annuity formed by the discounted annual earnings plus salvage rate must equal annual returns plus the change in the salvage value. But in real life this equality condition is unlikely to hold. Therefore the decision rate of replacement could be expressed in the form of an inequality.

$$\{ R(s)+\Delta M(s) \} > \{ \sum_{0}^{s} R(t)(1+r)^{-t}+M(s) \} \frac{r(1+r)^{s}}{(1+r)^{s}-1} > \{ R(s+1)+\Delta M(s+1) \} \qquad (2.4.3)$$

In order to calculate age 's', one must repeatedly proceed to check the inequalities in equation 2.4.3 in each time period.

The application of the equation 2.4.3 to rubber conditions in Sri Lanka, using changes in yield, prices, interest rates, subsidy rates, tapping systems and technological change, leads to a number of conclusions (Jayasuriya, 1973; Etherington and Jayasuriya, 1976). In order to assess the farmer's decision on replanting in future, it is useful to discuss the manner in which optimal replacement dates change with changes in expectation of the above factors.

2.1 Yield Expectation

The government replanting policy is based on a standard replacement cycle of 33 years. Trees are generally tapped for the first time between the fifth and sixth year after planting, when the circumference of the tree reaches 18 inches at a height of three feet from the ground. Rubber yields gradually increase during the early years of tapping, then continue at a stable output for a certain period, and thereafter begin to decline gradually in the later years. However with a high intensification of tapping in the latter part of the life of the tree, a considerable amount of high output can be achieved. This pattern of yield over the age of rubber is set out in Tables 2.1 and 2.2 which show the yield per hectare, calculated by different sources. A detailed description of the tapping panels, phases and yields are given in Sections 3.1 and 3.2 of Chapter 3.

Table 2.1

Yields in Kilogrammes per Hectare per Year

Estates Below 40.5 Ha. (100 acres)

Year of Tapping (x)	ANRPC (xx)	RRISL (xxx)	RRISL (hypothetical) (xxxx)
1	420	560	800
2	672	700	1000
3	840	805	1200
4	980	910	1350
5	1120	980	1450
6	1120	1050	1550
7	1120	1120	1650
8	1120	1170	1700
9	1232	1190	1750
10	1232	1210	1800
11	1232	1210	1800
12	1232	1190	1750
13	1232	1170	1700
14	1232	1140	1650
15	1064	1110	1550
16	1064	1010	1500
17	1064	960	1350
18	980	860	1250
19	960	770	1150
20	960	630	900
21	-	700	650
22	-	900	-
23	-	800	-
24	-	700	-
25	-	900	-

x generally assumed to commence tapping when trees are about six years of age

xx largely based on the yield pattern of PB86 taking the areas of various clones into consideration - Association of Natural Rubber Producing Countries

xxx yield curve of clone PB86 disounted for smallholders by the Rubber Research Institute of Sri Lanka (RRISL)

xxxx Hypothetical yield curve of clones planted in 1981 and after - RRISL - assuming that the new plantation started in 1981 and for which planting material and fertilizer were issued by the state would give better yield

Table 2.2

Yields in Kilogrammes per Hectare per Year

Estates above 40.5 Ha.(100 acres)

Year of Tapping	ANRPC	RRISL	RRISL (Hyp.)
1	420	640	1000
2	728	800	1200
3	924	920	1450
4	1092	1040	1600
5	1172	1120	1700
6	1232	1200	1800
7	1288	1250	1900
8	1344	1330	1950
9	1400	1360	2000
10	1400	1380	2050
11	1400	1380	2050
12	1400	1360	2000
13	1400	1340	1950
14	1400	1300	1900
15	1400	1250	1800
16	1400	1160	1750
17	1400	1100	1650
18	1300	1000	1500
19	1200	900	1400
20	1150	800	1200
21	-	800	1000
22	-	1000	-
23	-	900	-
24	-	800	-
25	-	1000	-

The yield pattern is dependent on a large number of inputs; among them the age of the tree, the clonal type, the tapping system, the application of chemical stimulation and fertilizer, pest and disease control and climatic factors are crucial. However in the process of determining the influence of yield for alternative replacement strategies, it is very important to discuss the expectation of yield, rather than explaining any other factors.

Yield expectation is to a large extent influenced by technological change. The economic importance of recent technological change reduces the immature period and raises yields in the early years of the cycle. The impact of these changes on optimal replanting dates and annuity values are crucial (Etherington and Jayasuriya, 1976).

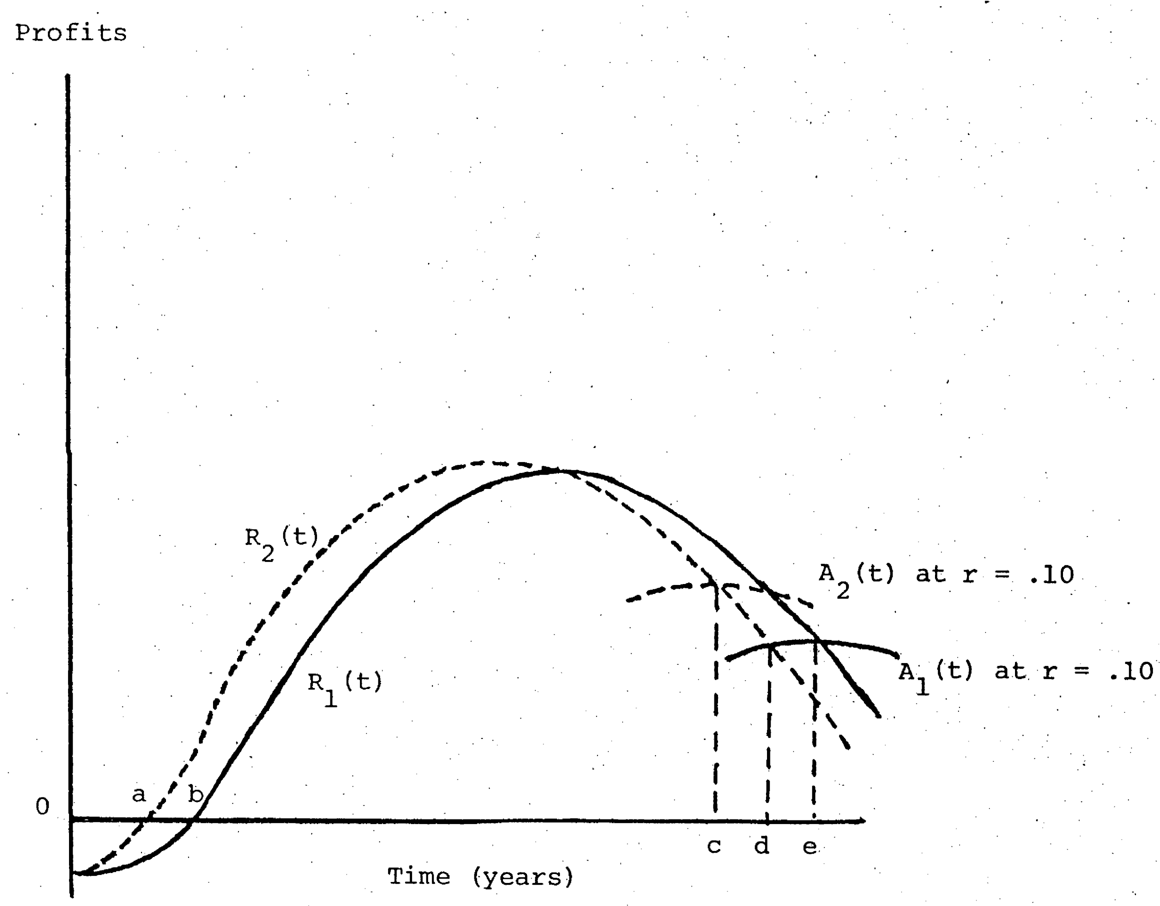
The effect on the date of replanting is dependent on the type of technological change, i.e. embodied or disembodied. Disembodied technological change can be adopted at any stage of production. In the case of rubber this might be in the form of alternative management practices on an existing stand of trees, e.g. ethral stimulation or intensification of tapping. This could be applied to an existing plantation and does not necessitate a delay until the planting of new trees. Therefore in this case both the annual profit function and annuity curve are raised. Since the effect is not only to raise the curves but also to change their shapes, the direction of change in the optimal date cannot be predicted.

Adopting a high yielding clone is an example of embodied technological change. These high yielding characteristics are embodied in the genetics of the specified clones and this could not be 'injected' into an existing stand of trees. The result of embodied technological change can be to reduce the immature period and to raise the expected yields of the potential new stand of trees (i.e.the 'challenger' in Perrin's terminology). These changes will have the effect of raising the expected annuity curve, while the net revenue curve of the existing stand of trees remains unchanged.

Where the technology reduces the immature period or raises yields in the early years, the impact on optimal replanting dates and annuity values, and hence profitability, is very marked indeed. The analysis carried out by Etherington and Jayasuriya (1976) examines a radical change in embodied technology which reduces the immature period from 5 to 3 years. The reduction of the immature period depends on the interest rate and how fast yields in later years fall off. At the lowest interest rate (0 to 10 per cent) the impact of the data used in that analysis is to reduce the length of cycle by the amount of reduction in the immature period. At 15 per cent interest rate the reduction in the length of cycle (5 years) is substantially greater. The reason for this situation is explored in Figure 2.1 which shows that when the immature period is reduced there is an effect on the resultant increase in the annuity curve.

Figure 2.1

Effects of Reduced Immature Period



R(t) = annual net returns

A(t) = annuity

ab = de → simple effect of reduced immature period

cd → effect of increased annuity

Source: Etherington and Jayasuriya (1976)

Thus the theory of replacement explains that the embodied technological change (improved clones) will raise the expected yield and, if other things remain constant, the effect is to raise the annuity curve, resulting in earlier replanting. Therefore it can be concluded that the 'yield' has an impact on the alternative replanting strategies. However the historical data given in Table 2.3 shows that the average yield per hectare in kilogrammes has increased gradually since 1953 and had almost doubled by 1977. A major factor causing this increase in yield was the Rubber Replanting Subsidy Scheme (RRSC) which started in 1953. The programme encouraged the farmers to replant rubber with high yielding budded stumps (Rubber Controller, 1974, pp.91.). The high yielding budded stump exhibits different characteristics not only of yield but also in many other important aspects such as resistance to wind damage, pests and diseases.

This suggests that not only does yield expectation affect the alternative replacement strategies, but also that factors such as prices, subsidy, etc. are also important. Hence we now turn to an examination of these factors.

2.2 Price

In discussing the effect of changes in price expectations for alternative replacement strategies, it is important to distinguish between long term and short term expectations of prices. Theoretically, if the long term price expectation of rubber is rising, this will shift the expected annuity curve upward resulting in earlier replanting. Such a change does not affect the current net revenue. In contrast, a rise in the short term price expectation will affect only the current net revenue curve, without affecting the expected annuity. This will result in a delay in replanting. In the case where both short term and long term price expectations change together, this could have an impact on the date of replanting, since it affects both current net revenue and annuity. The result of this on the replacement date is indeterminate.

Table 2.3

Average Yield, Price, Replanting and New Planting

1948-1978

Year	Average Yield (Kg/Ha.)	Average Price (Rs/Ha.)	Replanted Area (Ha.)	New Planted Area (Ha.)
1948	402	1.36	592	119
1949	375	1.23	890	232
1950	355	3.43	1565	272
1951	380	4.73	1387	570
1952	363	3.04	1700	553
1953	461	2.97	2348	348
1954	426	2.42	7472	619
1955	393	2.82	8464	502
1956	420	3.19	9953	174
1957	447	2.49	9809	1130
1958	464	2.09	8355	935
1959	428	2.75	7503	813
1960	467	2.71	7244	786
1961	478	2.20	7565	572
1962	486	2.13	7269	277
1963	493	2.05	6442	268
1964	504	1.98	5487	171
1965	627	2.00	5061	260
1966	682	1.96	4689	157
1967	725	1.74	4083	55
1968	752	1.94	5155	237
1969	754	2.31	4892	126
1970	792	2.00	4145	112
1971	736	1.76	3431	238
1972	737	1.78	3539	180
1973	777	2.60	2946	186
1974	687	2.80	2865	34
1975	774	na	3230	142
1976	790	na	2550	56
1977	794	4.51	2617	45
1978	845	6.92	3225	378

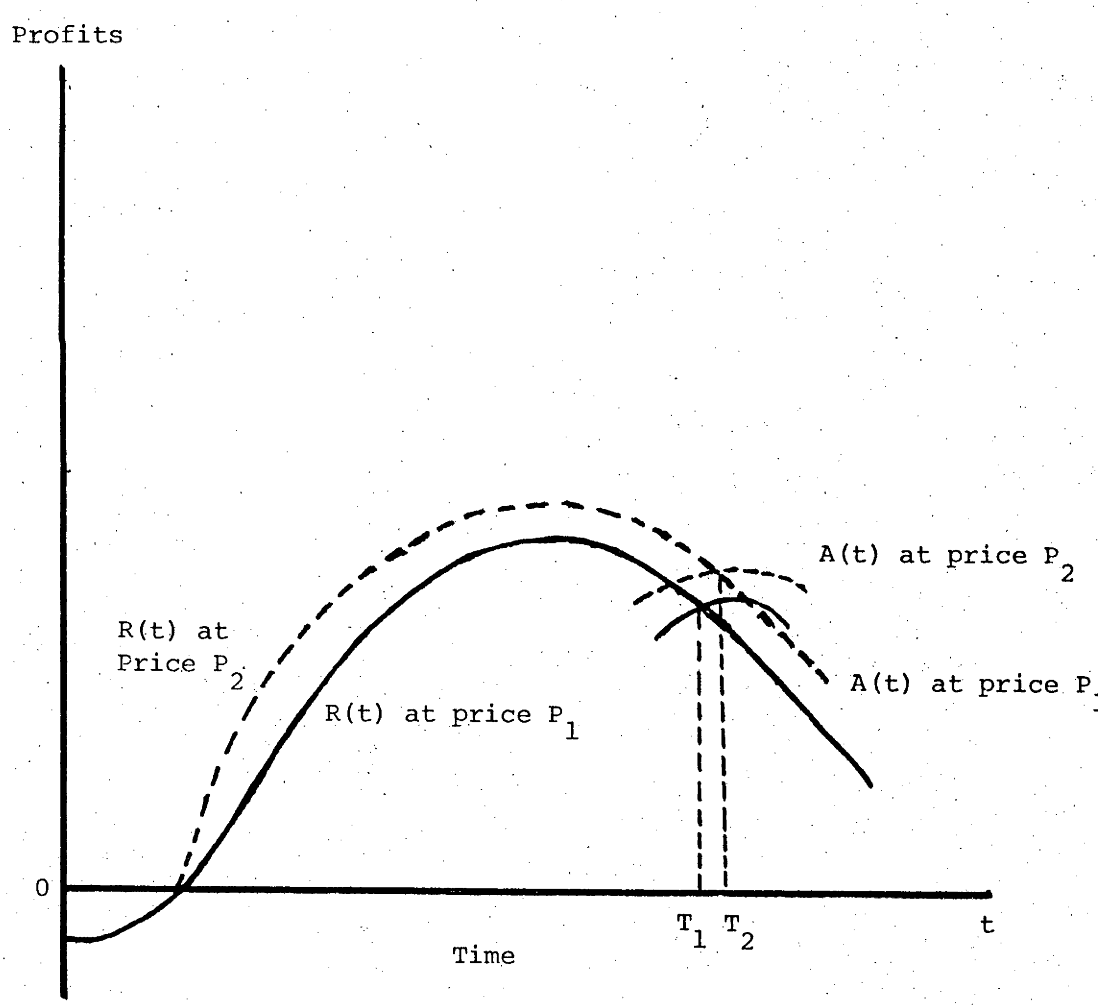
Source: Rubber Controller, 1974.
Central Bank of Ceylon, 1978.

The behaviour of the decision rule given in Equation (4.3) to the changes in prices is presented in Figure 2.2, which shows the annual net revenue curves as R(t) and the annuity curves as A(t). The salvage value M(s) in this case is presumed to be insignificant.

In Figure 2.2, it is clear that the changes in rubber prices have little influence on the replacement dates since both the annuities and net revenue curves move up and down together. The conclusion drawn in this analysis is very general and is not tied to any specific data or to any particular country.

FIGURE 2.2

Effects of Price Changes on Optimal Replacement Dates



The actual behaviour of the average price of rubber in Sri Lanka is given in Table 2.3. The very high prices in the early 1950's were caused by the Korean War. The reaction of the producers to this leap in prices was immediate; both small holders and large estates raised their output, as a result of short term price expectation. The yield obtained per hectare of mature area in smallholdings in 1950 was 34 per cent higher than in 1949. The respective figure for estates was 22 per cent higher (Rubber Controller, 1949, p..50).

Table 2.3 suggests that the farmers responded to short term price expectation in 1950-51 by replanting very few areas and attempting to maximize profit from the existing areas.

The effects of the price boom, however, were not all negative after the Korean War, especially as prices in the next few years continued to be relatively high, but lower than the peak in 1950-51. Subsequently in the following two decades, there was a steadily declining trend in rubber prices. Although the profit margins increased in 1973, with higher prices received in consequence of the oil crisis, the slump in rubber prices since the latter half of 1974 has created an atmosphere of uncertainty in the rubber market. The rubber industry has been able to survive under the depressed price levels largely because of the massive replanting undertaken in the early years of the Rubber Replanting Scheme (Rubber Controller, 1974, pp.87). The subsidy was a major cause of the increase in the annuity of future plantings as against current income.

2.3 Subsidy

Theoretically the result of the subsidy for replanting only affects the annuity. Therefore any increase in subsidy should induce earlier replanting. The study carried out by Jayasuriya (1973) indicated that increases in the level of replanting subsidy tend to shorten the optimum replacement age. Further it concluded that decreases in replanting costs by subsidy shorten the optimum replacement age, since this reduces the financial burden of replanting.

However the increase in subsidy just in money terms is not sufficient incentive to replant. The survey done by Jayasuriya and Carrad (1976) reported the difference in replanting subsidy needs between groups. A majority of those who used hired labour claimed the subsidy was insufficient, while most users of family labour thought the subsidy adequate to cover the actual cost. However it is important that apart from covering the actual cost, the present subsidy is not sufficient for smallholders to compensate their forgone regular income until the replanted area becomes mature. The only source of cash income for most of the smallholders appears to be rubber (Premachandra and Houtman, 1976). Although the owners of large holdings claim that the subsidy is insufficient for the use of hired labour, they do have other sources of income to compensate for having foregone six years' income during the immature period. It is also more likely that the owners of large holdings would replant part of their holdings at a time. The income of the other areas would even out income flows and thus encourage replanting, unlike the situation of smallholders, who may own only a single rubber area which has to be replanted all at one time.

The analysis of the Rubber Industry Master Plan Study shows that inefficiency or apathy on the part of the permit holders in pressing on with their replanting programme, and inefficiency or inadequacy and lack of follow up from the subsidy offer (Rubber Controller in Sri Lanka) is leading to long delays in replanting. Further delays can be caused by bureaucratic procedures discouraging the farmers from making early applications for replanting. Such difficulties would account for the falling-off of replanting, well below the target, despite increases in subsidy payments.

2.4 Labour Use (Hired or Family)

The importance of labour has different implications for alternative replanting strategies in the rubber industry. The type of labour, hired or family, is important in this respect. Since the type of labor used in the operation of replanting is closely correlated with the cost structure, the availability of the labour supply is crucial in replanting.

Table 2.4 shows the average replanting expenditure by different types of labour used.

Table 2.4

Average Replanting Expenditure per Hectare

Type of Labour Used	Expenditure (Rs./Ha.)
Only Family	5044
Mainly Family	4420
Mainly Hired	7472
Only Hired	7750

Source: Jayasuriya, 1977.

The higher expenditure for hired labour would have the impact of delaying replanting among large holdings. Further delays could also occur due to scarcity of labor in some areas.

Moreover, the use of hired labour could be a major factor in the exploitation of existing trees. This to a certain extent depends on the degree of absentee landlordism which is not great in the smallholding sector, but there is a tendency for it to go up with the size of the holding. It is very high among the medium sized holdings. The high intensity of exploitation will influence alternative replanting strategies.

2.5 Subjective Discount Rate

The farmer's subjective discount rate will be affected by several factors: changes in expectation in future yield, prices and income, the risk bearing capacity of the farmer and possibly his age. In addition the capital market of Sri Lanka has many imperfections, as elsewhere in the world, and there is no unique market rate of interest that is appropriate for all private and public investments.

However the impact of increases in interest rates is to lengthen the optimal replacement cycle, because although the annuity expression increases somewhat, the discount term causes the annuity value to fall. The increase of interest rate could also influence the annuity curve to be flat. Therefore the choice of sub-optimal dates two or three years either side of the optimal date has a negligible impact on the annuity value.

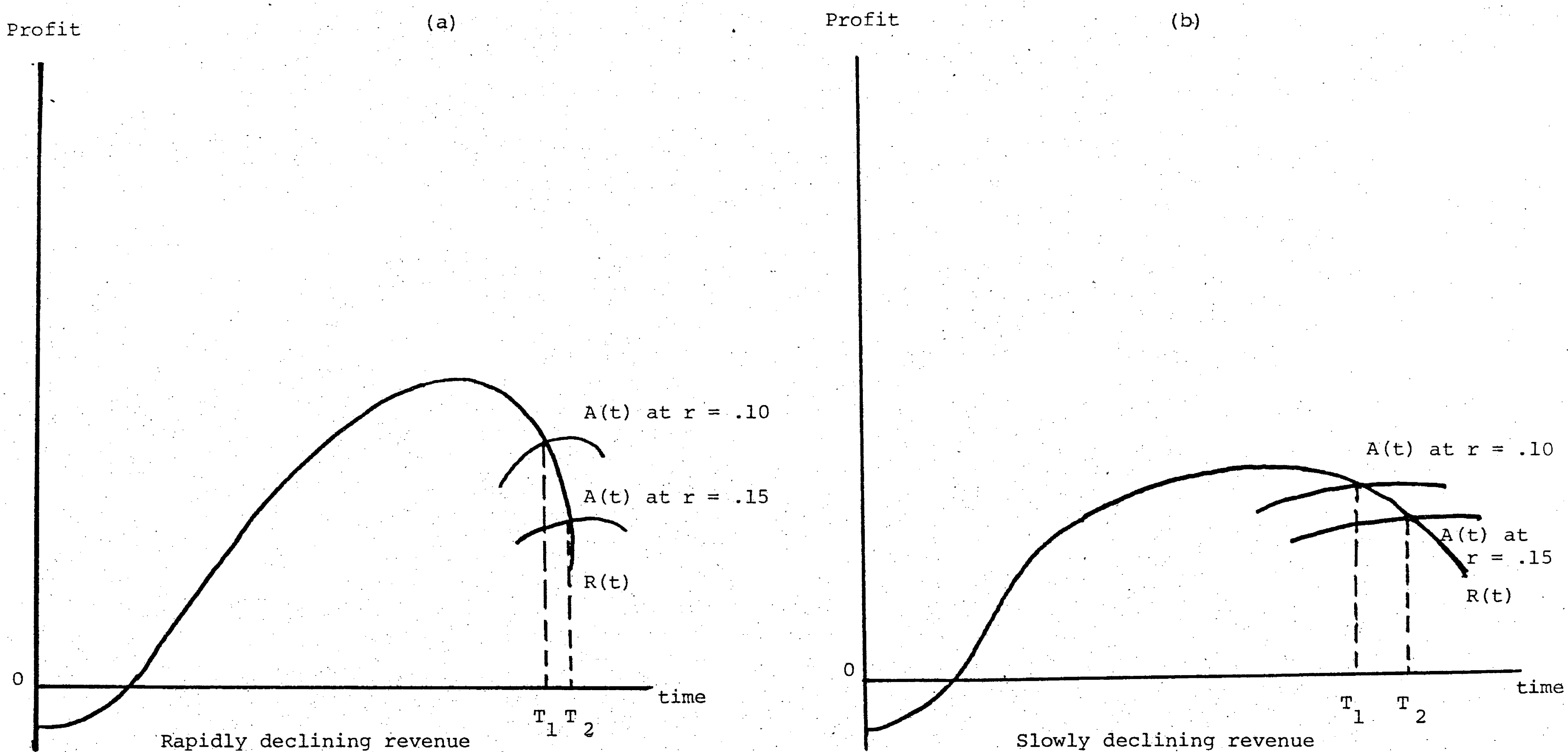
In addition to this, if other things are equal, each interest rate will result in a somewhat different replacement decision, although the sensitivity of replanting dates to interest rate changes depends on the slope of the yield function. This is shown in Figure 2.3(a) and (b).

It is clear from this figure that the curve representing a slowly declining revenue is more sensitive than the other. The more gradual decline in annual returns in that curve shows greater sensitivity to interest rate changes.

However the impact of the discount rate (interest rate) in general is that any possible rise in discount rate will induce a delay in replanting. This is dependent largely on the slope of the yield function.

Figure 2.3

Effects of Interest Rate Changes on Optimal Replacement Dates



2.6 Land, Land Reform and Land Ownership

The inventory study results of the Rubber Industry Master Plan Study (1979) indicate a declining rubber industry with land being removed from rubber production at a steady rate. Approximately 11,000 Ha., 5 per cent of the total, was lost during the period from 1971 to 1978. A significant area was lost due to producers having no confidence in the crop and shifting into other crops, and to village expansion for residential purposes due to the continued rapid growth of population in the rural areas of Sri Lanka.

In addition, the ownership of the rubber area has undergone great changes with the Land Reform Laws of 1972 and 1975.[1] Uncertainty surrounding land reforms resulted in maximizing short term earnings in private management before the takeover. Retaliatory action on the part of former landlords, in the form of damage and neglect of plantations in anticipation of dispossession, contributed to lower output from 1972 to 1976 (Land Reform, 1976).

Also before the land reform was enacted there was a degree of uncertainty among the private holdings, about the area in excess of 20.25 hectares (50 acres), for the determination to be made as to what portion of land the owners were to be allotted. It was clear that there was a tendency to neglect the holdings until the final determination was made (FAO-World Bank, 1979). Hence the Land Reform Law led to a slower rate of replanting and to destruction of plantations mainly due to the temporary abandonment of agricultural practices. Corruption and mismanagement are still rampant in the newly organized Electoral cooperatives, as has been admitted

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1 The Land Reform Law, No.1 of 1972 which imposed a ceiling on private ownership of land and provided for the setting up of a Land Reform Commission with powers to acquire privately held land in excess of the ceilings. The Land Reform Law (amendment), No.39 of 1975, under the provisions of which land held by public companies was nationalized.

even by the defenders of the reform programme.[2] Malpractice and political influence were apparent in the plantations after land reform, as private ownership was replaced by state ownership. This influenced development programmes very seriously and resulted in delays in replanting.

All the abovementioned factors have both a direct and indirect impact on the replacement of rubber trees and provide important background information for the present study. Although this study does not attempt to measure the importance of each of these factors, it is necessary to keep these in mind when considering the implications of alternative replanting strategies for the future.

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2 Many specific allegations of corruption and mismanagement were made during the debate of the 'Janawasa Bill' in the National States Assembly (Hansard, XIX:17, XIX:18, XIX:19).

CHAPTER 3

INTENSITY OF EXPLOITATION OF RUBBER

The relationship between the system of tapping and the optimum replacement age is very close. The system of tapping determines the rate of bark consumption, which in turn determines the effective life span of the trees. Hence there is some justification for investigating the systems of tapping and bark consumption and also the possibility of intensive exploitation of the trees due to fluctuation of prices, among the different size groups of rubber holdings. 'Intensity of exploitation' is one of the crucial factors which determine alternative replacement strategies.

3.1 System of Tapping

The Rubber Research Institue of Sri Lanka (RRISL) recommends the best tapping system as one which gives the highest yields at lowest tapping cost with the best growth and bark renewal, the lowest rate of bark consumption and the lowest incidence of bark diseases (Handbook of Rubber, 1970). The choice of a suitable tapping system is a compromise between the two interacting factors of yield and growth. It is possible to increase yield by practising intensive tapping systems, but this is likely to adversely affect the growth of the tree.

There is no particular tapping system which is ideally suited to all clones under all conditions. The system also varies according to the condition of the rubber stand.

Four systems of tapping are recommended by the RRISL.[1]

(a) Half-Spiral Alternative-Day System (S/2, D/2, 100 per cent)

As the name suggests, in this system a one half-circumference cut of the tree is tapped once in two days. This system is highly satisfactory for most clones from the commencement of tapping. On the assumption of 280 tapping days per year, each tree will be tapped on 140 days. The bark consumption will be 7 inches at 20 cuts per month.

(b) Double-Four System (2 S/2, D/4, 100 per cent)

This system has two half-circumference spiral cuts tapped once in four days. On 280 tapping days per annum, each tree will be tapped on two cuts on 70 days. Theoretically about 3.5 inches of bark will be taken off each cut per year. About 7 inches of bark are consumed per annum.

(c) Half-Spiral Third-Day System (S/2, D/3, 67 per cent)

This system tapped a one half-circumference spiral cut once in three days. On 280 tapping days per annum each tree will be tapped on a single cut on 94 days. The bark consumption per year is 5 inches under this system.

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1 In the discussion of tapping systems, the author relied heavily on the Rubber Handbook published by RRISL (1970).

(d) Double-Three System (2 S/2, D/3, 133 per cent)

This is used for tapping budded rubber before the completion of tapping on the first renewal bark. This system taps two half-circumference spiral cuts once in every three days. The double three system is recommended in the last few years before replanting. Any earlier introduction of this system results in a reduction of the tapping intensity for the remainder of the tree's life. Therefore it is not advisable to introduce this system for tapping budded or clonal rubber until it is definitely known that such rubber stands will be due for replanting within 8-10 years.

It is to be noted that none of the above systems is used exclusively throughout the exploitation cycle. The method of tapping used in most of the large estates begins on the S/2, D/2, Half-Spiral Alternative-Day System and continues this until the 30th year when more intensive systems are introduced. During 30 to 36 years of age, there is a gradual change to intensive systems of 2 S/2, D/3, 2 S/2, D/2, and 4 S/2, D/2. In the case of smallholdings, the method of tapping begins with S/2, D/1, Half-Spiral Daily tapping system and continues until the 25th year. As a result of this system, the replanting cycle is shortened, due to poor growth of the tree. For the rest of the period until the 26th and 27th years when replanting is necessary, the system of 2 S/2, D/2 is adopted. This method is not commonly used in estates but is widely practised in the smallholdings.

In addition to these two widely practised methods, there is another method which begins with the S/2, D/2 system and continues for four to five years. Thereafter tapping continues until the age of 30 years by using the 2 S/2, D/3, 2 S/2, D/2 and 2 S/2, D/1 and at the end of the 35th year trees are replaced.

It has been mentioned earlier that the high yields realised with the intensive tapping systems during early years affects the growth of the tree and the yield begins to decline later. At this stage high tapping intensities above 100 per cent could be adopted, possibly six years before replanting, as follows:[2]

First year	2 S/2, D/3, 133 per cent
Second year	do.
Third year	do.
Fourth year	2 S/2, D/2, 200 per cent
Fifth year	do.
Sixth year	4 S/2, D/2, 400 per cent

However, the farmers do not always carry out the RRISL recommendation and at times they exploit virgin bark above the normal tapping panels, when adequate bark reserves exist. The introduction of the RRISL system earlier in the life of the trees could have implications for the economical replanting cycle. This system is directly concerned with the consumption of bark and its effects on the alternative replacement strategies.

3.2 Bark Consumption

The accepted bark consumption for a tapping year and the tapping height for a particular tapping cycle are based on 20 tapping cuts per inch of bark. But the bark consumption for any tapping year will depend upon the total number of tapping days. Supposing a once in two days tapping interval working on a basis of 240 tapping days per year, bark consumption will be about 6 inches. In any case the thicker bark

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2 In order to calculate the relative intensity, multiply the fraction of the formula by 400, ignoring alphabeticals. ex S/2, D/2 system - 0.5 x 0.5 x 400 = 100 per cent.

shavings do not result in an increased yield. However somewhat thicker shavings of bark are necessary only if a four day interval of tapping is adopted or after rest, due to the dryness to a greater depth of the cut surface.[3]

It should be stressed that the criterion of 20 tapping cuts per inch of bark is not a fixed bark consumption for every month. This is highly dependent on the number of tapping days per month, i.e. in wet months there are fewer tapping days (because tapping is not done in rain). Therefore the practice of marking a rubber tree on the amount of bark consumed per month is not advisable. The tappers of some holdings practise marking of rubber trees, thus resulting in waste bark in order to use up the marked amount, especially in the wet months. This practice could also have an impact on the intensity of exploitation.

There are a number of ways of tapping panels which are employed by most countries.

The description of the Half-Spiral Cut System is as follows:

PANEL	PERIOD	
	Age (Yrs)	Age (Yrs)
X1 - 1st Panel of Virgin Bark	7-11	5
X2 - 2nd Panel of Virgin Bark	12-17	5
X3 - 1st Panel of 1st Renewed Bark	18-21	4
X4 - 2nd Panel of 1st Renewed Bark	22-25	4
X5 - 1st Panel of 2nd Renewed Bark	26 years and above	
X6 - 2nd Panel of 2nd Renewed Bark		

The high panel of virgin bark is designated X5 and X6. This is illustrated in Figure 3.1.

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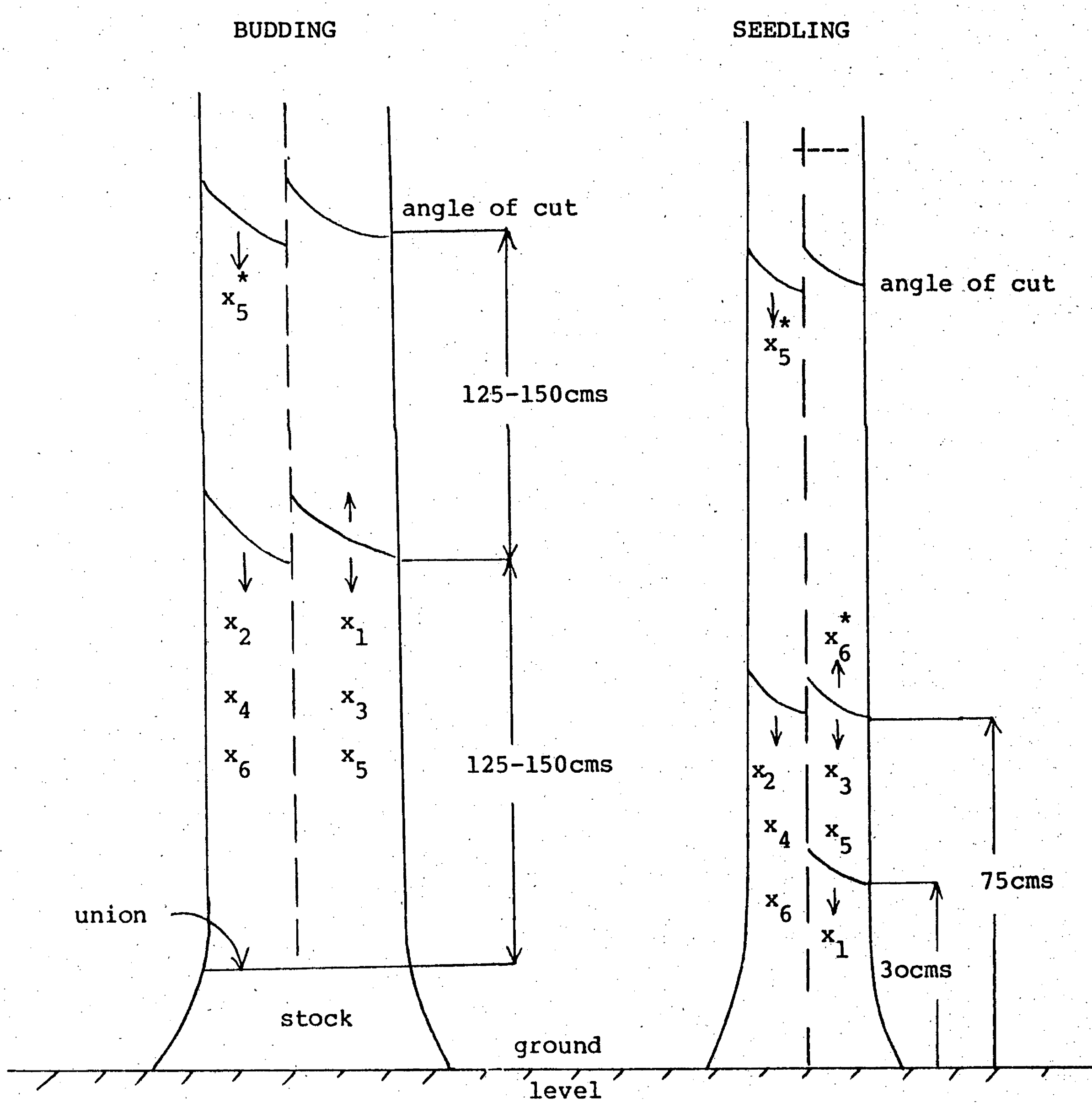
3 If once in four days tapping intervals is adopted the total number of cuts per tree is 60 and subsequent bark consumption is 3 inches.

Figure 3.1

Tapping Panels



This is the recommended way of exploiting a rubber tree without affecting its growth badly. However in practice the tappers often exceed these limits and exploit the bark more rapidly in order to maximize short-term profits.

The study carried out by the Rubber Industry Master Plan investigating bark consumption has drawn a comparison between the actual rate of bark consumption and the standard rate (Rubber Industry Master Plan Study, 1979). It is not clear from the Report in what way the comparison was made but the results shown in Table 3.1 are very interesting.

Table 3.1

Bark Consumption

		SIZE OF HOLDINGS (Ha.)								
		0-0.5	0.5-1	1-2	2-4	4-10	10-20	20+	State*	Total
		PERCENTAGE OF AREA IN TAPPING								
	-5	6	5	3	11	8	-	-	1	4
	-4	8	5	3	3	8	5	9	8	6
Ahead	-3	10	5	10	-	3	-	5	9	7
(years)	-2	11	8	6	8	7	3	13	12	9
	-1	12	14	27	22	17	16	20	24	19
Standard	0	17	32	17	16	13	47	5	22	22
	1	7	10	5	9	11	6	10	7	8
	2	11	8	16	6	8	8	8	4	8
Behind	3	3	1	3	10	11	1	6	3	4
(years)	4	3	5	1	6	-	5	-	4	3
	+5	12	8	9	9	15	9	23	7	10

Source: Rubber Industry Master Plan Study, 1979, P.6 of Appendix 1.

* State refers to all nationalized estates.

The Report further emphasizes that on average for all size groups bark consumption tends to be ahead of the standard. It is clear in the above table that about 67 per cent of the overall area under tapping was equal to or ahead of the standard. This exploitation of rubber trees is a response either to price or some other factor. This affects the date of replanting and is proof that the theoretical 33 year replanting cycle is not actually being practised.

The Report further explains that the proportion of the area below the standard is a reflection not of undeveloped trees but rather of the large area of old, average rubber which is still in tapping although yielding small quantities of latex (Rubber Industry Master Plan Study, 1979). This issue will be discussed again later when considering the intensity of exploitation in Section 3.3.2.

The consumption of bark of a rubber tree can be regarded as the most important factor determining the remaining life of the trees and, subsequently, the rate of replanting. The Rubber Industry Master Plan Study (1979) has also estimated the remaining life of the tree by reference to the amount of bark remaining on the tree, allowing 4.5 years per panel for low level tapping and 6 years for final exploitation. This is illustrated in Table 3.2.

Table 3.2

Estimated Remaining Life of Trees

Remaining Life Years	25-31		20-24		15-19		10-14		5-9		0-4	
Holding Size (Ha.)	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%	Ha.	%
0- 0.5	1546	6	3138	10	5241	17	6490	20	4769	15	10765	33
0.5- 1.0	1932	6	2310	8	3111	10	5550	19	4815	16	11943	40
1.0- 2.0	1685	9	2083	12	1924	11	2955	16	3521	20	5850	32
2.0- 4.0	1920	14	1443	10	2682	17	3124	23	1297	9	3425	25
4.0-10.0	2128	11	960	5	3704	17	4405	23	3325	17	4679	25
10.0-20.0	97	11	2119	19	865	8	4142	36	2299	20	1830	16
20.0 +	535	6	1242	14	909	10	1284	15	2045	24	2717	31
State	8046	13	6695	11	8840	15	14308	24	8120	14	13398	23
TOTALS	18187	9	19990	11	27276	14	42258	22	30191	16	54607	28

Source: Rubber Industry Master Plan Study, 1979, p.7 of Appendix I.

It is clear in the table that 28 per cent of total area is in the category of 0-4 years of remaining life. About 35 per cent of the area of the smaller groups below 2.0 Ha. has a remaining life of 0-4 years. This either suggests a higher intensity of tapping over the life of the trees among small farmers than the large estates or else it could be a result of a slower replanting rate and older trees. However the major reason is certainly the higher intensity of tapping which is reflected in the bark consumption rates, which are significantly higher than the standard. Hence, the economic life of trees is affected to a great extent by the rate of bark consumption. It will be shortened if the rate of bark consumption is higher than the recommended consumption. This has implications for the rate of replanting, implying alternative replanting strategies.

3.3 Price and Intensity of Exploitation

In this section an attempt is made to identify how the farmers respond to price changes and their reaction to bark consumption and intensification of tapping.

3.3.1 Price Expectation and Intensification in the Past

As mentioned in Section 2.2 of Chapter 2, price is the most crucial factor in determining high bark consumption. Short-term price expectations are important in this respect, since farmers attempt to maximize the net revenue function. The ultimate result of this is the consumption of bark beyond its optimum economic level.

The history of the rubber industry before and during the period under investigation in this study gives a ready and clear explanation of this behaviour. The period 1930-1950 was a period of stagnation for both the smallholder and the plantation sector. During 1930-32 rubber prices plummeted down to their lowest recorded levels and the growers temporarily ceased tapping about 40 per cent of the total rubber area (Rubber Controller, 1932). The areas of new plantings during this period were the lowest annual figure ever recorded since the beginning of the industry. With the slight improvement of prices in 1933 and the following year planting began slowly. However this was not allowed to continue in the subsequent period, with the establishment of the International Rubber Regulation Agreement (IRRA) in 1934. Thus even though the prices rose almost continuously right up to a peak during the Second World War period, new plantings were not legally permitted until 1939. However during the period of 1934-1941 replantings were allowed to a certain extent. Although the area had not increased to any great extent the outbreak of the Second World War in 1939 raised the demand for rubber. Even in 1941 prosecutions were still being made for undertaking new plantings. Although the replantings were encouraged, the actual area replanted was not high. The rational farmer attempted to maximize the short-term profit function rather than uprooting and dreaming of the future yield. As a result during 1942 and 1943 abnormally high yields were recorded. This has been attributed to the intensified tapping during the Japanese occupation of most of the other rubber producing countries. When Malaya was occupied by the Japanese in 1942, Sri Lanka became the major source of supply of natural rubber for the allied war effort. In order to supply rubber to meet the demand created by the War, rubber plantations were strained to the utmost as a result of intensive tapping. During this period replanting was strongly discouraged except when the trees were yielding no latex. However over 12000 Ha. were permitted to be brought under new planting by the IRRA, because of the high prices and more intensive forms of tapping being adopted by the small producers (Rubber Controller, 1943). Although permission was given to new plantations of over 12000 Ha. the actual planting achieved was little over 8000 Ha. due to rising costs and the uncertainties generated by the war.

In order to obtain the maximum possible supply of rubber, the British Government appointed a Commission to enquire into ways and means of increasing the output. It introduced a Capital Compensation Scheme (CCS) in 1943, whereby rubber growers were voluntarily induced to tap to exhaustion 20 per cent of their acreage in return for the payment of the cost of replanting such areas. As set out in the

'Whitelaw-Perera' Commission Report (1947), the main conditions of the scheme were as follows:

> 'Each proprietor was asked to volunteer to tap to complete exhaustion, 20 per cent of his acreage within a period of two years from joining the agreement, as well as to intensify, to an intensity of 133 per cent (but not slaughter tap) the tapping on the balance 80 per cent of the acreage. Provided these conditions were met to the full satisfaction of the Ceylon Rubber Commissioner, His Majesty's Government undertook to repay the participants a sum of $45 per acre for the purpose of replanting that portion (20 per cent) of the acreage which he had tapped to complete exhaustion.' (The Report of the Commission of Inquiry into the Rubber Industry of Ceylon, 1947).

As a result of this scheme an area of 9070 Ha. was 'slaughter tapped' and the rest of the 80 per cent was intensively tapped. As expected the scheme resulted immediately in increased output but left an appreciable part of Sri Lanka's rubber plantation in a derelict condition. In addition to the scheme, war time inflation on the one hand and the relatively high rubber prices on the other would have further induced greater intensification of exploitation. This is reflected in the relatively high but steadily declining yield per hectare of rubber from 1942 to 1945, as shown in Table 3.3.

Table 3.3

Yield per Hectare of Rubber 1940-45

Year	Average Yield (kg./Ha.)
1940	367
1941	375
1942	479
1943	413
1944	418
1945	392

Source: Administrative Report of the Rubber Controller, 1940-45.

The combined effect of this intensification, the adverse effect on upkeep, and the continuing preoccupation with output and the age structure of trees, posed serious problems at the end of World War II. One conclusion reached by the

Whitelaw-Perera Commission was that the rubber industry as a whole was in need of rehabilitation. It was estimated that about 14575 Ha. out of a total of 59360 Ha. in the smallholding sector were yielding less than 280 kg./Ha. (Rubber Controller, 1949, p.50). In addition, a substantial amount of the additional areas would reach that stage in the next few years. Thus replanting was becoming an important problem for smallholdings. The cost of living had increased significantly, due to post war price inflation, while rubber prices declined. This situation continued until the onset of the Korean War in 1950. The reaction of rubber growers to this new price boom was immediate: the smallholdings as well as large estates raised their output, adopting high tapping intensity. The response given to the high prices in World War II extended right to the period of the Korean War, and left a further portion of the plantations tapped beyond repair. This was reflected in the production figures for the following year when the growers were unable to increase yields despite the still higher prices recorded in 1951, following the high degree of intensification (in many cases slaughter tapping) in previous years.

The Rubber Commissioners in their report (Sessional Paper No.XVII of 1947) stated that:

> 'the greater part of the island's rubber was well past its prime, being over 35 years old, and that heavy tapping during the Second World War had greatly accelerated the deterioration of this rubber. In the view of the Commissioners, 175000 acres (70850 Ha.) of rubber were in such poor condition that they could not be profitably worked at that time. Since then especially in view of the intensified tapping brought about by boom prices in 1950 and 1951, a further extent of about 25000 acres (10120 Ha.) would probably have become uneconomic, thus making the present total area of uneconomic rubber land in Ceylon approximately 200,000 acres (81000 Ha.).' (Rubber Controller, 1952)

As mentioned in that report the most important effect of this intensified tapping was to aggravate the already acute problem of uneconomic rubber. However when high prices prevailed in 1971-73, a reasonable change in output to price was observed as during the Korean War period. But unlike during the Korean War period, this has been achieved as a result of the introduction of high yielding clones under the Rubber Replanting Subsidy Scheme. Even then there would have been intensified tapping to respond quickly to the high prices. In 1978, although the area under tapping fell by 2 per cent, a notable increase in production was recorded. This was largely due to a positive response to attractive prices coupled with continued favourable weather conditions. The attractive producer margin seemed to have induced some marginal producers to resort to slaughter tapping as well.

The above historical pattern of the behaviour of rubber growers to prices suggests that the tapping intensity can be very high due to short term expectations of high prices.

3.3.2 Intensity of Exploitation of Rubber

In this section an attempt has been made to calculate an index of the intensity of exploitation (INTEX) of rubber. The data collected by the Rubber Industry Master Plan Survey was used in this study.[4] Among other information collected by the Master Plan, the data on the age of the trees and the estimate of the remaining life of the trees are of utmost importance. Although the remaining life of the trees is a highly subjective judgement, it gives valuable information on the future life of the national rubber plantation. If we presume the standard replanting cycle to be 33 years, the formula for calculating the index of the intensity of exploitation (INTEX) is as follows:

$$INTEX = \frac{33}{(A+R)} \times 100 \qquad (3.1)$$

where A = Age of trees
R = Remaining life of trees

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4 Details of the data made available by the Commonwealth Development Corporation (CDC).

Table 3.4

Intensity of Exploitation (INTEX) of Rubber

INTEX	Absolute Frequency % (Sample Ha.)	Relative Frequency %	Cumulative Frequency %
46	24	0.2	0.2
62	1	0.0	0.2
65	15	0.1	0.3
70	13	0.1	0.4
72	14	0.1	0.6
73	1	0.0	0.6
75	35	0.3	0.9
77	25	0.2	1.1
79	50	0.4	1.5
85	100	0.8	2.3
87	54	0.5	2.8
89	221	1.8	4.6
92	137	1.1	5.8
94	432	3.6	9.4
97	306	2.5	11.9
100	406	3.4	15.3
103	583	4.9	20.1
106	2532	21.1	41.2
110	1586	13.2	54.4
114	2511	20.9	75.4
118	576	4.8	80.2
122	439	3.7	83.8
127	317	2.6	86.5
132	1310	10.9	97.4
138	107	0.9	98.3
143	135	1.1	99.4
150	37	0.3	99.7
157	9	0.1	99.8
165	25	0.2	100.0
174	1	0.0	100.0
276	1	0.0	100.0
TOTAL	12003	100.0	

The calculated INTEX values from the sample data of the Rubber Industry Master Plan are presented in Table 3.4. Rubber holdings with a total cycle length of 33 years will have an INTEX value of 100. Those with an excessively long cycle (eg. 78 years of age and remaining life) will have a low INTEX value of 42. An INTEX value of 132 indicates a relatively short cycle length of 25 years. This result confirms the bark consumption rates presented in Table 3.1, which were calculated by the Rubber Industry Master Plan Study.

The 100 percent INTEX value means that the age plus remaining life of a tree is exactly equal to 33 years. If age and remaining life is below 33 it gives an INTEX value of more than 100 per cent, and vice versa. At times the age would be 6 years or even 2 years and the remaining life 0 years, reflecting the early death of the rubber trees.

The results of Table 3.4 show that the intensity of exploitation is equal to or below 100 per cent only in 15.3 per cent of the rubber area. This area is a reflection not of undeveloped trees, but of areas of proper bark consumption which have a reasonable age and remaining life. It has been explained earlier in this chapter that the remaining life of the trees is calculated with reference to the bark consumption. High consumption of bark during the early years of age, of course, reduces the remaining life. If this happens frequently, age and remaining life is below 33. This is reflected in the table where intensity of exploitation is greater than 100 per cent. Thus 84.7 per cent of the total area falls into this category mainly due to high bark consumption. However it is important to note that there are some areas of rubber which go out of production due to pests and diseases and climatic factors. There are some areas where the rubber trees die in the immature period. Such areas are not very significant, but it could be a minor reason for the intensity of exploitation being above 100 per cent.

As mentioned earlier this high intensity could be affected mainly by short run price and income expectations. It has been argued in the literature that the size of holding has a different response over price expectation.

In order to identify the INTEX among different size groups, it can be hypothesised that the small farmers exploit the rubber trees more intensively than the large farmers. To test this hypothesis, the INTEX value has been calculated individually for each group and presented in Table 3.5.

Table 3.5

INTEX Among Size Groups

Category	Size (Ha.)	Mean Value of INTEX	Standard Deviation
Smallholding	0 - 4.0	113.7	18.7
Medium Holding	4.0 - 40.5	108.2	14.1
Large Holding	40.5 & above	113.7	11.7
Entire Population		111.5	16.8

This shows on average that the INTEX for each size group is greater than the standard value of 100. However it can be seen that the INTEX is high and equal among small holdings and large holdings, both of which are higher than medium sized holdings.

The results of this table could be interpreted in different ways. Of course smallholders do respond to price changes. Rubber is the main or only source of income for most of the smallholders. It is justifiable for them to maximize income by intensification when prices are high. This affects the growth of the rubber tree and subsequently the remaining life of trees. This pattern is explored in Section 3.3.1 using historical evidence. The high INTEX among large holdings is a result of retaliatory action on the part of former landlords, in the form of damage and neglect of plantations in anticipation of dispossession. While this explanation can neither be substantiated nor refuted with a specific set of data, it does seem possible that the institutional transformation is also responsible for the high INTEX. However the INTEX among medium size holdings is not as high as small and large holdings. This has been affected by the drawbacks which characterize 'medium size holdings' such as absentee ownership.

In order to recognise the differences in INTEX among size groups a test of the differences between the groups was carried out by using the 'T-test'. The results are presented in Table 3.6.

Table 3.6

Calculated F-Values and T-Values (INTEX)

Size(Ha.)	Mean	STD Deviation	STD Error	F-Value	T-Value (pooled variance estimate)	T-Value (separate variance estimate)
0 - 4.0	113.7	18.7	0.82	1.78xxx	4.92xxx	5.12xxx
4.0 - 40.5	108.2	14.1	0.70			
10.5 & above	113.7					

xxx highly significant

The T-test sub-program of the Statistical Package for the Social Sciences (SPSS) has given two estimates of T-values, such as 'pooled variance estimate' and 'separate variance estimate'. In both estimates the t-value is highly significant, indicating the difference between Group 1 (0 to 4.0 Ha.) and Group 2 (4.0 to 40.5 Ha.). It is clear from the table that the mean values of INTEX among smallholdings and large holdings are equal and significantly higher than the medium size holdings. This indicates the high intensity of exploitation among small and large holdings.

Thus it is felt that the intensity of exploitation is very crucial in the behaviour of replanting. The ultimate result of this is to consider different life spans for the trees. It is obvious that the different life spans of the trees caused different replanting cycles in real life. The variation of INTEX values from 46 to 206 per cent imply different replacement dates. The implication of this to the area and production is crucial. Therefore any planning model which studies the future behaviour of rubber should incorporate the impact of intensity of exploitation.

CHAPTER 4

DATA COLLECTION

The data used in this analysis was collected from two sources. The main source of data on the rubber industry of Sri Lanka is given in the Annual Administrative Report of the Rubber Controller. Various aspects of data on area, production and prices are published in this report. Data on age-specific area and stock depletion of rubber are not readily available due to non-maintenance of such records. Thus the immature and mature bearing areas cannot be separately ascertained in order to make projections of the future area. Moreover, in the available data there are errors and discrepancies.

The second source of data used was collected by the Rubber Industry Master Plan (RIMP) Study (1979) of Sri Lanka. Unlike the Rubber Controller's data sources, this is a cross-sectional survey carried out in 1978, to investigate age-specific area, bark consumption, remaining life of trees and general condition.

In order to obtain accurate estimations, both of the above main sources of data have been used in this analysis, and similarities between these two and other minor sources of data have also been taken into account.

4.1 Rubber Controller's Statistics

The data relating to the rubber industry and in particular the operation of the Rubber Replanting Subsidy Scheme, are available from the Rubber Control Department of Sri Lanka. Some of the information already collected is in fact inaccurate and unreliable due either to the collection methods adopted or methods of recording and analysis.

The administrative report published annually by the Rubber Controller provides annual area data as registered under the Rubber Control Act. The registered areas as well as disaggregated areas among different sized holdings, small, medium and large, comprise the records. However, a great discrepancy exists between the area registered and the actual area. This arises as a result of several factors. Firstly, prosecutions for illicit plantings is one of the main reasons, as this area is not included in the registers. The other possible reason is the abandonment of substantial areas of rubber land especially in regions which are considered to be marginal land. These registers do not maintain the records of the area deleted from rubber. This unawareness of the stock depletion figures from the existing areas and obliterated area reduce the usefulness of the Rubber Controller's data in any analysis. Moreover serious data problems arise when the planting and replanting patterns of the smallholders are examined.

Data on replanting from 1952 onwards are more accurate since there does not seem to have been any replantings outside the subsidy scheme. Thus replanting figures can be considered as an accurate guide to the area replanted since 1953.

The difference in area between actual and registered has been revealed by the Agricultural Census of 1962, which shows that an area of 42,500 Ha. (105,000 acres) registered at the Department of Rubber Control as being under rubber was in fact diversified or abandoned. In addition analysis in this study reveals that the area figures given by the rubber controller are not so useful due to lack of age-specific area and the stock depletion data.

However, age-specific area could be grossed up from the replanting figures, though it is not accurate. Knowledge of the sequence of new and replanting of each year provides partial information as to the age-structure in production in future years. This is partial since the normal death of trees due to diseases and bad weather are not taken into consideration. However this data could be utilized when comparing the accuracy of other sources of data or information.

The data on age structure and stock depletion could be easily maintained by the Department if desired. The set-up of the Department and the organization of the field service could easily collect the data. Inefficiency and inadequacy within the Rubber Control Department are the main reasons for these imperfections.

Hence key information, which is required for planning purposes, is missing. This is especially critical for a study of this nature, in order to make predictions of the area and production based on the current age-specific area. Obviously any assumption one could make about the area should be based on the existing age of the trees.

4.2 Rubber Industry Master Plan (RIMP) Study Data

As mentioned in Section 3.2 one of the terms of reference of the RIMP Study was the requirement to prepare an inventory of the rubber area in terms of agro-ecological regions, age yield levels and holding size (Rubber Industry Master Plan Study, 1979, p.1.). Although some other surveys have been carried out on the socio-economic aspects of rubber plantations, these surveys suffer from lack of information on the age profile of the existing trees, on the condition of the bark and on estimated bark reserves. Therefore there was an urgent necessity to obtain data on the above aspects of rubber for planning purposes.

4.2.1 Survey Methodology

The survey carried out by the RIMP was a two-stage survey. The first stage was an analysis of aerial photographs at a scale of 1:25,000 to determine the total area under rubber in the rubber growing areas. These photographs had been taken in 1971 to 1975. The team has argued that the changes that had occurred in the last 3 to 7 years after the date when the photographs were taken would not affect the accuracy of the survey too seriously in a tree crop such as rubber. However this is a controversial point since during this period remarkable changes occurred in the plantation sector as a result of the Land Reform Laws of 1972 and 1975.

The second stage of the RIMP survey was a ground survey of a sub-sample of the areas selected from the aerial photo analysis. This collected current information on the condition of the rubber and details on the distribution of holding size and land tenure.

4.2.2 Sample Frame

The establishment of a sample frame is essential for estimates of population characteristics to be established from sample data. The sample frame of the RIMP study was based on the land use maps produced from the detailed land use survey of 1962/63. This survey was based on aerial photographs taken in 1956. Since the rubber area has been contracting over a period of years, the RIMP concluded that the land use maps would provide a reasonable frame, which would incorporate all current areas under rubber. Hence all rubber areas shown in land use maps were shaded and overlays reproduced indicating their distribution, within revenue districts. In these maps 'significant rubber areas' were identified, which contained a high density of the shaded region. Lastly the survey frame was identified as the 'significant rubber area' within a revenue district, which in statistical terms is a 'stratum'.

4.2.3 Sampling Procedure

Although the RIMP explained the procedure they used as a 'two-stage sampling', it could perhaps have identified an additional third stage. The first stage was to select a sample of photographs covering the significant rubber areas and the second to select a sub-sample of photographs from the first selection. The RIMP has not revealed the third stage separately, which selects the sites for ground survey work. The imposition of this stage under Stage Two is incorrect since different procedures are adopted. In order to select the aerial photo sample in the first stage, a series of aircraft flightlines were drawn on overlays showing the significant rubber area and the position of each photograph was shown on the flightline. There were some overlapping photographs due to the direction of the flightlines. To avoid this, photographs were 'sized' in batches and a set of unique frames for the ground survey produced. Then photographs were selected at random from the significant rubber area in each stratum. The number of samples of each stratum was dependent upon the proportion of significant rubber area of the stratum as a proportion of the significant rubber area of the island. The photographs sampled represent 43 per cent of the significant rubber area in the nine revenue districts (stratums). The sampling procedure was with replacement and with probabilities proportional to size (PPS) measures.

The ground survey was carried out by selecting a sub-sample of photographs from the sample already selected for aerial photographic analysis in the first stage. The procedure adopted to select photographs was also random and with replacement and with probabilities proportional to size, from the sample assigned to a stratum. In the selection process, some photographs with a density of less than 10 per cent of rubber area have been eliminated. Here again the number of samples was based on the significant rubber area of the district as a proportion of the total.

The third stage of the sampling procedure was the selection of sites for enumeration. The sites were selected at random with replacement but not with probabilities proportional to size as in the two earlier stages. A number of points were identified for enumeration by reference to a grid frame overlaid on the photographs. The size of the grid frame varied according to the sizing procedure followed in order to make each photo-frame unique without overlapping. The sampling within each photograph was based on the expectation that an enumerator would visit approximately twenty sites per day. This leads to a biased selection of samples since it is based on expectation rather than selection on a purely random basis.

A summary of the significant rubber areas, aerial photographic coverage and the ground survey are presented in Table 4.1.

Table 4.1

Significant Rubber Areas, Aerial Photographic Coverage and Distribution of Ground Sampling Points

District	Significant Rubber Area (ha.) (A)	No.of Photographs	First Stage			Second Stage		Third Stage	
			No.of Photos Selected for Analysis	Area Covered (Ha.) (B)	(B) as a % of (A)	Clusters	% of Total	Sample Points	% of Total
Kalutara	135970	164	112	68275	50	14	17	236	18
Kegalle	138540	176	101	61650	44	16	20	281	21
Ratnapura	126135	140	88	49925	40	14	17	249	19
Colombo	134927	167	100	60650	45	14	17	205	15
Galle	118347	131	86	54700	46	10	12	153	12
Matara	52831	68	36	21800	41	3	4	47	4
Kurunegula	38940	47	30	16975	44	4	5	52	4
Matale	22040	15	7	4462	20	3	4	46	4
Kandy	26696	41	11	4862	18	3	4	36	3
TOTAL	794428	949	571	343299	43	81	100	1305	100

Source: Rubber Industry Master Plan Study 1979.

4.2.4 Estimating Procedure

The analysis of aerial photographs was undertaken by the Sri Lanka Survey General's Department. The sample photographs were analysed using grid point overlays which consist of an average 96 points, at a scale of 1:25,000.

In the ground survey, information was sought on characteristics of the rubber area, including physical condition of rubber, age, tapping status, bark consumption and estimated remaining life, clone type and physical characteristics of sites. In addition, details were collected on location, ownership, registration and extent of rubber etc. The information collected from 1305 sample points was processed by computer showing both the results of tabulating sample data and the grossed up population figures (Rubber Industry Master Plan, 1979, p.6). Population data were derived from the sample by applying two scale factors: the first to allow for the scale of photography and the second to allow for the sampling fraction of the photography as a proportion of the 'significant rubber area'.

The procedure for grossing-up the population figures from a three-stage sample of this nature could be illustrated mathematically as follows:

The estimate of total area in the jth stratum

$$T_j = \frac{1}{n_j} \sum_j \frac{A_j}{a_{ij}} t_{ij} \qquad (4.1)$$

Where, A_j = total significant rubber area in jth stratum

t_{ij} = total area of ith photo in jth stratum

a_{ij} = area of ith selected photo in jth stratum

n_j = number of photo selected in jth stratum

Since

$$t_{ij} = \sum_g \frac{n_{ij}}{n_{gij}} \sum_g t_{gij} \qquad (4.2)$$

Where

t_{gij} = total in gth grid of the photo in sample in jth stratum

n_{gij} = number of grid areas in sample from ith photo in jth stratum The total equation could be expressed by incorporating equation (4.2):

The total equation could be expressed by incorporating equation (4.2):

$$T_j = \frac{1}{n_j} \sum_i \frac{A_j}{a_{ij}} \frac{n_{ij}}{n_{gij}} \sum_g t_{gij} \qquad (4.3)$$

since

$$\frac{a_{ij}}{n_{ij}} = a_{gij}$$

$$T_j = \frac{1}{n_j} \sum_i \frac{A_j}{(a_{gij}\ n_{gij})} \sum_g t_{gij} \qquad (4.4)$$

Where a_{gij} = area sampled in gth grid, or ith photo in jth stratum.

Finally the total area for the island in the nine revenue districts:

$$T = \sum_{j=1}^{9} T_j \qquad (4.5)$$

If the RIMP Study adopted either two-stage sampling or three-stage sampling (or multi-stage sampling), the procedure would have been similar to the above equation system. However the ground survey of the RIMP Study was carried out only to determine the characteristics of an already calculated area. The results of the ground survey were in the form of ratios, with error estimation, which were applied to the rubber area estimates for each district. The area was calculated from the results of aerial photographic analysis carried out by the Department of Survey of Sri Lanka. However since the ground survey was not used to determine rubber areas, upon reflection the whole survey could not be described as a multi-stage sample procedure. [1] This could be a mis-identification and mis-interpretation of the sample procedure.

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[1] Private communication with Commonwealth Development Corporation (CDC).

4.2.5 Limitation of RIMP Survey and Data

The major problem encountered in the RIMP Survey data is the possibility of using sample parameters for estimating population parameters.[2] The lack of clarity in the text of the report and the fact that the ground survey and area were not directly linked with each other has created severe difficulties for further analysis. Additionally, repetition of marking the same area in the raw data, lead to over-estimation of the area in Ratnapura District. In fact Ratnapura district, amongst the four main districts, had the highest proportion of state owned rubber in large holdings, which is not exactly true in reality. Therefore the use of this sample data to gross up population values was misleading.

In order to overcome these estimation problems, the values for equation (4.4), for different stratums have been assumed on a 'best guess' basis, based on the significant rubber areas. These values give the weight for each stratum. Application of these weights to the sample data has enabled grossed-up population values to be calculated. Although this procedure is not exactly accurate, it has been necessary to proceed in this way, in order to complete this study in time.

The other main limitation upon this study is lack of information on stock depletion which occurs as a consequence of extraneous weather conditions, disease, and deliberate decisions made by farmers to uproot or abandon the old rubber trees.

In addition to these two main sources of data, the age-specific area data given by the Rubber Research Institute of Sri Lanka was also examined. Since these data are also based on the Rubber Controller's data, no significant difference could be observed between them.

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2 The data of 1305 questionnaires were provided by the CDC in a tabulated hard copy format. This was re-typed onto magnetic tape for analysis on the Joint Schools DEC10 Computer System at the Australian National University.

CHAPTER 5

METHODOLOGY

Anderson (1974) precisely defined 'simulation' as the numerical manipulation of a symbolic model of a system over time. According to Morgenthaler (1961) simulation in a broader sense, means to duplicate the essence of a system or activity without actually attaining reality itself. Naylor, Balinky, Burdick and Chu (1966) defined simulation as a technique that involves setting up a model of a real situation and then performing experiments on the model. This is an applied and useful definition which highlights the essential phases of modelling and experimentation in operation. Although simulation has been defined in terms of both modelling and experimentation, the models involved are not basically those of recognized programming techniques such as linear programming, mathematical programming and budgeting. The mathematical programming models are encompassed by simulation, because of the rigidity of model structure and the difficulty of incorporating different aspects of the data into mathematical programming models.

'Systems analysis' is used to describe the corresponding steps in the simulation of a particular system. This is the technique that is used to solve complex decision problems by following the changes over time in a dynamic model of a system.

Simulation models can be divided into two groups:

A) Predictive simulation models

B) Mechanistic simulation models

The predictive simulation models are used to provide predictions relating to alternative options under study, while the mechanistic simulation models are concerned with assisting in understanding the simulation. Both of the models can take a number of forms, one of the most popular and widely used is computer based. Although the computer is not essential in simulation modelling, computer based simulation models permit more formal consideration of the information pertaining to a decision.

The model chosen in this study is a computer based simulation model, which incorporates alternative options of the rubber replanting policies in Sri Lanka. It is concerned with the further implications for the area and production. Hence, the model adopted here is a predictive type simulation model, in that it predicts the output of the system given the 'inputs' to its interacting subsystems.

The whole process of simulation considered in this analysis consists of a few clearly defined steps. These steps are interlinked with each other, as shown in Figure 5.1. The general methodology of the simulation model is illustrated in this figure. The main feature of this is the feedback to any previous stage, which is a characteristic of most simulation studies.

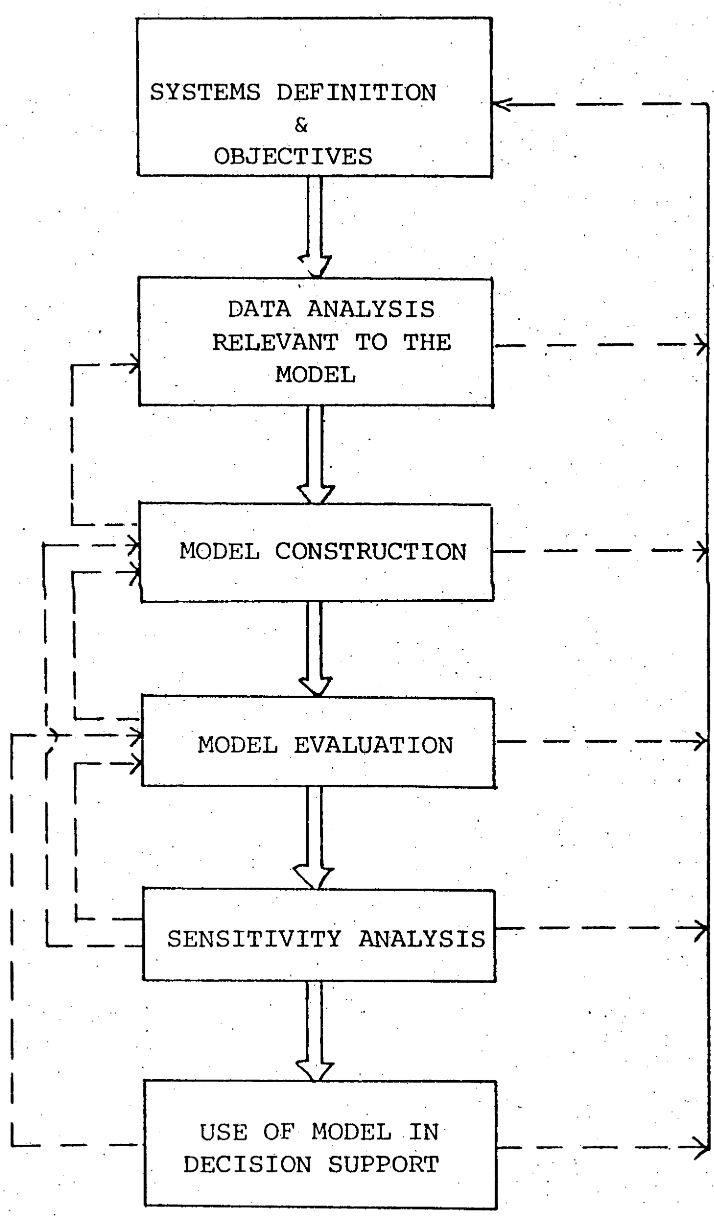
5.1 Objectives for Modelling and Definition of the System

The objective of this modelling is to predict the future area and production of rubber in Sri Lanka. This is a somewhat complex problem, as the system involved in the modelling for forecasting becomes complicated when it includes the implications of alternative replanting strategies. As mentioned in previous chapters there are a number of factors which affect alternative strategies. In addition, the intentions of the farmers towards replanting will also have a significant impact on the area and production.

Figure 5.1

The Basic Steps of a System

Simulation Model



Source: Dent and Blackie, 1979

In order to define the system involved in this study, it is necessary to understand the background of the problem. The standard replanting cycle of rubber accepted by rubber authorities in Sri Lanka is 33 years or 3 per cent of the area annually. However, this has not been subjected to any economic evaluation as such. There are few independent studies which attempt to evaluate the economic life of rubber. Jayasuriya (1973), using the evidence of his study, states that the optimal replanting cycle is below 33 years.

In addition to that, the farmers' decisions to replant are not necessarily based on government policy, but based on their attitude as to whether to keep an existing stock of trees with a declining income flow or replant in the expectation of a higher future income. Therefore the willingness of the farmers to replant is crucial among the list of factors influencing replanting. The simulation model employed should be shown to be able to capture this real situation before it can be used for performing predictions. Such a model then includes the two essential phases of simulation: modelling and verification, which then lead to experimentation and providing future values.

The detailed information required from this model in its first stage is the generation of population values for future areas by using sample data and population weights. The model becomes more complex when it generates production values in the second stage. After calculating area figures, it incorporates yield functions in the model. At that stage the model should be capable of estimating respective production figures by using age-specific future area.

5.2 Analysis of Data Relevant to the Model

The effectiveness of the model is essentially influenced by the structure of the model and its quantification. The availability of data and the feasibility of generating data for the future within the limits set are controlled by the model design to a large extent.

In addition to the capability of the model, availability of data is crucial to the whole modelling exercise. According to the objectives of this study, the data on area under rubber cultivation and its distribution across age-classes is required. As mentioned in the previous chapters the data collected by the survey consists of age-specific areas. However this is not systematic time-series information on age-structure, but it is a survey conducted at bench-mark intervals. The practical problem of modelling at this stage is thus how to integrate this information with the available time series data on yield, area under cultivation and production. The approach adopted in this model is to combine the data on age-structure (which was estimated by the RIMP Study) with yield estimates (calculated by the Rubber Research Institute of Sri Lanka and by the author) endogenously via the sequence of new planting and replanting decisions made by farmers.

In addition to that an attempt has been made to focus on the historical reconstruction of age-structure estimates, by using the Rubber Controller's annual records and to develop forecasts of capacity solely from the technical production relations between age-structure and yield. However it was necessary to exclude the Rubber Controller's data from the final model because of the unavailability of data on stock depletion, caused by weather, disease, and other natural causes. The Rubber Controller's figures make no provision for the mortality of trees prior to the intended year of replacement.

5.3 Model Construction

Before proceeding to the construction of the model it is reasonable to ask whether it is essential to build a simulation model or are any other approaches possible? The nature of this study suggests that it is indeed necessary to construct a new model rather than attempting to modify earlier studies to answer the problem, for two reasons. First, because of some quite unrealistic assumptions regarding replacement decisions and secondly, because a new body of data (the RIMP Survey) has become available. It is a data set which highlights some of the problems associated with the data used in previous studies.

The task of modelling a simulation to suit a problem consists of the multi-stage procedure shown in Figure 5.2.

5.3.1 Stage One - Diagram of the System

The general idea of this stage is to promote systematic and clear thinking about the system under study. Thus information flows are presented in diagrammatic form in Figure 5.3. It is very easy to understand the sub-systems and their interrelationship with other sub-systems and the main body from Figure 5.2.

Figure 5.2

The Multi-Stage Procedure of Model Building

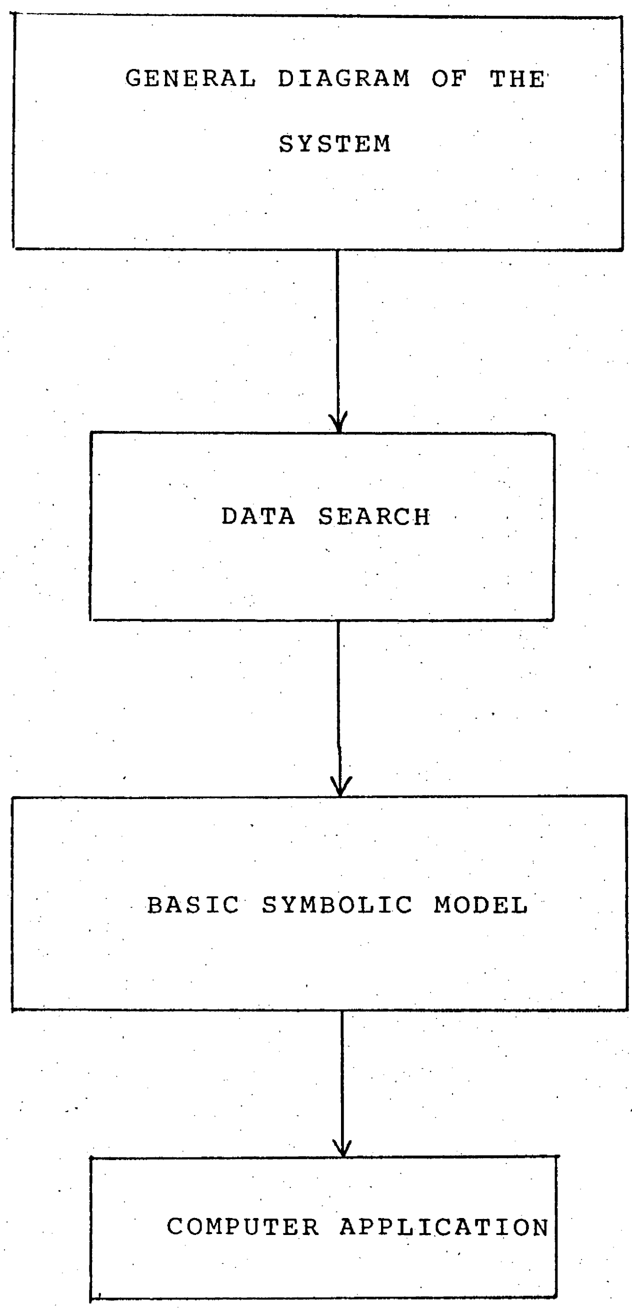
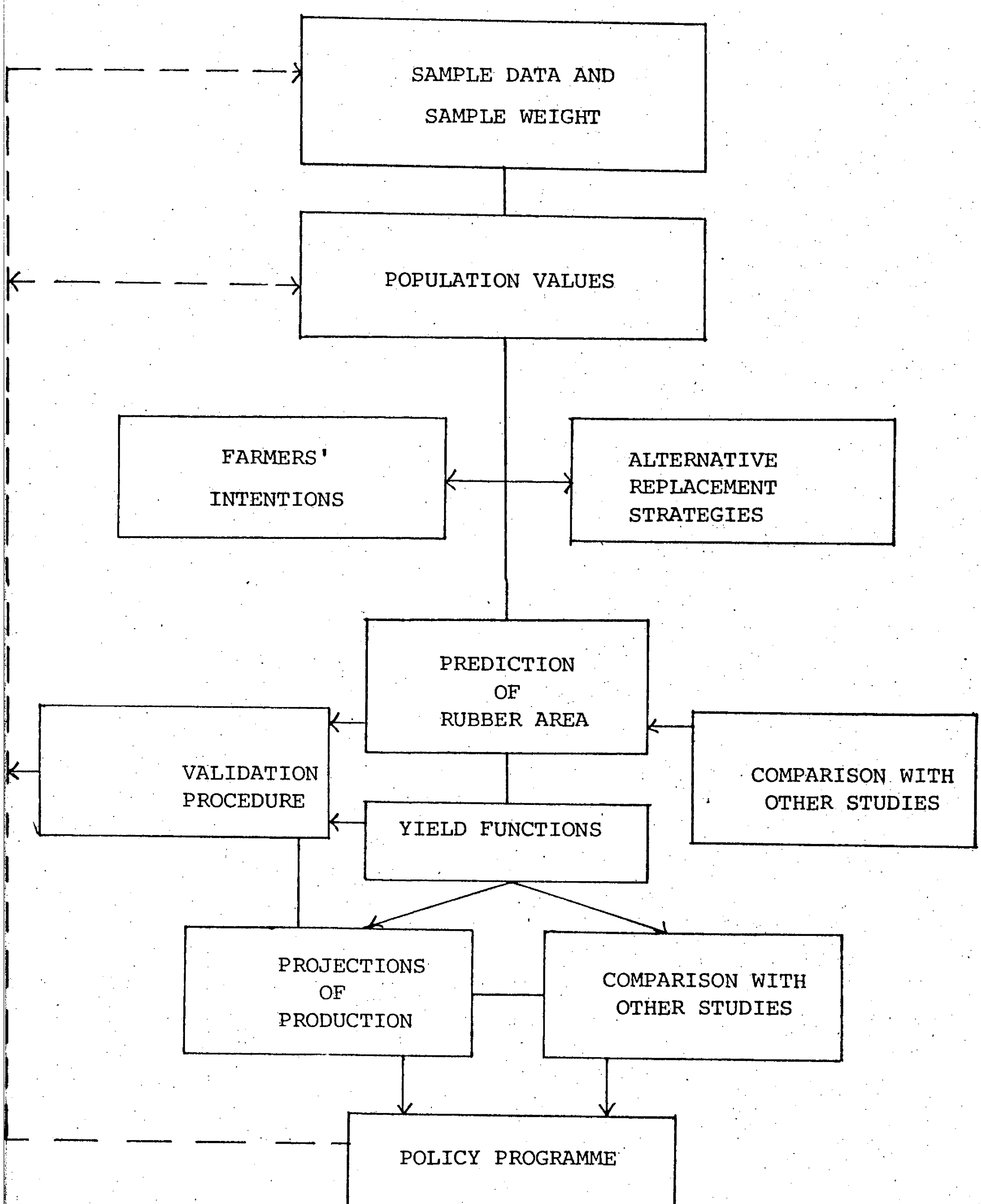


Figure 5.3

Block Diagram for Systems of Rubber Projection



This first presentation of the system is general and is concerned only with identifying the major sub-systems. As implied by the interconnecting arrows each of these sub-systems influences others. So both the subsystems themselves and the links between them must be examined in detail (Section 5.3).

5.3.2 Stage Two - Data Search

This stage represents a quantification of the diagrammatic model developed in Stage One. Limitations are usually found in the existing or potential data base. The seriousness of these depends on the ability and facilities to generate new research data for the model. In this study there is no flexibility since the data were collected for other reasons and there is no possibility of collecting further data for this particular exercise. In order to overcome these limitations, available data was modified in an objective way to suit the model developed. As mentioned in the previous chapter, the major modification (and limitation) was in grossing up population figures from the sample data. This was necessary because of the lack of time and funds to collect data especially for the requirements of this model.

The process of quantifying the conceptual base of this model and refining this quantification will proceed from this stage through to the final stage. It is actually a continuous process which involves interactions with other steps in constructing the simulation model and achieving final guidance for planning purposes from the completed model.

5.3.3 Stage Three - Basic Symbolic Model

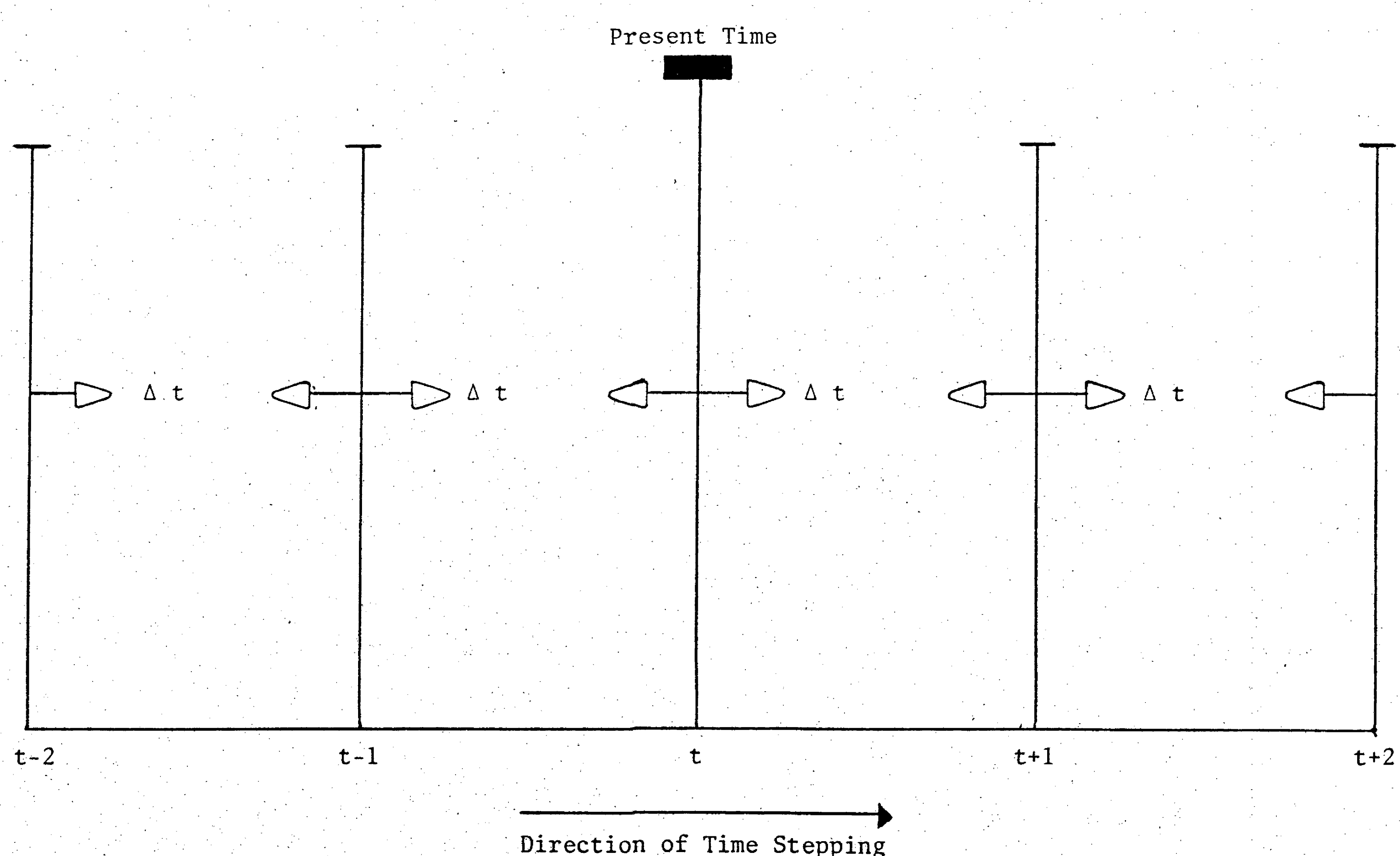
The model construction involves not only the building of a model, but the preparing of the model for computer coding. At this stage it is necessary to describe the details of the model in order to build up a comprehensive picture of the eventual model. One of the major factors in this is the introduction of 'time'into the model.

There are different ways in which time can be built into the model. One method is the fixed time unit basis. If time is advanced in fixed unit basis it is known as a 'time-stepping' type. Here time moves forward with the same intervals from the start of the simulation to the end. Projected events occur and the rate of change takes place only within the fixed time period. The basic time notation used in this type of simulation is illustrated in Figure 5.4.

The present time (defined as 't') in this model is 1978, because the main data set was collected in that year. The fixed interval (±t) on either side of 't' denoted by 't-1', as one interval before 't' and 't+1' as one interval later than 't', which is one calendar year. In the process of projecting at time 't' (or year 1978) various calculations are carried out and then when these are complete time advances one interval to the right. Once that happens, the 't+1' becomes 't' and what was 't' becomes 't-1'. Again at this stage all the necessary calculations are carried out before moving to the next time step. This same procedure is followed until the defined terminal date.

Figure 5.4

Time Stepping Simulation Model
(time notation)



Although all projections carried out in this study are based on the pre-defined period of single year intervals, for convenience of presentation many of the results are presented in five year intervals. The time interval selected was directly related to the likely level of detail required for policy decisions.

The 'time-stepping method'[2] has been chosen for this modelling exercise because although replanting and uprooting rubber occurs regularly, annual records are kept for planning purposes.

The equation form of the model can now be established on the assumed 'time-stepping' basis.[3]

The planting decision in a particular year of 't' could be expressed in linear form as,

$$a_{t,o} = \tilde{X}_t \; \beta + e_{t,o} \qquad (5.1)$$

Where,

$a_{t,o}$ = area of age zero in year 't'

$\tilde{X}_t$ = a vector of determinants of planting in year 't'

β = parameter of the vector

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2 The alternative method of representing time is 'event-stepping', where time advances by irregular intervals. This is used where there is a difficulty in determining the size of time increments. Under this the system is static over certain periods of time and time skips from one point to the next, when the next event occurs. The simulation system of queueing is commonly used for this procedure.

3 The following discussion draws heavily upon the personal communication of Dr. Michael Hartley of the World Bank with my Supervisor.

$e_{t,o}$ = random disturbance

In order to predict total area and potential output it is necessary to estimate not only the total area under rubber, but also the distribution of this area across age-classes and the associated yield of each age-class. Thus ideally the model attempts to endogenize the determination of age structure and yield.

Equation 5.1 determines the historical sequence of area planted in each year. The simplest approach is to assume that the area of age 'j' in years t, (a_{tj}) is equal to the area of age j-1 in the preceding year.

Thus

$$a_{t,j} = a_{t-1,j-1} \;...., \quad j = 1,2,3,....t. \tag{5.2}$$

Since

$$a_{t,j} = a_{t-j,1-1} \tag{5.2a}$$

Equation 5.2a implies that $a_{t,j}$ is identical to the area planted in year t-j, ie. $a_{t,j} = a_{t-j,o}$. Therefore it is possible to determine the age structure by the historical sequence of previous planting. However, understanding the sequence of new planting each year provides only partial information on the age-structure in production in future years. The area of age 'j' in year 't' should be less than the same area previously planted in year 't-j', due to depletion of stocks.

$$a_{t,j} < a_{t-j,o}. \tag{5.2b}$$

Obviously from the area of existing trees some may be depleted, either deliberately or as a consequence of diseases or pests, drought, rain and wind damage. Therefore the knowledge of new plantings in previous years gives only one side of the information about the surviving trees within each age class of the current year. In order to overcome this problem, it is important to ascertain the effects of weather conditions and other variables on the rate of stock depletion. It is necessary to undertake a detailed study of agronomic literature of the crop under study. However the lack of time and available resources do not allow such a study. Equation 5.2 may be modified in order to capture the annual depletion rates.

$$a_{tj} = \theta\, a_{t-1,j-1} + e_{t,j} \qquad (5.2c)$$

$$0 < \theta < 1$$

Where

θ = annual average depletion rates

$e_{t,j}$ = random disturbance, $j = 1,2,3,\ldots.t.$

Although the depletion rates may be subjected to change across different age classes within a given year, in this equation it shows as constant each year. This could be overcome by introducing a vector $\tilde{W}_t$, of determinants of the annual depletion rate which would include weather and disease condition and price expectation.

$$a_{t,j} = \theta_t\, a_{t-1,j-1} + e_{t,j} \text{ where} \qquad (5.2d)$$

$$\theta_t = f(\tilde{W}_t; p)$$

Where

$\tilde{W}_t$ = a vector of annual depletion variations

p = a vector of parameters

f denotes a cumulative distribution function with a domain in the unit-interval

Since the factors affecting depletion have a differential impact on different ages, a realistic model for depletion requires age-specific depletion rates. Some factors like weather and disease are very crucial during the immature age of trees.

Taking this into account, Equation 5.2d becomes:

$$a_{t,j} = \theta_{t,j}\, a_{t-1,j-1} + e_{t,j} \tag{5.2e}$$

Where

$\theta_{t,j} = f(\tilde{w}_t, j, p)$ now influences both (t) and age (j).

The total area under cultivation in year 't' is determined by,

$$A_t = \sum_{j=0}^{J} a_{t,j,p_i} \tag{5.3}$$

Where J = oldest trees in year 't'

and p_i = rubber replanting policy

In the process of estimating output (production) based on the area estimations, the model requires data on the actual yield associated with the age-structure. As noted in Chapter 2 the main source of variation in yield over the life of a rubber tree is the age of the tree. The average yield per hectare for the stock of rubber of age 'j' is denoted by the yield curve, given in Equation 5.4.

$$Y_{t,j} = \bar{Y}_j \tag{5.4}$$

for j = 0, 1, 2, ..., t.

The pattern in yield per unit of planted area y_j over time reflects the distinctive pattern in yields per tree.[4] However the yields for a given area exhibit variations from year to year due to changes in methods of cultivation, weather conditions, diseases and market conditions. Therefore any modelling exercise of yield should incorporate the influence of these variations. The yield equation then becomes more complicated with the inclusion of the age-specific effects of 'δ' on yields:

$$Y_{t,j,p} = \bar{Y}_{jp} + \ell(j,\delta;Z)\mu_{t,j} \tag{5.4a}$$

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4 Further details of this nature yield curve see Behrman (1968).

Where

ℓ = function explaining the effect of variations in the observed determinants

δ = difference of actual yield from normal levels in year 't'

Z = a vector of parameters

$\mu_{t,j}$ = random disturbance

p = replanting policy

Therefore the potential output of the model could be expressed as the products of area and yield per hectare over the overall age classes.

$$Q_{tp} = \sum_{j=0}^{J} a_{t,j} \, Y_{t,j,p} \qquad (5.5)$$

This potential output obviously deviates from actual output due to producer prices, wage rates, availability of labour and weather conditions. If the model is modified to capture such possibilities the equation of the linear model becomes:

$$Q^{*}_{t} = Q_t + V_t \, d + \mu_t \qquad (5.6)$$

Where,

V_t = a vector of determinants of such differences with associated co-efficient 'd'

μ_t = random disturbance

The model presented thus far is general and its application to the forecasting of rubber area and production will depend crucially upon the availability of data. Depending on the accuracy of data the following error of output function could be minimized.

$$\text{ERROR} = \sum_{t=1}^{n} [Q_t - Q^{*}_{t}] \qquad (5.7)$$

The application of this model using data collected from different sources is discussed in detail in Chapter 6.

5.3.4. Stage Four - Computer Application

The next step is to implement the basic symbolic model by computer application. Although there are special purpose simulation languages, it was decided to use FORTRAN (a general purpose language), because it is a widely understood code. The respective main programme of the model is presented in Appendix I. A strict modular approach to the programming of the model allows adaption and expansion as required.

We have so far discussed the various aspects of constructing the model. However it is virtually impossible to build a realistic simulation model unless stochastic elements are included (Mihram 1972). The term 'stochastic' is used to describe both unexplained elements and events which are random, especially in a predictive model of this nature, which is particularly concerned about an uncertain and risky future. Anderson (1974) pointed out that simulation models which are the most flexible and least confined of symbolic models, can accommodate stochasticity easily and directly. Accordingly such a model will often find favour over more restrictive and less-easily stochasticised models whenever refined and versatile modelling is undertaken. If uncertainty is included in the model structure it reflects the degree of understanding of the real system as a decision support role.

However the inclusion of stochastic elements into a model at times creates confusion about the system and reduces its acceptability. Therefore it is better to introduce deterministic elements into the model initially and then introduce stochastic elements where deterministic models are found to be inadequate. The model used in this analysis is already an advance on previous attempts to project rubber areas and output. It is felt that the objectives of this particular modelling exercise can best be achieved by using a deterministic basis while suggesting in the conclusions the mechanism and data requirements needed to introduce uncertain-ty into extensions of the current model.

The model adopted explicitly includes the changes occurring in status and output variables over time. These changes are partly determined by the values of the exogenous variables in each time period, so it is clear that realistic values for the exogenous variables must be provided in the model for each time period. This does not mean that the model is attempting to predict 'exact values' for future rubber area and production. These time series of exogenous variables used in the model represent the environment, taking account of known patterns in and interactions among the variables. This representative series is obtained by applying information from the RIMP survey to the structures in the model and generating representative time-series data. However these data of course may never occur in the real world in exactly the sequence generated by the model.

5.4. Model Evaluation

The evaluation of the model is a two-stage process with two different purposes.

Model verification

Model validation.

The model verification is concerned with the testing of the model, whereas the validation phase assesses the model in relation to its prescribed use.

5.4.1. Model Verification

In practical terms the verification process is used to compare the model with the current understanding of reality. In order to adhere to this, the model has been executed with given input data and with prescribed exogenous conditions. The generated output of the model is then used to assess its functioning ability. This has been done without introducing stochastic elements. Dent and Blackie (1979) have explained two sets of techniques to evaluate and correct a model, known as 'antibugging' and 'debugging'. Actually the above two terms are computer programming jargon; the inclusion of a 'bug' in a programme makes for inconsistent behaviour and produces wrong answers. Incorrect data are among the most common causes of bugs in simulation models, consequently the exercise of 'debugging' involves tracing the cause of bugs and their removal. 'Anti-bugging' is the process of preventing the occurrence of bugs. In the model developed in this exercise the programme itself has devices to indicate 'bugs', should they exist.

5.4.2. Validation of the Model

Validation is not so much concerned with the correctness of the model, unlike verification, but is concerned with whether it is effective or suitable for the specific purpose for which it was constructed.

In the literature on simulation, three fundamental positions have been presented on the issue of validation procedure (Naylor et al, 1966). Among them the 'positive step' is important in this exercise, [5] which accepts the validity of a model, if it is capable of accurate prediction, regardless of the internal structure underlying the logic of the model. Schrank & Holt (1967) proposed that the only criterion for model validation is its 'usefulness'. Naylor and Finger (1967) suggest a multi-stage procedure which tests a selected number of structures for formal empirical assessment, but not all the structures in a model. This procedure gives equal weight to the validity of the hypothesis used for the model structure and the predictive capabilities of the model.

The subjectivity of all validation procedures has been emphasized in the literature, which arises essentially from the human limitation to knowledge, especially regarding the behaviour of systems. In a situation where a subjective

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5 The other two positions are the 'rationalist step' and the 'empirical step'. The rationalist step ensures that assumptions are in accord with the theory and the 'empirical step' subjects assumptions to empirical testing.

appraisal is the basis of validation, it is crucial that all the conditions of input to the model are detailed over the simulation time.

If statistical testing is considered for validation, there are some sources of real data for comparison. The historical data already used for model building could not be used in this exercise since it was used essentially for verification. Therefore the data especially generated or collected for validation are most suitable. In this exercise the data for validation have been collected by two methods. One method is to generate data for the past using a 'cranking back' forecasting model. These data generated from the model from past periods can be compared with the actual historical evidence about the area and production of rubber. If the generated values are identical to historical data under the replanting policy investigated, it can be concluded that the above policy is more appropriate and the performance of the model is accurate. The prediction made by the model under such a policy could be accepted.

The second method of validation used in this analysis is comparison with the other estimations provided by research institutions and organizations. There are few such sources of estimation available, and it is intended to show their limited usefulness since they are based on highly restrictive assumptions.

The comparison of generated data and the data used for validation can be carried out in two different ways. A set of graphs could be produced comparing both distributions. The second way is statistical testing of the model output. In the literature there are a number of reviews of statistical tests for validation which have been suggested (Mihram 1972; Naylor & Finger 1967).

One simple method is simple regression analysis between the mean model output and real system measures. This is perhaps useful in deterministic models where a linear regression is fitted and a model provides a line with the intercept and the slope. The second method is testing hypotheses. Since the hypotheses that are simulated and the real recorded system output have the same type of distribution, it is possible to perform goodness-of-fit tests. It is also possible to formulate two hypotheses, null and alternative, and test each. In addition to this goodness-of-fit test, the common tests like chi-square test and the Smirnov test could also be applied. The interpretation of results from statistical tests are discussed in detail in Chapter 6.

Validation is a crucial step in the modelling exercise, and it is a continuing series of assessments into the commissioning stage of the model's life. When it is verified that the behaviour of the model is satisfactory the process of validation is over.

As mentioned earlier numerous statistical tests are available to determine whether the model's behaviour is different from the real system, to some level of significance. The acceptable level of confidence could be achieved by a series of assessments and modification procedures. The feedback procedure given in Figure 5.1 is crucial in this exercise.

Model evaluation is an important part of model-building and application. However the model must be built with allowance to modify it if necessary during evaluation and its subsequent use.

5.5 Sensitivity Analysis

Anderson (1974) stated that 'sensitivity analysis is the testing of the robustness of a model through recognition of its imperfections'. This involves exploring the operation and performance of the model. Changing a parameter may result in changing output and this will be analysed by sensitivity analysis to determine whether or not the changed parameter values are crucial for changing output. If sensitivity to the given parameter is insignificant as far as the given model is concerned, the model is said to be robust.

Sensitivity analysis is concerned with discovering what happens when an unsure parameter is changed while others remain unchanged. When there are several unsure parameters and the procedure of adjusting these one at a time can be applied effectively, there remains the need to keep in mind the limitation of ignoring possible interactions between unsure parameters.

At times sensitivity analysis can provide guidelines for validation as shown in Figure 5.1, suggesting feedback between stages 5, 4 and 3. This happens if a model is shown to be sensitive to particular aspects of a model design or data about which there are suspicions of inaccuracy.

Sensitivity analysis is crucial in the whole process of simulation, because of its feed-back ability to the stages of model construction and model validation. In addition it is possible to redefine the objectives of the study if necessary. Experience indicates that sensitivity analysis is an on-going procedure even when the model is finally approved for application (Dent & Blackie, 1979).

5.6 Model Application

The ultimate aim of the system simulation procedure is to provide decision support as a planning tool in relation to the real system under study. The main objective of modelling of this nature is to assist in the closer understanding of the system.

Applications of simulation models are to be found at all levels of aggregation of economic phenomena. Those levels include macro, micro and mixed levels. There are also the more aggregative simulations which attempt to model future world variables such as population, income, food. Most of such futuristic simulations have been criticised on the grounds of methodology, assumptions and data (Freeman 1973, Krenz 1973, Nordhaus 1973).

The application of the model developed in this chapter to predict the area and production of rubber is discussed in detail in Chapter 6. Further, the limitations of the study due to data and methodological problems are also investigated.

CHAPTER 6

THE EMPIRICAL APPLICATION, RESULTS AND INTERPRETATION

6.1 Introduction

In the empirical application of the model five alternative replacement strategies are examined. They are,

a) 26 years replanting cycle;

b) 30 years replanting cycle;

c) 33 years replanting cycle;

d) 3 per cent of the area replanting per annum;

e) Replanting policy based on farmer's expressed intentions to replant.

The first three strategies are based purely on the age of the plantation, i.e., 26, 30, 33 years. The results of the analysis done by Jayasuriya (1973) on the optimal replacement age under different tapping systems, discount rates, technological change, subsidy, and prices shows that the economically feasible cycle is below 33 years under socially and privately determined conditions. Further he concludes, that the date of replacement of rubber under different conditions typically varies over the range of 25 years to 33 years. Thus three cycle lengths which are mainly based on age, have been selected within that range. The selection of the 33 years policy is particularly important since the current official rubber replanting scheme operates within an implied replacement cycle of this length. Although this has not been subjected to any detailed economic evaluation, the plans for the rubber industry are based on the 33 years replacement cycle as a basic rule of thumb. A crop cycle of 33 years implies 3 per cent annual replacement. However, a major distinction must be drawn between a cycle based on age and one based on a percentage of the area planted. In the former case the annual replanted area depends critically on the cohort structure of past planting. In the latter case, the annual replanting depends only on the total area under rubber and not on the age structure of the trees. The rubber industry planners in Sri Lanka have not faced up to this fundamental distinction since alarm is expressed whenever the replanting falls below 3 per cent with no discussion as to whether this is simply because 33 years earlier fewer trees had been planted and/or replanted. An age-specific replanting policy will only match a corresponding 'percentage-of-area' policy, if the latter policy is in fact implemented every year.

The final strategy under investigation is probably the most realistic since it is based on the survey results of the intentions of the rubber farmers towards replanting. This was discussed in detail in Chapter Three. Clearly the intentions of farmers are crucial in replanting policy decisions. The most significant aspect of this procedure is its capability to capture both the 'infant' and 'juvenile' mortality of the trees. In reality whatever the replanting strategy adopted, it is also important to consider the premature 'death' of trees due to wind, drought, excessive rains, disease or pests.

Table 6.1, which is based on the survey results, bears out the contention that replacement should be viewed as a probability distribution rather than a deterministic fact. The cumulative distribution shows that 14.1 per cent of

Table 6.1

Frequencies of Intended Removal Age

Age	Sample Frequency (Ha.)	Relative Frequency	Cumulative Frequency
0	81	0.586	0.586
1	0	0.000	0.586
2	1	0.007	0.593
3	27	0.195	0.688
4	1	0.007	0.695
5	0	0.000	0.695
6	61	0.441	1.136
7	1	0.007	1.143
8	1	0.007	1.150
9	12	0.087	1.237
13	3	0.021	1.258
15	19	0.137	1.395
16	1	0.007	1.402
17	0	0.000	1.402
18	5	0.036	1.438
19	1	0.007	1.445
20	40	0.289	1.734
21	11	0.079	1.813
22	52	0.376	2.189
23	135	0.976	3.165
24	129	0.932	4.097
25	1385	10.014	14.111
26	320	2.314	16.425
27	488	3.528	19.953
28	587	4.244	24.197
29	2517	18.200	42.397
30	1657	11.981	54.378
31	3118	22.545	76.923
32	664	4.801	81.724
33	446	3.225	84.949
34	306	2.213	87.162
35	469	3.391	90.553
36	137	0.991	91.544
37	221	1.598	93.142
38	215	1.555	94.697
39	120	0.867	95.564
40	68	0.492	96.056
40&above	533	3.944	
TOTAL	13830	100.000	100.00

Source: RIMP Survey Data.

replacement is premature in the sense that removal has taken place at ages less than that normally considered to be economic (i.e. 25 years). A further 6.9 per cent are allowed to continue into 'old age' (over 37 years) and 3.9 per cent into 'senility' (over 40 years).

Before examining the implication of these strategies, the model is evaluated by performing different tests, which include both verification and validation processes. At the stages of model verification and validation, an attempt is made to assess the correctness of the model. Following the validation of the model, experimentation and interpretation are considered with the five replanting strategies. The results are then related to their policy implications.

6.2 Model Evaluation

The two procedures of model evaluation, verification and validation, are quite distinct in practice, and have different purposes. In practical terms verification can only be achieved by selecting a suitable criterion with which to compare the model output. Once we decide this, the next problem is whether the model, already constructed is an adequate representation for our purposes. This involves process of validation.

6.2.1. Model Verification Procedure

At this stage, model output is compared with the current understanding of the real situation. The trend of the rubber replanting from the inception of Rubber Replanting Subsidy Programme shows a declining pattern over time (see Table 1.4). The same declining but cyclical pattern is shown in the output generated by the model (see Table 6.7). Without doing any comprehensive testing this gives some indication that the model is a reasonable representation of reality. However, this is barely enough to ensure that the model confirms the correct representation of reality. Further this procedure is used to gain an insight of the model, by checking the logic of the model.

6.2.2. Model Validation Procedure

One simple method of validation is comparison of the model output with the available historical records. The test for model predictive capacity against historical data involves selection of an appropriate time period for analysis. The period chosen in this case is 1950-1978, since the Rubber Replanting Subsidy Scheme was introduced in 1953. Also this is the period that recorded the largest area of replanting since the inception of the Rubber Industry. Furthermore accurate records were maintained during this period.

As mentioned in Chapter 4, the required statistics were collected from the Annual Administrative Report of the Rubber Controller, and the Annual Economic Review of the Central Bank of Ceylon. The statistical series chosen for the validation of the model is the annual time series of the area replanted and total production. The model output for the past period was generated by 'cranking' the model backwards. This is the only way to get past records, since the data is based on 1978 conditions. Additionally, this procedure is simple and accurate. The logic behind the procedure is to go back to the past in the same way and under the same policy that future values are simulated. This has a dual purpose. First, it validates the model by comparing it with past records. Second, it allows the selection of the most accurate replanting strategy for future prediction purposes. It is presumed that the correct policy for future prediction is the one which gives past values closest to the actual records.

The set of unambiguous and generally accepted time-series data on replanting for the period of 1950-1978 and the model generated values for the same period are presented in Table 6.2. Strategy No. 4, which involves the replanting of 3 per cent

Table 6.2

Comparison of Rubber Replanting Area with Model Output

Year	Actual Replanted Area (Ha.)*	MODEL OUTPUT (Ha.)			
		Strategy 1 (26Yrs)	Strategy 2 (30Yrs)	Strategy 3 (35Yrs)	Strategy 5 (Intentions)
1950	1837	250	3140	3142	4035
1951	1957	2804	1450	1499	1844
1952	2253	1400	5990	3995	7112
1953	2696	3400	4173	4180	4837
1954	8091	5528	5528	5530	5766
1955	8966	10726	10726	10706	11083
1956	10127	2037	2037	2037	12084
1957	10939	4543	4543	4533	14631
1958	9290	10660	10660	10680	10858
1959	8316	10743	10743	10643	10991
1960	8030	4703	4703	4723	4776
1961	8137	11806	11806	11806	11985
1962	7546	16695	16695	16695	15948
1963	6710	9140	9141	9134	9279
1964	5658	7845	7845	7846	7953
1965	5321	2717	2817	1718	2755
1966	4846	5070	5078	5078	5146
1967	5138	2520	2518	2519	2552
1968	5392	2206	2206	2207	2236
1969	5018	1010	1007	1008	1021
1970	4257	4623	2463	4623	4681
1971	3669	10265	10265	10256	6933
1972	3719	1290	1289	1289	4305
1973	3121	4509	4909	4060	4091
1974	2899	1350	1350	1350	1361
1975	3372	1993	1993	1993	2009
1976	2606	1381	1381	1381	1989
1977	2662	248	248	249	2250
1978	3603	2803	2804	2804	2820

* Source: Annual Administrative Report of the Rubber Controller, 1940.

of the area annually, is not shown as it just generates a constant amount for each year since the total area is assumed to remain constant.

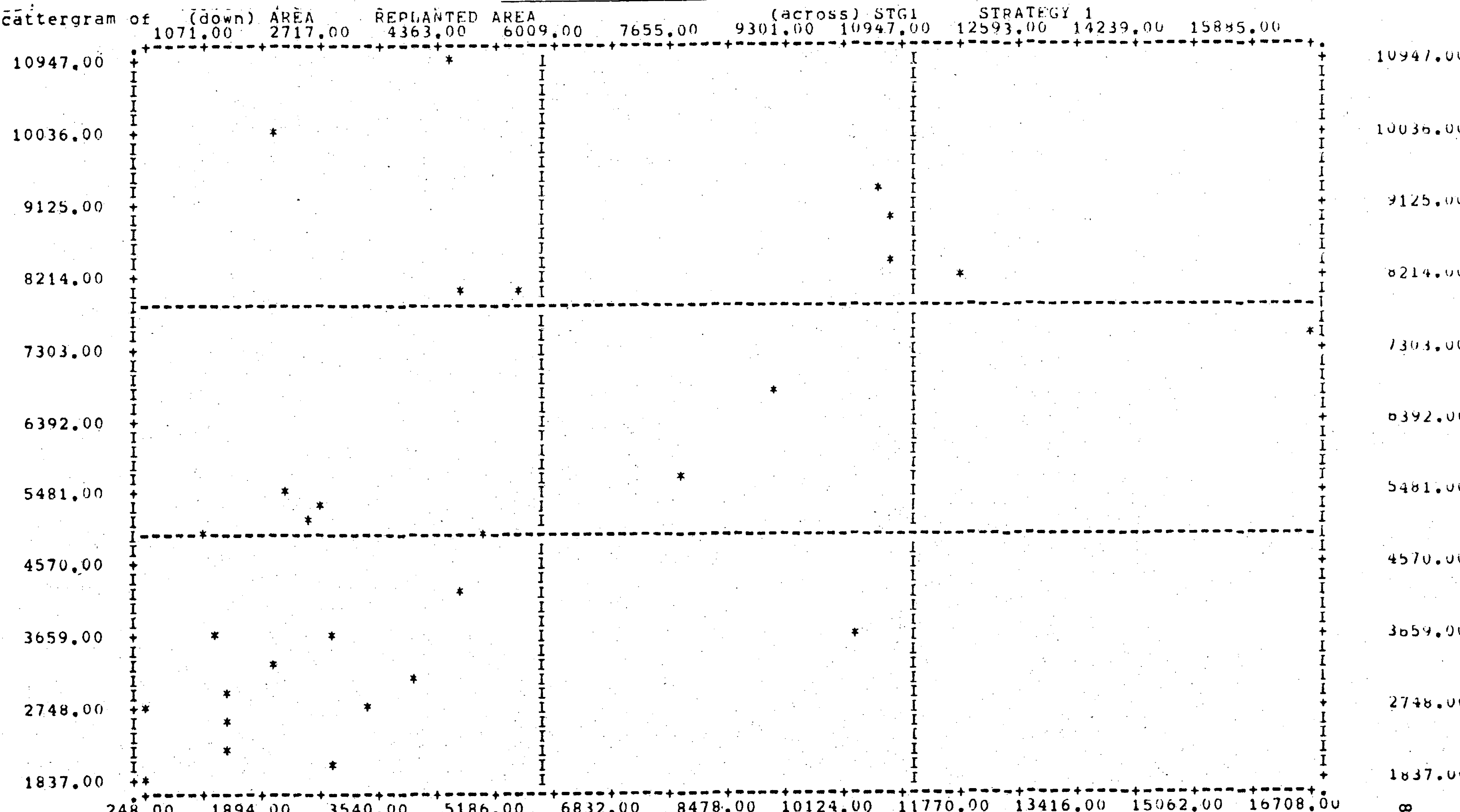
The results are barely satisfactory with the model output comparing not very closely with the actual replanting records. The plots of the data generated by the model with the historical data are presented in Figure 6.1; (a), (b), (c) and (d). Although this procedure is simple, it provides a 'feel' for the situation and it is a good basis for further analysis.

This in itself does not validate the model, since it is also necessary to demonstrate that the data generated for the period of 1950-78 is realistic and the parameter values of this prediction can be justified. In fact statistical testing could be considered at this stage for further comparison. Among the comprehensive series of statistical tests available for validation, two general approaches have been selected; 'simple regression analysis' and 'goodness of fit tests'.

Simple regression analysis is performed between mean model output and actual past records as paired observations. By using a sub-program scattergram of the Statistical Package for the Social Sciences, (SPSS) prints a two dim^nsional plot of data prints, where the co-ordi^ates of the points are the values of the actual area and generated output being considered. These plots indicate the relationship of the paired variables and the equation lines as shown in Figure 6.1 (a), (b), (c) and (d). Each strategy predicts the area values, one different to the other, based on the assumptions of life cycle.

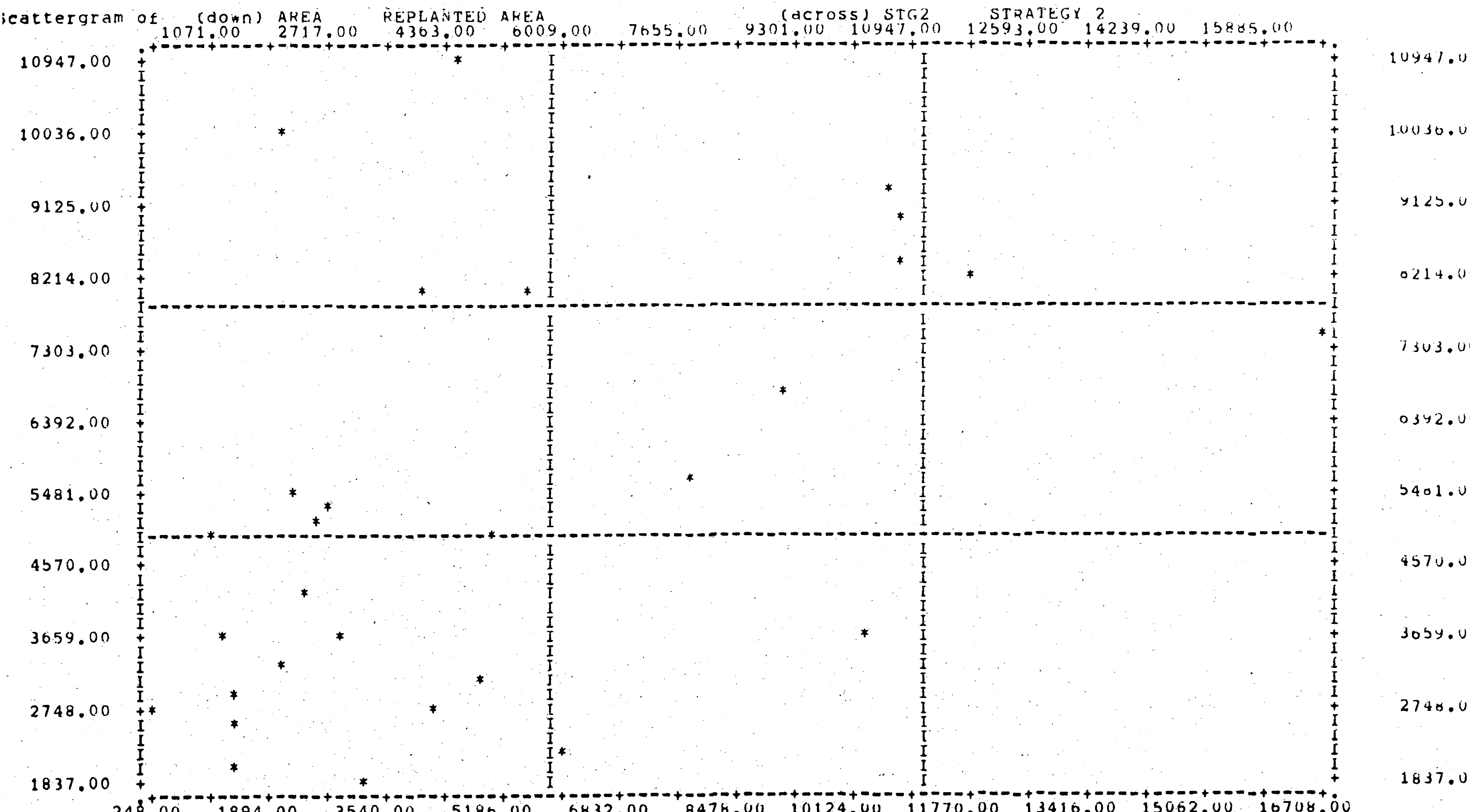
Out of the fitted regression lines a perfect model would provide a line passing through the origin with a slope of one. It can be seen from Figure 6.1, that each of the plots of the different strategies has a different slope and intercept. The data points are represented by asterisks (*). There are some extreme points in the first strategy with one observation plotted towards the left-hand corner and one towards the right-hand corner of the diagram. Most of the plots of strategy 2 and 3 are plotted unevenly. But strategy 5, unlike the others, shows a slight approximation to a 1:1 correspondence.

FIGURE 6.1(a): Validation Procedure - Comparison of Model Output & Actual Data



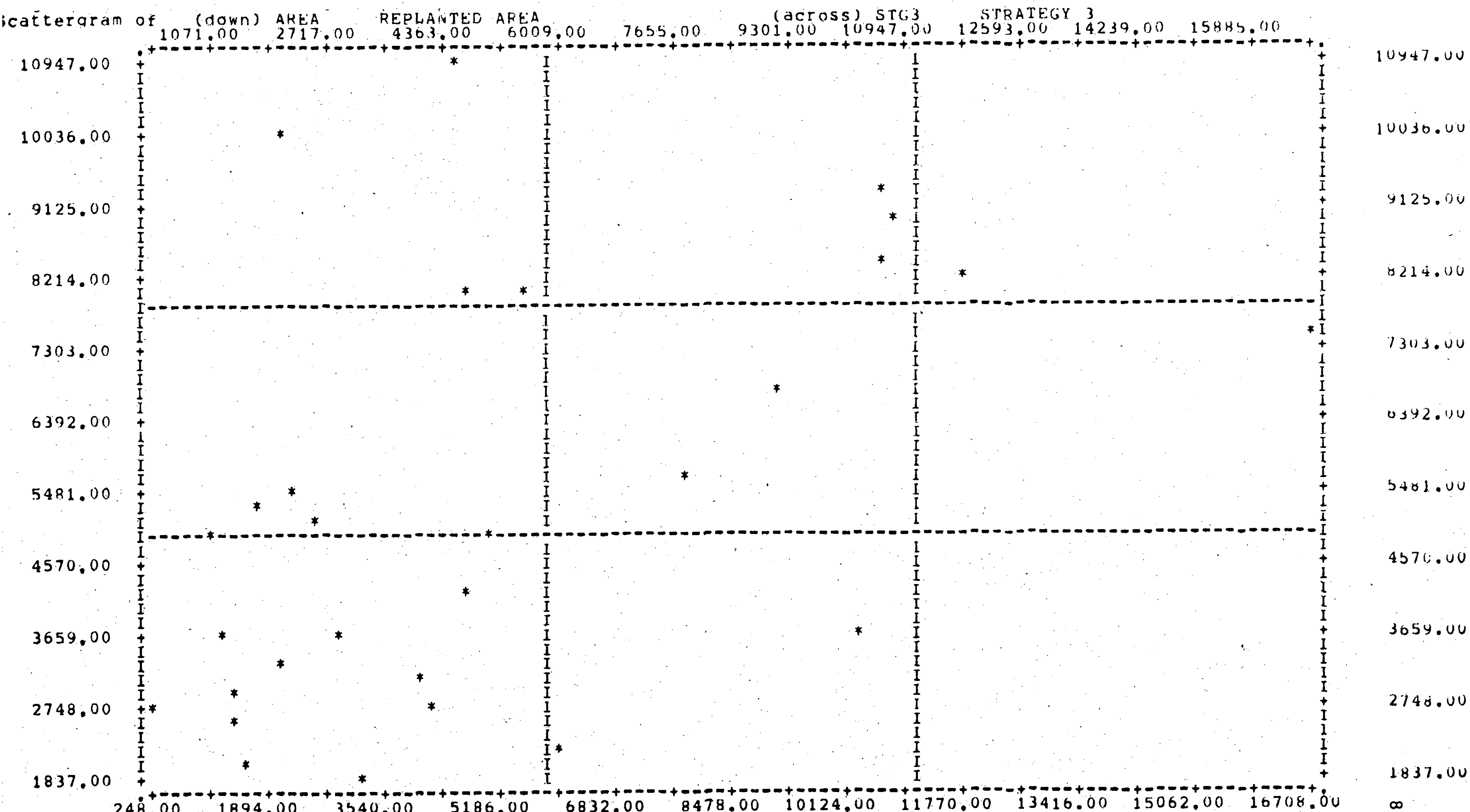
Source: RIMP Study
Annual Administrative Reports of Rubber Controller, Sri Lanka.

FIGURE 6.1(b): Validation Procedure - Comparison of Model Output & Actual Data



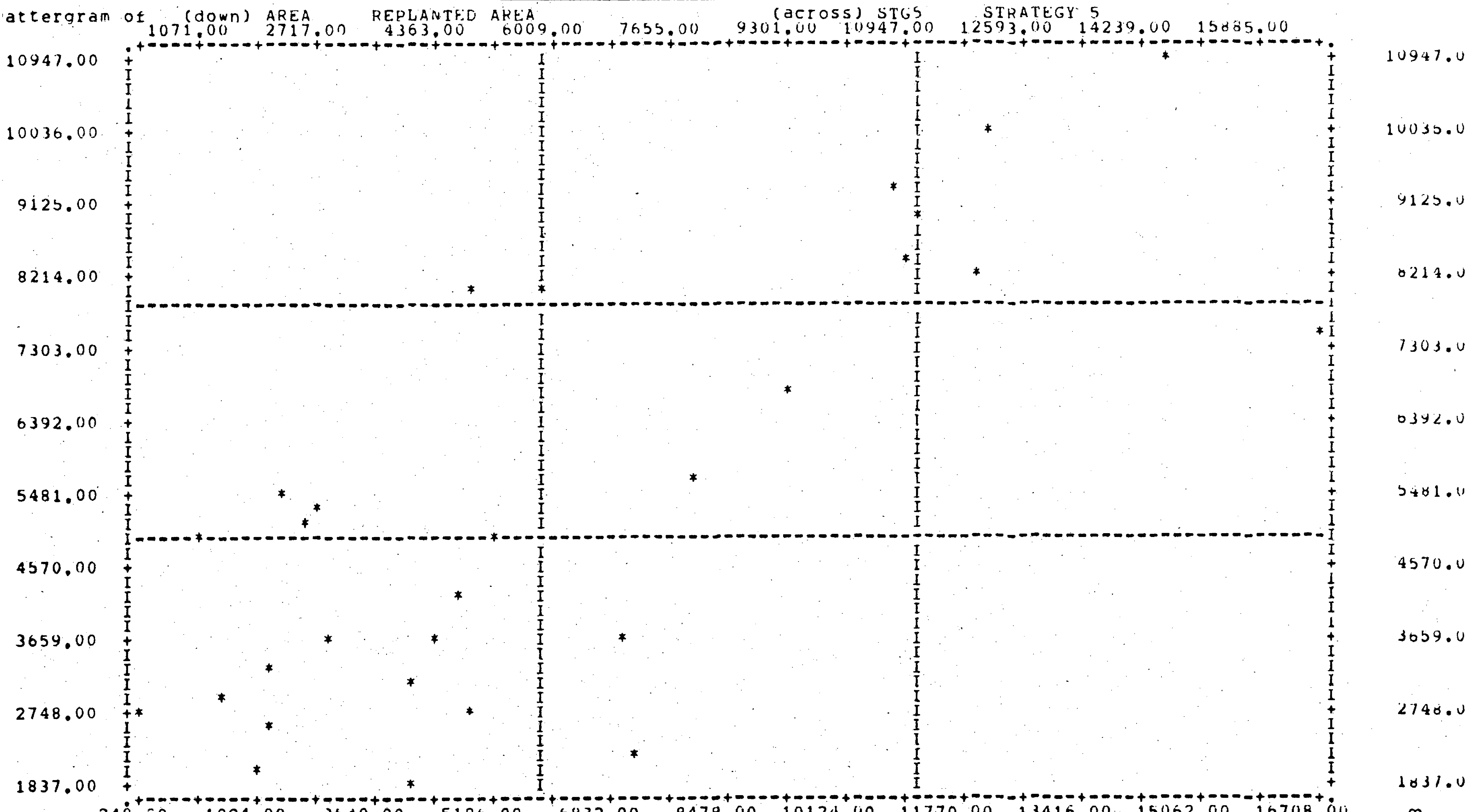
Source: RIMP Study
Annual Administrative Reports of Rubber Controller, Sri Lanka.

FIGURE 6.1(c): Validation Procedure - Comparison of Model Output & Actual Data



Source: RIMP Study
Annual Administrative Reports of Rubber Controller, Sri Lanka.

FIGURE 6.1(d): Validation Procedure · Comparison of Model Output & Actual Data



Source: RIMP Study
Annual Administrative Report of Rubber Controller, Sri Lanka.

In addition to plotting, the statistics associated with simple regression was also computed. The dependent variable in this case was the actual replanting figures, and each strategy was considered separately as an independent variable. Further the slope and intercept of the regression line, the Pearson Product - moment correlation , and standard error of estimation were also computed. The results of this exercise are presented in Table 6.3.

Table 6.3

Regression Analysis* among Actual Area and Model Output

Strategy	Intercept (a)	Slope (b)	R^2	Standard error of estimate	R-Value
1	3619.5	0.356	0.315	2258.0	0.561
2	3735.0	0.322	0.247	237.6	0.497
3	3706.7	0.325	0.251	2360.8	0.501
5	2437.6	0.464	0.583	1761.4	0.764

* The values for intercept (a) and slope (b) of the equations calculated by using the following formulae:

$$\hat{a} = \frac{(\sum_{i=1}^{N} Y_i \sum_{i=1}^{N} x_i^2) - (\sum_{i=1}^{N} x_i \sum_{i=1}^{N} x_i y_i)}{(N \sum_{i=1}^{N} x_i^2) - (\sum_{i=1}^{N} x_i)^2} \qquad \hat{b} = \frac{(N \sum_{i=1}^{N} x_i y_i) - (\sum_{i=1}^{N} x_i \sum_{i=1}^{N} Y_i)}{(N \sum_{i=1}^{N} x_i^2) - (\sum_{i=1}^{N} x_i)^2}$$

Among these four regression analyses, a perfectly fitted one could be decided by different methods. One method is to take a line which will pass through the origin with a slope of one. Under these four strategies it is difficult to select a perfect line as such, but the line under strategy 5 is better than the others. The intercept value of stragegy 5 is 2437.6 which is the closest value to zero among the strategies considered. It is 'close to zero' in the sense that this value would represent a very low figure for annual replanting. Also the value for slope (b) in strategy 5 gives a maximum value of 0.464, implying a greater closeness to one than the others. The Pearson Product Moment correlation is 0.764 in strategy 5, whereas the other coefficients are 0.561, 0.497 and 0.501 respectively for strategies 1 - 3.

The results of the regression analysis are not strong enough to make a definite conclusion regarding the two distributions. Therefore a 'goodness-of-fit test' was carried out. This test was used to examine the hypothesis that the simulated and actual recorded system output have the same parent distribution. In this case two hypotheses were formulated: i.e. the null hypothesis assumes that the two distributions are the same, while the alternative hypothesis expects the two sets of data to have different parent distributions.

In the process of validation the null hypothesis is used to establish that the model output is the same as historical records. This could sometimes lead to a Type II error which is the error of accepting that these are the same when in fact they are not. However, the distribution of the model output and the observed real system distribution are from different populations and are not known accurately enough to calculate a Type II error.

In order to test the two different distributions, a 'paired T-test' has been carried out by using SPSS.[1] The correlation values of the two distributions were also computed. The calculated correlation coefficient must be positive for pairing to be effective and if it is negative then the initial assumption of pairing needs to be re-examined (Nie and others, 1970).

Presuming that the population values of actual replanting and estimated replanting values for each strategy are distributed normally, two hypotheses were formulated.

$H_0;\ \mu_a = \mu_e$

The null hypothesis is that actual and estimated distributions are equal. The alternative hypothesis against this is

$H_1;\ \mu_a \neq \mu_e$

under two tailed conditions. Having formulated the hypothesis, the T-Values and other statistics have been calculated. These are presented in Table 6.4.

The hypotheses have been tested under a level of significance of 0.05 and 0.01. The critical region for 0.05 significance level is -1.701 to 1.701 and under 0.01 significance level -1.467 to 2.467. Thus the null hypothesis (Ho) could be accepted at both probability levels. It concludes that all four strategies do not differ significantly from actual output. Thus it is impossible to select the best strategy

---

1 To compute 't' for a paired sample, the paired difference between two variables is formed.

$$D = X_1 - X_2$$

D is normally distributed with the mean value of δ. Then the 't' value

$$t = \frac{\bar{d} - \delta}{S_{\bar{d}}^2} \qquad \text{where } \bar{d} = \text{sample mean}, \quad S_{\bar{d}}^2 = \text{variance}$$

$$s_{\bar{d}}^2 = \left(s_1^2 + s_2^2 - \frac{2\Sigma x_1 x_2}{n-1}\right) / N$$

using the results of the 't' tests. However, the high positive correlation value between area and strategy 5 indicate the pairing to be more effective than other strategies.

Table 6.4

T-Test and Other Statistics

Pairs	Mean Difference	Standard	Standard	Correlation	2-Tail Probability	T-Values	2-Tail Production
Area 2 Strategy 1	-628.9	6860.2	1273.9	0.561	0.334	-0.49	0.625
Area 2 Strategy 2	258.8	3641.5	676.2	0.497	0.006	0.38	0.705
Area 2 Strategy 3	223.5	3623.6	672.9	0.501	0.006	0.33	0.742
Area 2 Strategy 5	-726.7	2796.2	519.2	0.764	0.000	-1.40	0.173

Degrees of freedom = 28

The conclusion can therefore be drawn that the model which is justifiable on a priori grounds provides a valid representation of the behaviour of rubber area. Except for the regression values, it is hard to say that one strategy is better than the others. Naturally the results are subject to error due largely to data collection difficulties, but it would seem that given reliable data the model is capable of generating accurate predictions.

Although confidence can be placed on the predictions of rubber replanting area, it is hard to accept that the production estimates are also likely to be realistic. Since the production is mainly determined by the respective yield curve, it is necessary to validate the yield curve and production.

Here again simple regression analysis is performed between the actual records of production up to 1950. Among the five strategies, the fifth one was more realistic and it generated data very close to past records. Since the area prediction under this strategy is close to reality it has been decided that the yield curve used in this strategy is also accurate. Obviously the accuracy of both area and yield curves is necessary to obtain accurate production estimations.

Having made the decision that strategy 5 is more accurate than the others, a simple regression analysis was performed. The two distributions used are presented in Table 6.5. In order to obtain a smooth distribution 'three year moving average' values of both distributions have been used.

Table 6.5

Comparison of Model Output and Actual Production (MT)*

Year	Actual	Model
1977	151400	148388
1976	149000	146928
1975	145000	145270
1974	146000	144193
1973	143000	142779
1972	145000	140075
1971	147000	138247
1970	151000	154961
1969	151000	105370
1968	148000	142524
1967	141000	144094
1966	131000	127186
1965	121000	108206
1964	107000	106896
1963	103000	98387
1962	101000	104663
1961	97000	102953
1960	98000	100887
1959	99000	102310
1958	100000	110403
1957	98000	107145
1956	96000	105970
1955	98000	103679
1954	102000	109340
1953	107000	104795

Source: RIMP Study Data

* Both distributions are on three year moving average values.

The statistics calculated among these distributions show the closeness to each other. The correlation value (R) is 0.97399 and R squared (R^2) value is 0.94866. The slope (b) is 1.09694 and intercept (a) is -12505.7. The two-dimensional plot among the variables also shows the closeness of both distributions. This is presented in Figure 6.2. These results are good enough to decide that both distributions are the same. If both distributions are the same, the conclusion is that the model is very accurate for the prediction of production.

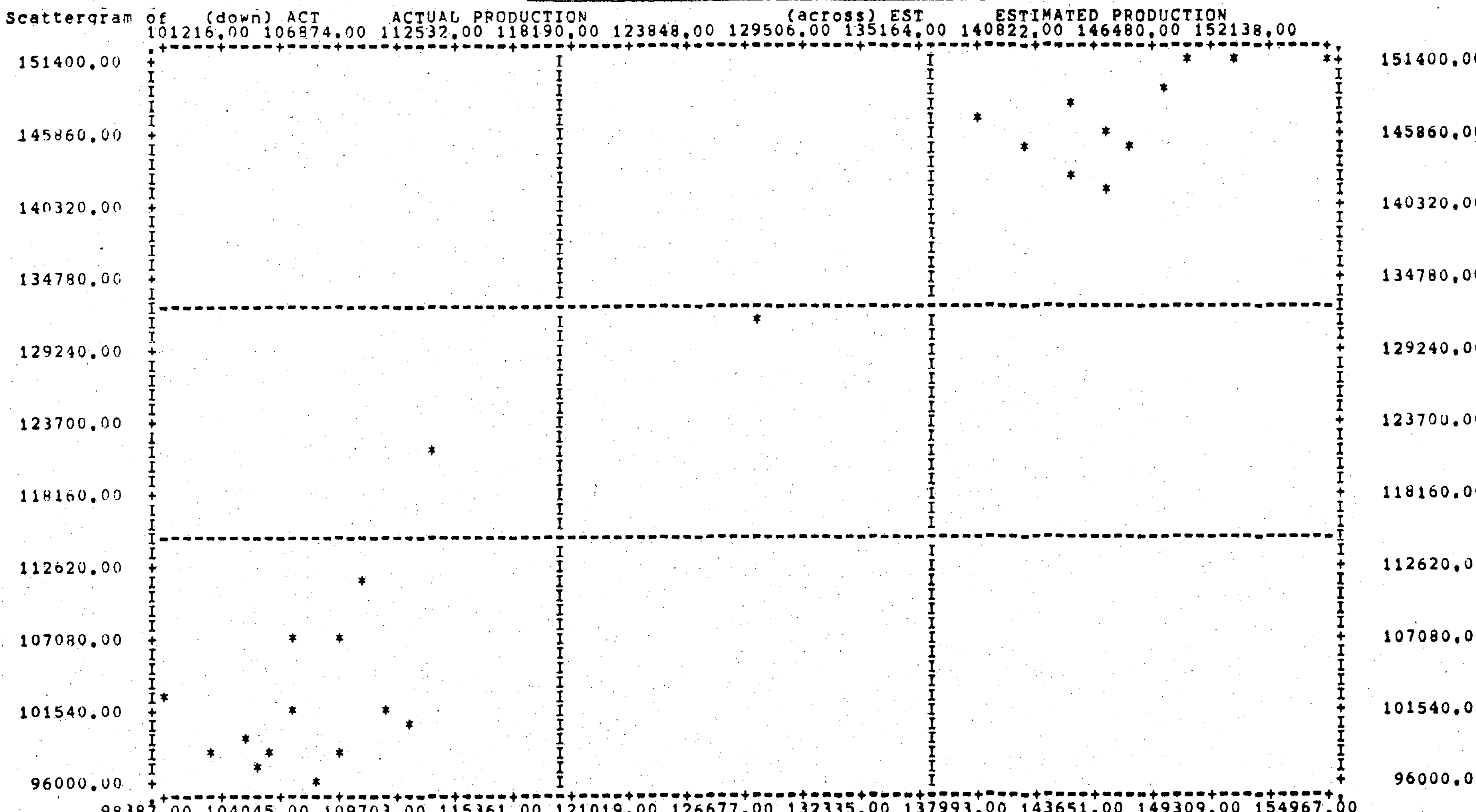
With this valid model it is possible to test the model projections for both area and production. The results of model experimentation and interpretation of results are presented in the next part of this chpater.

6.3 Model Experimentation and Interpretation

After the model was refined and the first two validity checks for area and production were made a computer execution was made to establish a base against which all other experimental executions could be compared. The base run started with initial conditions as of 1978, since the base data were collected from the 1978 cross-sectional survey. The computer programme generated the historical period up to 1980 and then the projected period to the year 2020.

The testing of the model was basically carried out under the five strategies mentioned in Section 6.1. In each case an attempt was made to predict the total area figures in terms of the age specific classes. This gives the projected value for area under each strategy based on equation 5.3. Second, projections were made for the replanting area annually up to the year 2020. This program was also used to generate historical records of replanting from 1950, for validation purposes, as explained in the previous section. Third, production was forecast by using the total area already calculated. The respective 'yield curves' were also investigated at this stage.

FIGURE 6.2: Validation Procedure - Model Output & Actual Production



Source: RIMP Study
Annual Administrative Reports of Rubber Controller, Sri Lanka.

6.3.1 Total Area Predictions Under Different Strategies

The simulations concept of equation 5.3 produced the age-specific area figures under each strategy and the simulation is continued through successive cycles up to the year 2020. The above figures are presented in Tables 6.6(a), (b), (c), (d) and (e). A bar graph for each policy showing the rubber area generated has been reproduced by the plotter of the Dec-10 computer. The projections are presented in Table 6.6(c). The graphs are presented in Figures 6.3(a), (b), (c), (d) and (e). The Fortran program for this exercise is shown in Appendix 1.

The data given in Table 6.6 (a) for the strategy of a 26 years cycle seems to be impractical for immediate implementation, since the replanting of 39068 ha. in the first year is impossible. Additionally this strategy implies very low nutrient production levels during the immature period of this area. Furthermore, this strategy would necessitate heavy capital investment in one large burst in order to replant such a large area. One alternative solution to this is spreading out this peak replanting over a few years.

The implication of the second strategy (30 years cycle) is presented in Table 6.6(b). Again a similar problem of impracticability arises here but not to the same extent. The initial block of replanting would be 22071 ha. and this also could only be implemented with a massive replanting programme. However, the one thing in favour of these two strategies is the rapid elimination of the senile area of 89000 ha.

The third strategy investigated the implication of the 33 years replanting cycle, which has been implied by the government replanting policy. Thus this projection should give a better approximation to reality. However, the senile area of 89000 ha. indicates how ineffective this strategy has been in practice. If this strategy functions in the initial year of the programme, 16605 ha. of replanting must be covered. This of course is not impossible, in contrast to the

Table 6.6(a)

Total Rubber Area under Strategy 1 (Ha.)

	YEAR					
	1978	1980	1990	2000	2010	2020
0	39528.809	2037.469	5077.877	1381.548	4703.781	4623.044
1	1399.600	10726.425	2717.963	1993.340	10743.476	1007.953
2	2803.714	39528.809	7845.485	1350.456	10660.231	2206.464
3	248.729	1399.600	9141.782	4059.393	4543.812	2518.880
4	1381.548	2803.714	16695.412	1289.277	2037.469	5077.877
5	1993.340	248.729	11806.088	10265.073	10726.425	2717.963
6	1350.456	1381.548	4703.781	4623.044	39528.809	7845.485
7	4059.393	1993.340	10743.476	1007.953	1399.600	9141.782
8	1289.277	1350.456	10660.231	2206.464	2803.714	16695.412
9	10265.073	4059.393	4543.812	2518.880	248.729	11806.088
10	4623.044	1289.277	2037.469	5077.877	1381.548	4703.781
11	1007.953	10265.073	10726.425	2717.963	1993.340	10743.476
12	2206.464	4623.044	39528.809	7845.485	1350.456	10660.231
13	2518.880	1007.953	1399.600	9141.782	4059.393	4543.812
14	5077.877	2206.464	2803.714	16695.412	1289.277	2037.469
15	2717.963	2518.880	248.729	11806.088	10265.073	10726.425
16	7845.485	5077.877	1381.548	4703.781	4623.044	39528.809
17	9141.782	2717.963	1993.340	10743.476	1007.953	1399.600
18	16695.412	7845.485	1350.456	10660.231	2206.464	2803.714
19	11806.088	9141.782	4059.393	4543.812	2518.880	248.729
20	4703.781	16695.412	1289.277	2037.469	5077.877	1381.548
21	10743.476	11806.088	10265.073	10726.425	2717.963	1993.340
22	10660.231	4703.781	4623.044	39528.809	7845.485	1350.456
23	4543.812	10743.476	1007.953	1399.600	9141.782	4059.393
24	2037.469	10660.231	2206.464	2803.714	16695.412	1289.277
25	10726.425	4543.812	2518.880	248.729	11806.088	10265.073

Source: RIMP Survey data.

Table 6.6(b)

Total Rubber Area under Strategy 2 (Ha.)

	YEAR					
AGE	1978	1980	1990	2000	2010	2020
0	22333.430	5994.061	16695.412	1289.277	5994.061	16695.412
1	1399.600	1499.393	11806.088	10265.073	1499.393	11806.088
2	2803.714	22333.430	4703.781	4623.044	22333.430	4703.781
3	248.729	1399.600	10743.476	1007.953	1399.600	10743.476
4	1381.548	2803.714	10660.231	2206.464	2803.714	10660.231
5	1993.340	248.729	4543.812	2518.880	248.729	4543.812
6	1350.456	1381.548	2037.469	5077.877	1381.548	2037.469
7	4059.393	1993.340	10726.425	2717.963	1993.340	10726.425
8	1289.277	1350.456	5528.196	7845.485	1350.456	5528.196
9	10265.073	4059.393	4173.728	9141.782	4059.393	4173.728
10	4623.044	1289.277	5994.061	16695.412	1289.277	5994.061
11	1007.953	10265.073	1499.393	11806.088	10265.073	1499.393
12	2206.464	4623.044	22333.430	4703.781	4623.044	22333.430
13	2518.880	1007.953	1399.600	10743.476	1007.953	1399.600
14	5077.877	2206.464	2803.714	10660.231	2206.464	2803.714
15	2717.963	2518.880	248.729	4543.812	2518.880	248.729
16	7845.485	5077.877	1381.548	2037.469	5077.877	1381.548
17	9141.782	2717.963	1993.340	10726.425	2717.963	1993.340
18	16695.412	7845.485	1350.456	5528.196	7845.485	1350.456
19	11806.088	9141.782	4059.393	4173.728	9141.782	4059.393
20	4703.781	16695.412	1289.277	5994.061	16695.412	1289.277
21	10743.476	11806.088	10265.073	1499.393	11806.088	10265.073
22	10660.231	4703.781	4623.044	22333.430	4703.781	4623.044
23	4543.812	10743.476	1007.953	1399.600	10743.476	1007.953
24	2037.469	10660.231	2206.464	2803.714	10660.231	2206.464
25	10726.425	4543.812	2518.880	248.729	4543.812	2518.880
26	5528.196	2037.469	5077.877	1381.548	2037.469	5077.877
27	4173.728	10726.425	2717.963	1993.340	10726.425	2717.963
28	5994.061	5528.196	7845.485	1350.456	5528.196	7845.485
29	1499.393	4173.728	9141.782	4059.393	4173.728	9141.782

Source: RIMP Survey data.

Table 6.6(c)

Total Rubber Area under Strategy 3 (Ha.)

	YEAR					
AGE	1978	1980	1990	2000	2010	2020
0	16800.220	2373.955	10743.476	1007.953	1399.600	2037.469
1	1399.600	17.551	10660.231	2206.464	2803.714	10726.425
2	2803.714	16800.220	4543.812	2518.880	248.729	5528.196
3	248.729	1399.600	2037.469	5077.877	1381.548	4173.728
4	1381.548	2803.714	10726.425	2717.963	1993.340	5994.061
5	1993.340	248.729	5528.196	7845.485	1350.456	1499.393
6	1350.456	1381.548	4173.728	9141.782	4059.393	3141.704
7	4059.393	1993.340	5994.061	16695.412	1289.277	2373.955
8	1289.277	1350.456	1499.393	11806.088	10265.073	17.551
9	10265.073	4059.393	3141.704	4703.781	4623.044	16800.220
10	4623.044	1289.277	2373.955	10743.476	1007.953	1399.600
11	1007.953	10265.073	17.551	10660.231	2206.464	2803.714
12	2206.464	4623.044	16800.220	4543.812	2518.880	248.729
13	2518.880	1007.953	1399.600	2037.469	5077.877	1381.548
14	5077.877	2206.464	2803.714	10726.425	2717.963	1993.340
15	2717.963	2518.880	248.729	5528.196	7845.485	1350.456
16	7845.485	5077.877	1381.548	4173.728	9141.782	4059.393
17	9141.782	2717.963	1993.340	5994.061	16695.412	1289.277
18	16695.412	7845.485	1350.456	1499.393	11806.088	10265.073
19	11806.088	9141.782	4059.393	3141.704	4703.781	4623.044
20	4703.781	16695.412	1289.277	2373.955	10743.476	1007.953
21	10743.476	11806.088	10265.073	17.551	10660.231	2206.464
22	10660.231	4703.781	4623.044	16800.220	4543.812	2518.880
23	4543.812	10743.476	1007.953	1399.600	2037.469	5077.877
24	2037.469	10660.231	2206.464	2803.714	10726.425	2717.963
25	10726.425	4543.812	2518.880	248.729	5528.196	7845.485
26	5528.196	2037.469	5077.877	1381.548	4173.728	9141.782
27	4173.728	10726.425	2717.963	1993.340	5994.061	16695.412
28	5994.061	5528.196	7845.485	1350.456	1499.393	11806.088
29	1499.393	4173.728	9141.782	4059.393	3141.704	4703.781
30	3141.704	5994.061	16695.412	1289.277	2373.955	10743.476
31	2373.955	1499.393	11806.088	10265.073	17.551	10660.231
32	17.551	3141.704	4703.781	4623.044	16800.220	4543.812

Source: RIMP Survey data

Table 6.6(d)

Total Rubber Area under Strategy 4 (Ha.)

AGE	YEAR 1978	1980	1990	2000	2010	2020
0	5141.282	5141.282	5141.282	5141.282	5141.282	5141.282
1	1399.600	5141.282	5141.282	5141.282	5141.282	5141.282
2	2803.714	5141.282	5141.282	5141.282	5141.282	5141.282
3	248.729	1399.600	5141.282	5141.282	5141.282	5141.282
4	1381.548	2803.714	5141.282	5141.282	5141.282	5141.282
5	1993.340	248.729	5141.282	5141.282	5141.282	5141.282
6	1350.456	1381.548	5141.282	5141.282	5141.282	5141.282
7	4059.393	1993.340	5141.282	5141.282	5141.282	5141.282
8	1289.277	1350.456	5141.282	5141.282	5141.282	5141.282
9	10265.074	4059.393	5141.282	5141.282	5141.282	5141.282
10	4623.044	1289.277	5141.282	5141.282	5141.282	5141.282
11	1007.953	10265.074	5141.282	5141.282	5141.282	5141.282
12	2206.464	4623.044	5141.282	5141.282	5141.282	5141.282
13	2518.880	1007.953	1399.600	5141.282	5141.282	5141.282
14	5077.877	2206.464	2803.714	5141.282	5141.282	5141.282
15	2717.963	2518.880	248.729	5141.282	5141.282	5141.282
16	7845.485	5077.877	1381.548	5141.282	5141.282	5141.282
17	9141.783	2717.963	1993.340	5141.282	5141.282	5141.282
18	16695.412	7845.485	1350.456	5141.282	5141.282	5141.282
19	11806.088	9141.783	4059.393	5141.282	5141.282	5141.282
20	4703.781	16695.412	1289.277	5141.282	5141.282	5141.282
21	10743.475	11806.088	10265.074	5141.282	5141.282	5141.282
22	10660.231	4703.781	4623.044	5141.282	5141.282	5141.282
23	4543.812	10743.475	1007.953	1399.600	5141.282	5141.282
24	2037.469	10660.231	2206.464	2803.714	5141.282	5141.282
25	10726.425	4543.812	2518.880	248.729	5141.282	5141.282
26	5528.196	2037.469	5077.877	1381.548	5141.282	5141.282
27	4173.728	10726.425	2717.963	1993.340	5141.282	5141.282
28	5994.061	5528.196	7845.485	1350.456	5141.282	5141.282
29	1499.393	4173.728	9141.783	4059.393	5141.282	5141.282
30	3141.704	5994.061	16695.412	1289.277	5141.282	5141.282
31	2373.955	1499.393	11806.088	10265.074	5141.282	5141.282
32	17.551	3141.704	4703.781	4623.044	5141.282	5141.282
33	1203.526	2373.955	10743.475	1007.953	1399.600	1713.761
34	1024.501	17.551	660.074	2206.464	314.161	0.000
35	0.000	1203.526	0.000	2518.880	0.000	0.000
36	1697.473	172.846	0.000	5077.877	0.000	0.000
37	2008.384	0.000	0.000	2717.963	0.000	0.000
38	0.000	0.000	0.000	7845.485	0.000	0.000
39	3194.359	0.000	0.000	2337.789	0.000	0.000
40	240.705	0.000	0.000	0.000	0.000	0.000
41	1762.163	0.000	0.000	0.000	0.000	0.000

Source: RIMP Survey data.

Table 6.6(e)

Total Rubber Area under Strategy 5 (Ha.)

	YEAR					
AGE	1978	1980	1990	2000	2010	2020
0	7910	3142	7208	4102	4809	6765
1	1391	4670	6728	6750	3193	4384
2	2803	7864	5293	6085	3523	4923
3	249	1391	6241	3839	2833	3803
4	1379	2798	6125	3197	3499	4183
5	1993	248	4827	7114	2604	4320
6	1350	1378	5220	5552	4706	3840
7	4041	1984	6515	5305	4940	4944
8	1289	1344	4705	7793	7664	3461
9	10264	4040	6040	6091	6809	6730
10	4619	1287	3100	7112	4048	4745
11	1008	10255	4635	6687	6669	3169
12	2206	4619	7805	5253	6039	3497
13	2519	1008	1318	6195	3810	2812
14	5077	2203	2782	6090	3179	3479
15	2717	2518	246	4800	7073	2859
16	7834	5069	1369	5184	5513	4673
17	9141	2714	1979	6497	5291	4927
18	16695	7834	1340	4064	7773	7645
19	11801	9138	4029	6022	6073	6789
20	4703	16688	1285	3093	7097	4039
21	10712	11767	10204	4611	6653	6666
22	10651	4686	4592	7760	5223	6005
23	4526	10663	998	1368	6136	3775
24	2017	10508	2164	2729	5975	3118
25	10626	4440	2447	240	4665	6875
26	4974	1798	4440	1199	4540	4825
27	4077	9340	2322	1693	5559	4527
28	5782	4688	6466	1106	5559	4527
29	1435	3766	7224	3185	4761	4802
30	2569	4529	10793	831	2000	4590
31	2090	1034	6718	5826	2633	3799
32	15	1752	2073	2032	3434	2311
33	1145	1540	4509	422	578	2595
34	991	13	4543	894	1128	2470
35	–	1084	1811	998	98	1903
36	1640	937	787	1945	525	1988
37	1988	–	4147	1030	751	2467
38	–	–	2122	2928	501	1519
39	3145	1598	1753	3363	1483	2216
40	238	1927	2555	6089	469	1128
41 & above	1753	3102	659	4285	3716	1679

Source: RIMP Survey data.

Figure 6.3(a)

Rubber Replanting Area Projection - Strategy 1

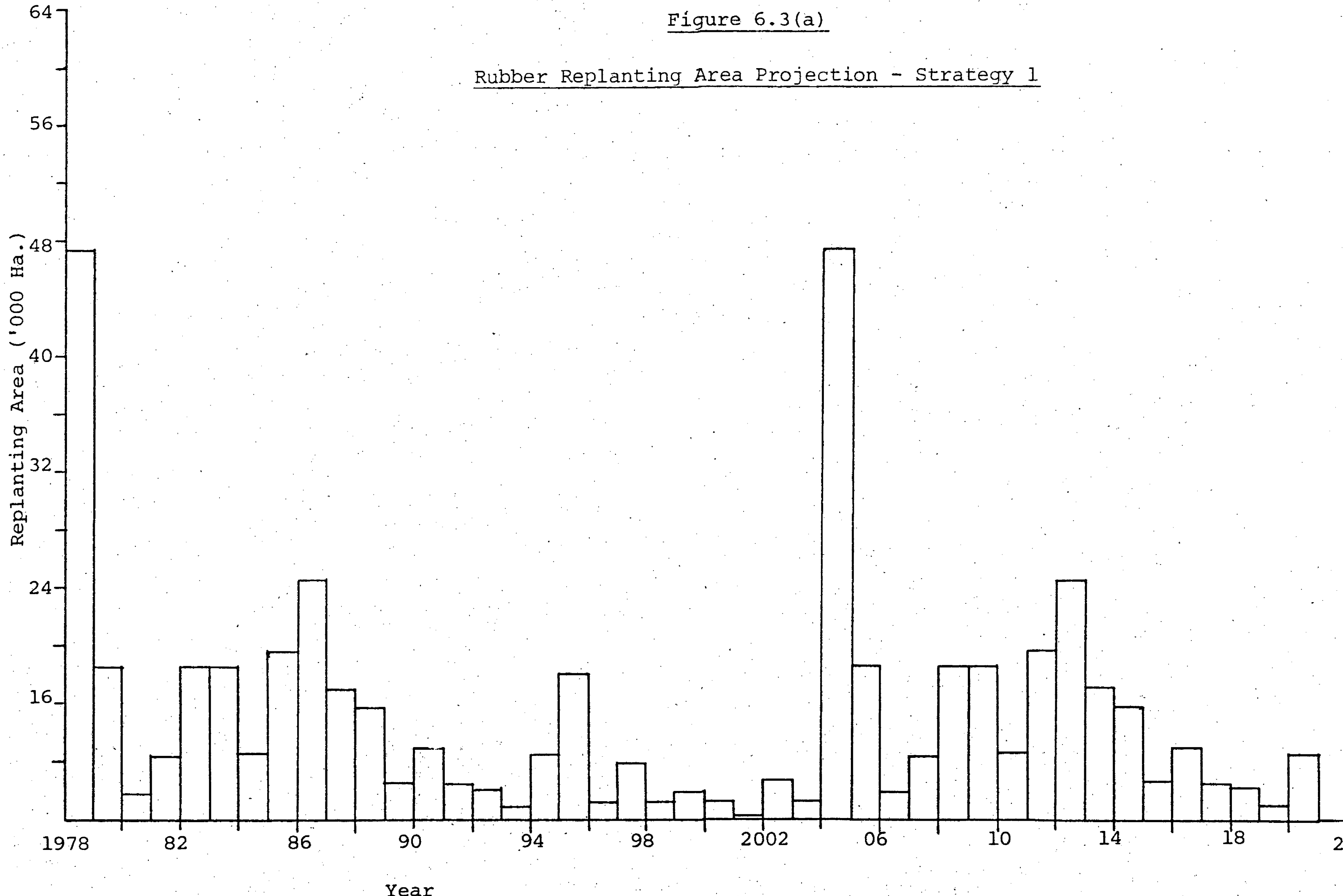


Figure 6.3(b)

Rubber Replanting Area Projection - Strategy 2

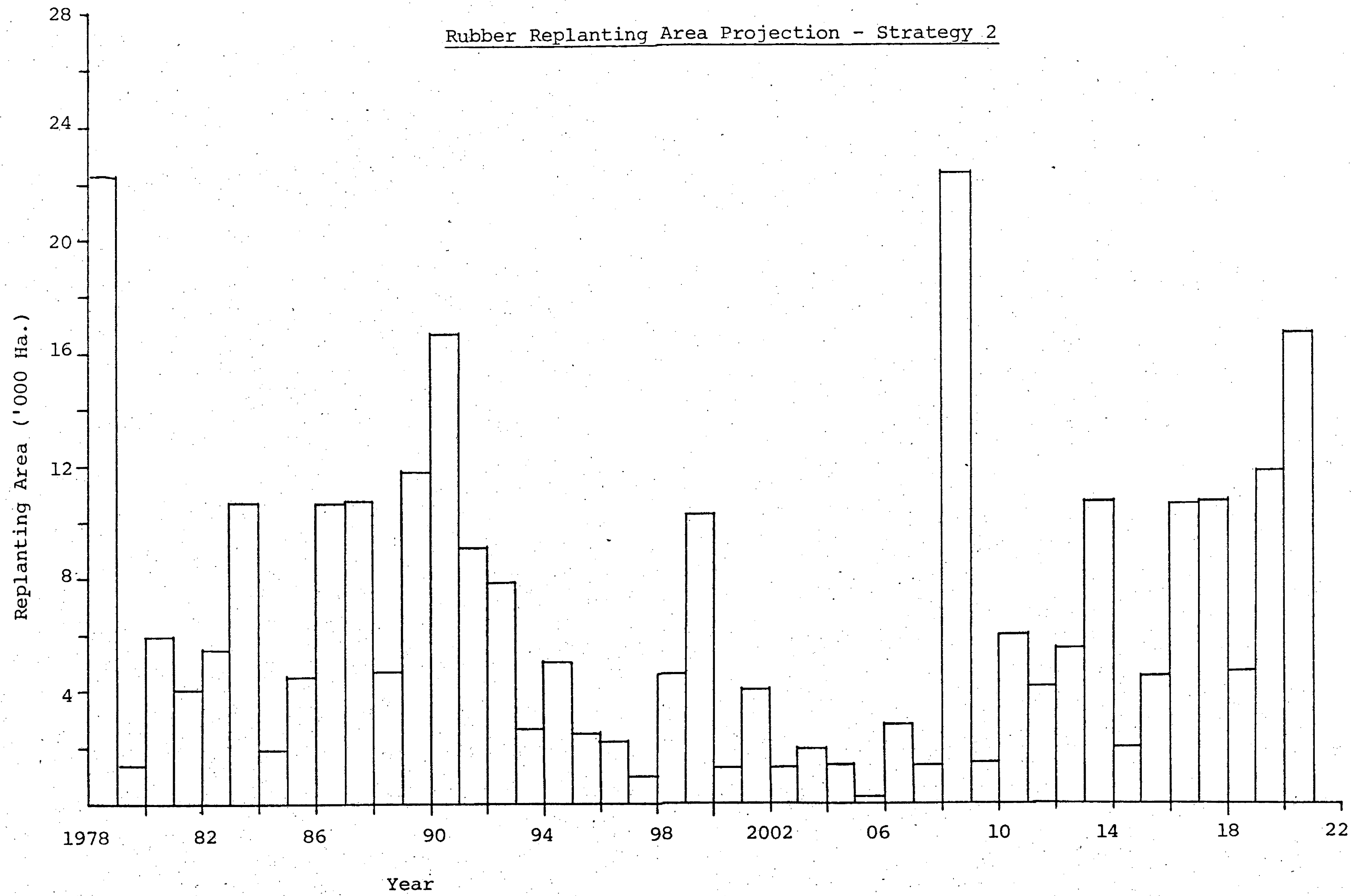


Figure 6.3(c)

Rubber Replanting Area Projection - Strategy 3

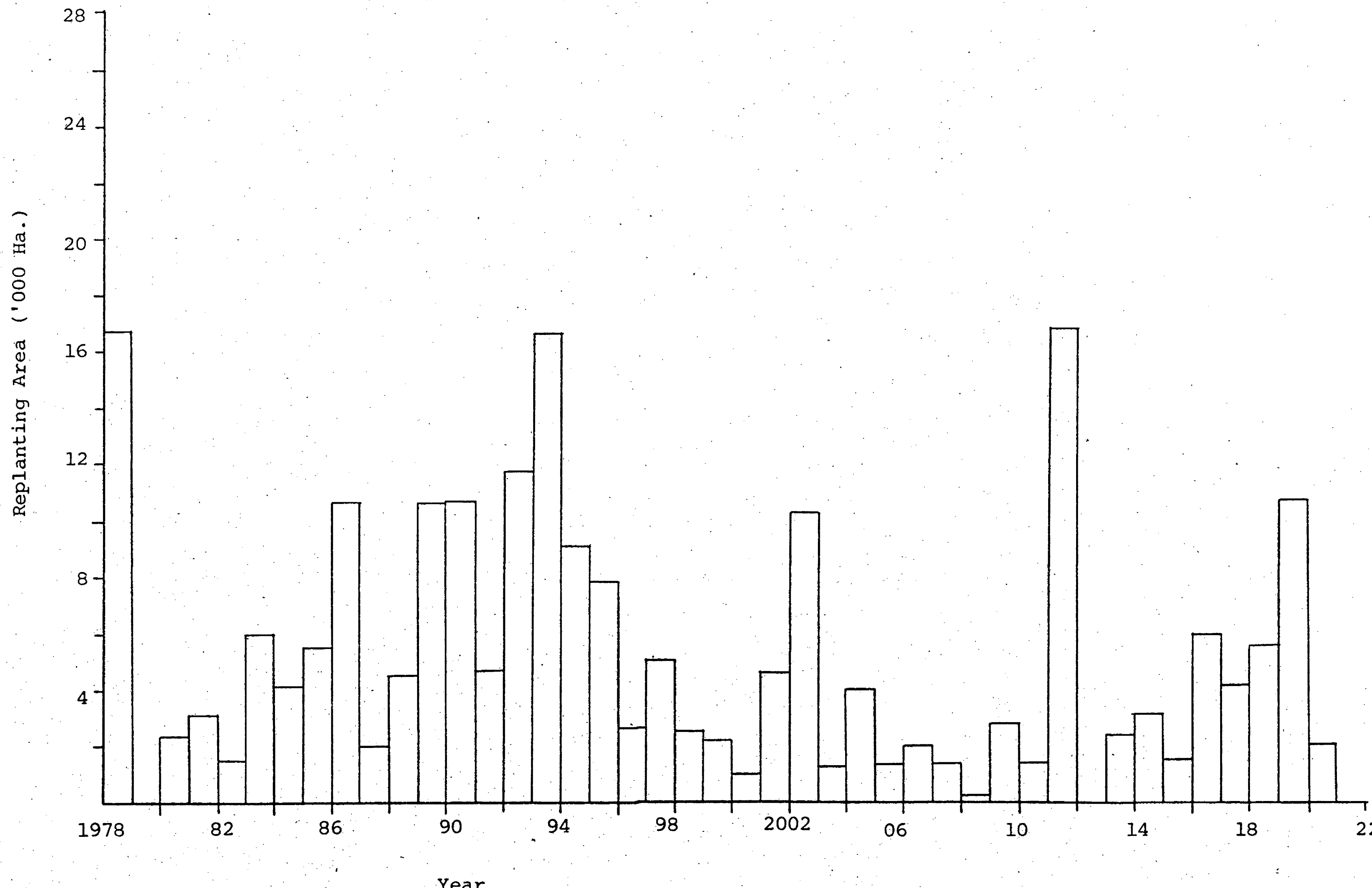


Figure 6.3(d)

Rubber Replanting Area Projection - Strategy 4

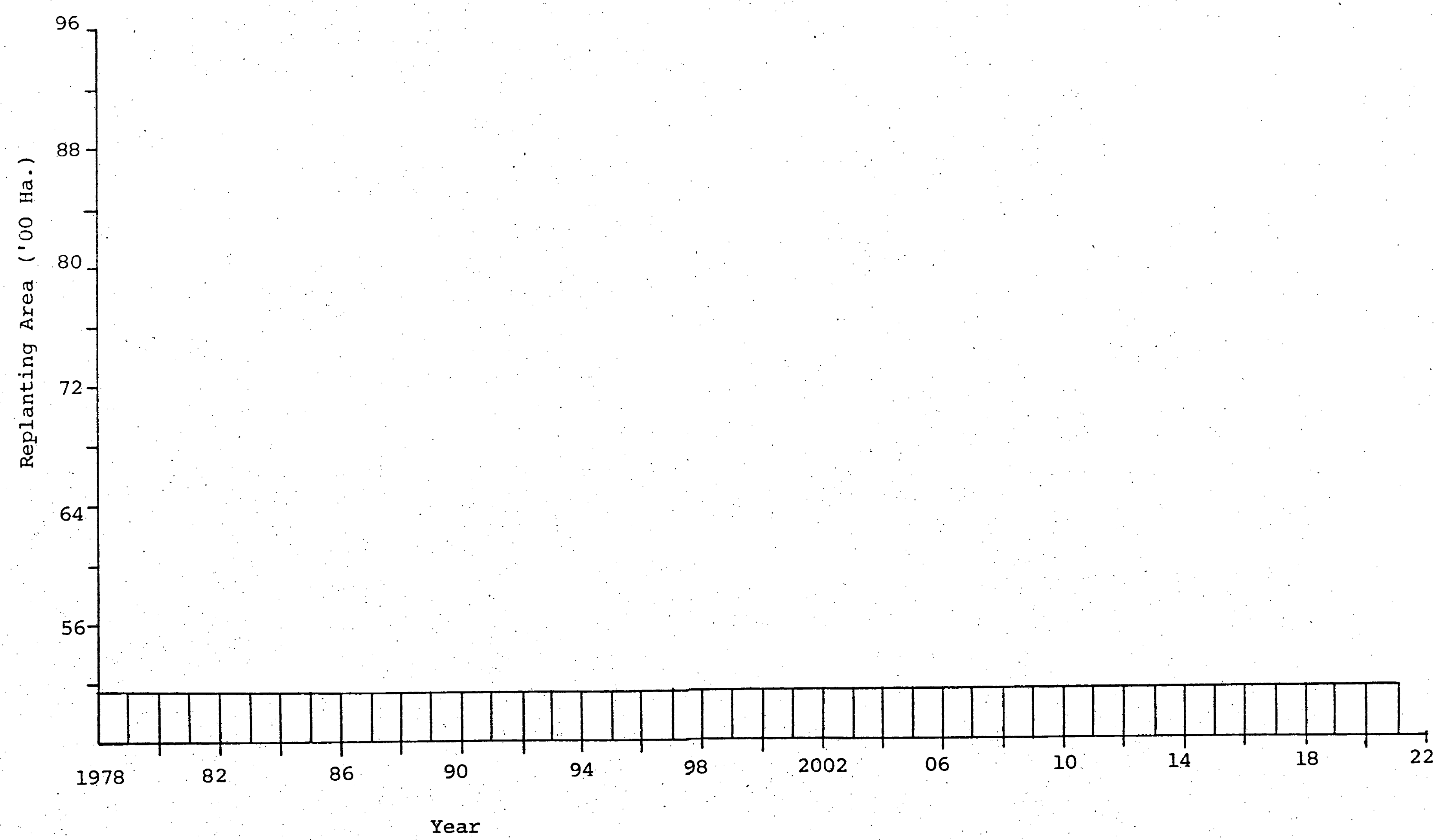
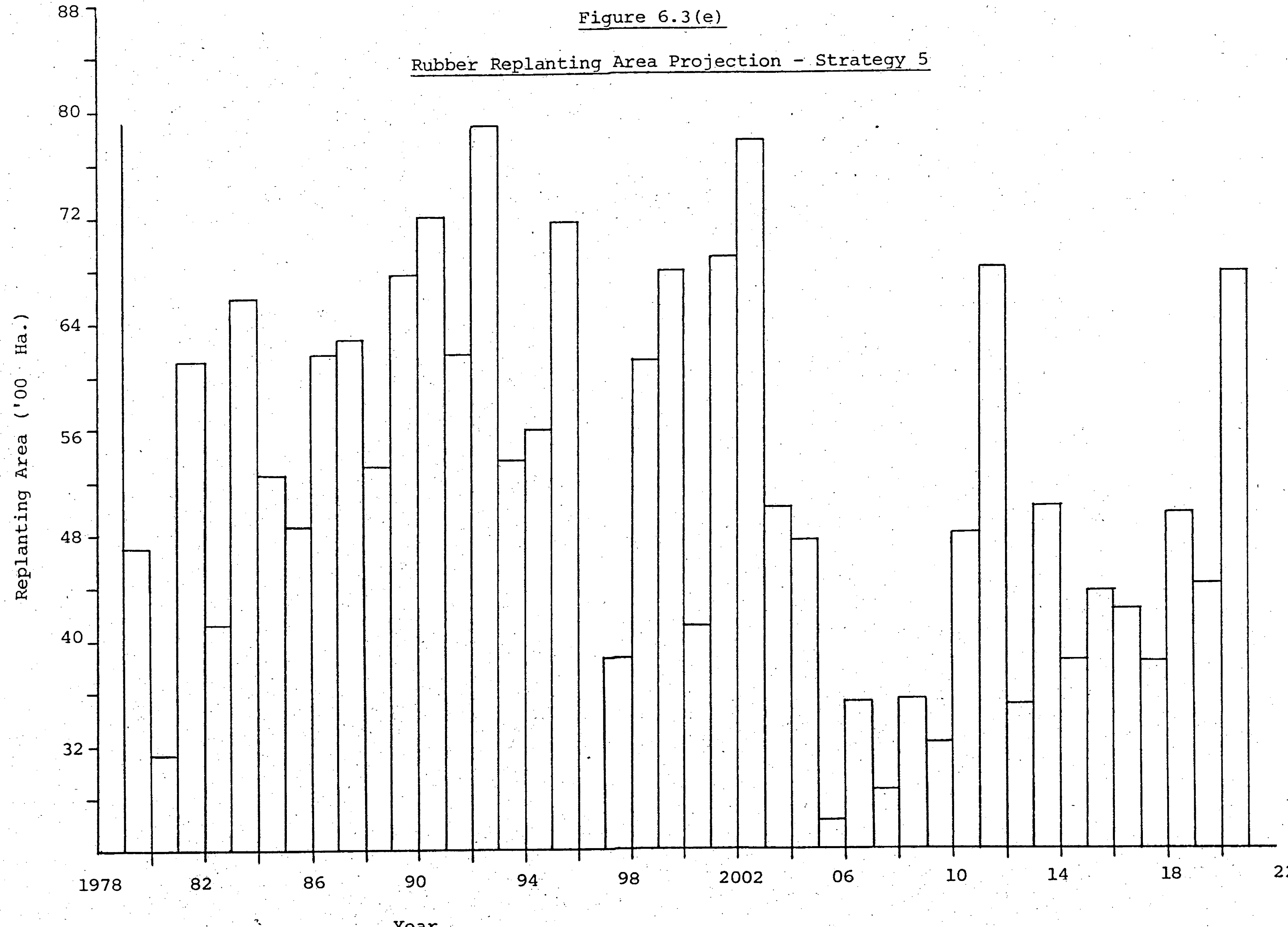


Figure 6.3(e)

Rubber Replanting Area Projection - Strategy 5



impracticability of the two previous policies. The projections are presented in Table 6.6(c).

The fourth strategy is, according to the rubber policy formulators, meant to be similar to the third. However, it can be seen from Table 6.6(d), that it has quite different implications for the total area. This strategy selects the oldest 3 per cent of the area and replants this amount every year. This replanting target has been set in order to secure the 33 years cycle. Thus the policy makers have attempted to relate this policy to the replanting of 6000 ha. per annum presuming that this represents approximately 3 per cent of the total area. However, in reality, the area to be replanted annually is not uniformly equal to 6000 ha. If the implementation of this policy commences in 1978 and only takes the oldest 3 per cent of the area each year it would only match the intended 33 years cycle by 2010 when the total senile area will have been eliminated. However, if this strategy did not just replant the oldest area of rubber, but took account of the area subjected to natural earlier 'mortality', the length of time needed to reach the perpetual 33 years cycle would be longer.

Table 6.6(d) makes it clear that a 3 per cent per annum replanting policy will only equate with a 33 year cycle provided the 3 per cent policy is adhered to every year (a most unlikely event). In general a 33 years exploitation cycle (or any age specific cycle) will always reflect the cohort history of previous plantings and replantings.

The total area under strategy five is presented in Table 6.6(e). Whatever government policy is, the real situation will deviate from it according to the farmer's behaviour. The advantage of this strategy is its closeness to reality, which has already been demonstrated by the validation procedure.

In order to compare predicted area by each policy the total annual replanting figures were generated under different strategies. The results are presented in Table 6.7. Also it can be seen from the comparison that strategy five is more realistic than the others.

Table 6.7

Annual Replanting Area (Ha.)

Year	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
1978	39528	22333	16800	5141	7911
1979	10726	1499	18	5141	4695
1980	2037	5994	2374	5141	3142
1981	4544	4174	3142	5141	6116
1982	10660	5528	1499	5141	4126
1983	10743	10726	5994	5141	6596
1984	4704	2037	4174	5141	5263
1985	11806	4544	5528	5141	4866
1986	16695	10660	10726	5141	6174
1987	9142	10743	2037	5141	6279
1988	7845	4704	4544	5141	5325
1989	2718	11806	10660	5141	6777
1990	5078	16695	10743	5141	7209
1991	2518	9142	4704	5141	6168
1992	2206	7845	11806	5141	7892
1993	1008	2718	16695	5141	5372
1994	4623	5078	9142	5141	5596
1995	10265	2519	7845	5141	7171
1996	1289	2206	2718	5141	3222
1997	4059	1008	5078	5141	3862
1998	1350	4623	2519	5141	6121
1999	1993	10265	2206	5141	6790
2000	1381	1289	1008	5141	4103
2001	249	4059	4623	5141	6895
2002	2804	1350	10265	5141	7761
2003	1400	1993	1289	5141	5002
2004	39528	1381	4059	5141	4744
2005	10726	249	1350	5141	2625
2006	2037	2804	1993	5141	3527
2007	4544	1400	1381	5141	2850
2008	10660	22333	249	5141	3544
2009	10743	1499	2803	5141	3212
2010	4704	5994	1400	5141	4810
2011	11806	4174	16800	5141	6816
2012	16695	5528	18	5141	3505
2013	9142	10726	2374	5141	5007
2014	7845	2073	3142	5141	3835
2015	2718	4544	1499	5141	4355
2016	5078	10660	5994	5141	4216
2017	2518	10743	4174	5141	3826
2018	2206	4704	5528	5141	4952
2019	1008	11806	10726	5141	4410
2020	4623	16695	2037	5141	6765

6.3.2 Total Production Under Different Strategies

The rubber production potential is to a large extent predetermined by the yield profile of the trees that are already being exploited. Hence the construction of an appropriate yield curve is a fairly cumbersome step.

In Chapter 2 there was a discussion of yield curves constructed by the Rubber Research Institute of Sri Lanka (RRISL) and the Association of National Rubber Producing Countries (ANRPC) for the area above and below 40.5 hectares. The yield curve of the ANRPC is largely based on the yield pattern of PB86 [1] taking the average of various clones into consideration. The yield curve of RRISL is also based on the yield of PB 86 over 16 years of tapping in large scale experiments.

The use of these two yield curves in the analysis is of only limited use since both curves are based on a 33 year replanting cycle. Obviously these yield curves have to be modified to fit the length of each replanting cycle. The yield of a particular age in a shorter cycle is of course higher than in a larger cycle. Therefore the yield curves given by RRISL and ANRPC were combined and modified to allow for shorter cycles. Further the size of the holdings is also considered in calculating the yield curve, and two yield curves were obtained. It is an accepted fact that the yield of the large holdings are higher than the small holdings. It is also presumed that the new plantations will be started in future with high yielding varieties and with the application of fertilizer and stimulants which together would give better yields. Considering these factors, two new yield curves are constructed. The yield curves related to the five strategies and the one based on a hypothetical yield assuming future improvements in technology are presented in Table 6.8 (a) and (b). The accuracy of these are ascertained by using the validation procedure of production estimates, discussed in Section 6.2. In

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[1] The area planted with the PB86 clone has been estimated to be over 60 per cent.

Table 6.8(a)

Yield Curve under Different Strategies

Area below 40.5 Ha.

Year of Tapping	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Hypo- thetical Curve
0	420	560	560	450	450	800
2	672	700	700	630	650	1000
3	840	805	805	900	750	1200
4	980	910	910	1035	850	1350
5	1120	980	980	1053	870	1450
6	1120	1050	1050	1080	900	1550
7	1120	1120	1120	1134	980	1654
8	1120	1170	1170	1215	1020	1700
9	1232	1190	1190	1180	1040	1750
10	1232	1210	1230	1220	1150	1800
11	1232	1210	1230	1210	1150	1800
12	1232	1190	1200	1210	1140	1650
13	1232	1170	1180	1200	1060	1700
14	1232	1140	1160	1180	1040	1650
15	1064	1110	1120	1140	1020	1550
16	1064	1010	1010	1010	1010	1500
17	1064	960	950	940	950	1350
18	980	860	840	840	820	1250
19	960	770	750	750	730	1150
20	960	630	650	730	630	900
21		700	700	700	640	650
22		900	900	850	720	650
23		800	800	800	720	600
24		700	700	700	650	600
25			700	650	640	580
26			650	650	640	580
27			600	650	640	560
28				640	630	560
29				640	620	560
30				600	620	560
31				550	580	580
32				540	540	540
33				540	540	540
34					530	530
35					520	520
36					510	510

Table 6.8(b)

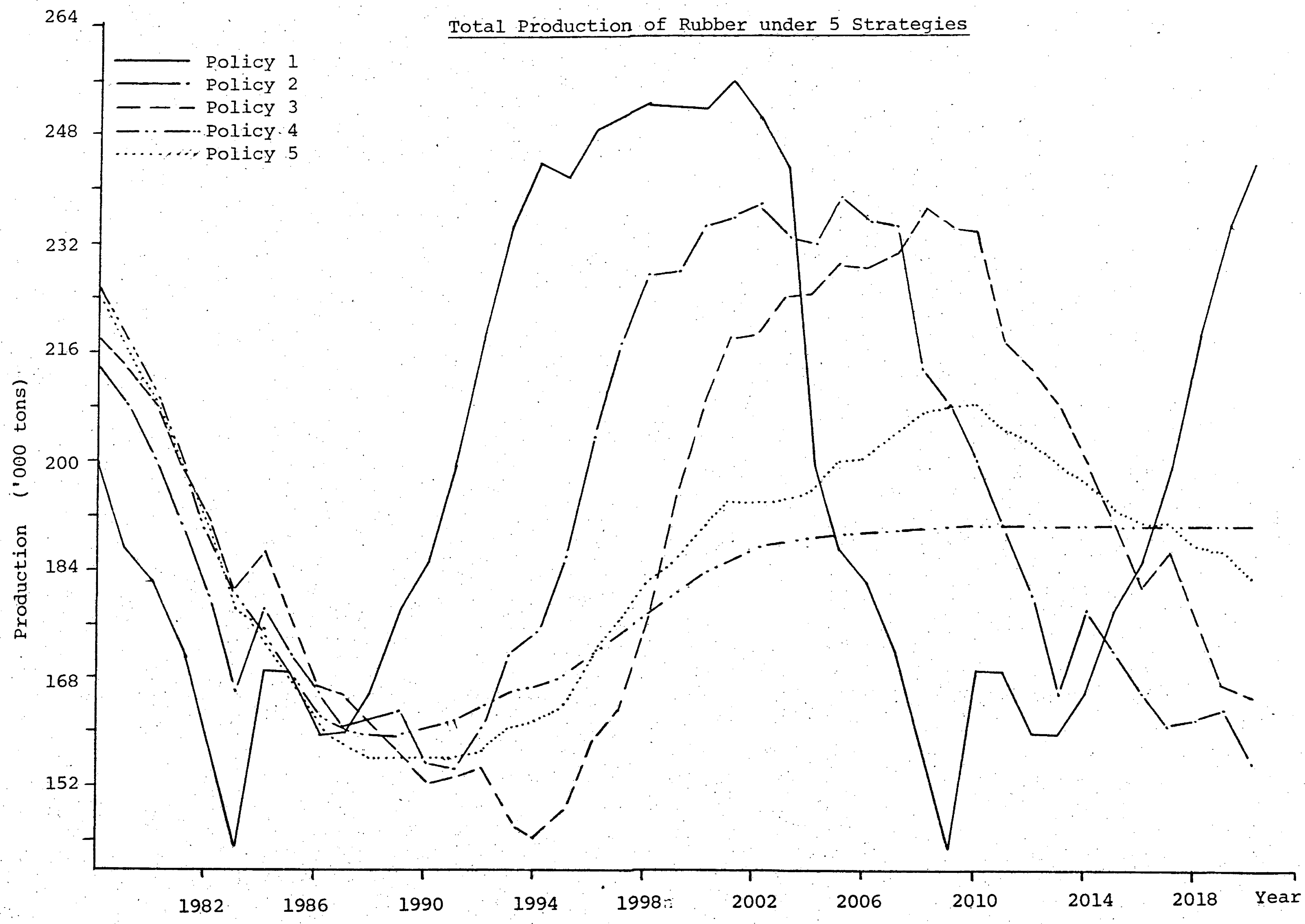
Yield Curve under Different Strategies

Area above 40.5 Ha.

Year of Tapping	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5	Hypo-thetical Yield Curve
1	420	640	640	640	640	1000
2	728	800	800	800	800	1200
3	924	920	920	920	920	1450
4	1092	1040	1040	1020	1020	1600
5	1176	1120	1120	1120	1100	1700
6	1232	1200	1200	1200	1180	1800
7	1288	1280	1280	1280	1240	1900
8	1344	1330	1300	1270	1280	1950
9	1300	1360	1340	1320	1310	2000
10	1400	1380	1360	1360	1340	2050
11	1400	1380	1380	1380	1340	2050
12	1400	1360	1340	1320	1320	2000
13	1400	1340	1320	1320	1300	1950
14	1400	1300	1300	1280	1260	1900
15	1400	1250	1250	1250	1250	1800
16	1400	1160	1160	1140	1120	1750
17	1400	1100	1100	1100	1000	1650
18	1300	1100	1100	1100	1000	1500
19	1200	1000	1000	1000	980	1400
20	1150	980	960	800	820	1200
21		40	820	800	780	1000
22		1000	980	980	840	1000
23		960	940	900	860	1020
24		940	920	800	720	950
25			1000	1000	860	940
26			1000	900	880	920
27			980	960	860	900
28				910	800	900
29				900	860	880
30				840	860	820
31				820	860	820
32				820	840	820
33				820	810	780
34					780	760
35					760	730
36					720	720

FIGURE 6.4

Total Production of Rubber under 5 Strategies



addition to validating the model this procedure has been used to select the most appropriate yield curve and strategy suitable for predictions of production. The analysis, similar to 'sensitivity analysis', was done in order to select an appropriate yield curve.

Rubber production is determined by the mature area and the yield curve. The area prediction made previously and the yield curves mentioned in this section are used together to work out the production capacity.

Rubber trees planted during the first half of the 1970's will come into bearing towards the end of the same decade and will reach maximum yield at the end of the next decade. Therefore the action that will be taken with respect to replanting and new planting today will have an impact, in terms of incremental production, in the mid-1990's. This pattern can be recognized from the projected norm of production given in Table 6.9. Under strategy one, the replanted area will only come into bearing in the latter part of the 1980's and full impact will not be felt until the mid 1990's. Gradually production begins to decrease again at the beginning of the 2000's. Generally with a shorter replanting cycle, high yields are obtained in the early years but the trees also go out of production early. Since the cycle is a little longer in strategy two, the impact of the newly planted area will come later. The full impact on increased production of the initiation of this policy will be felt in the latter part of the 1990's. However, in strategy 3 the full impact of the strategy only starts from the year 2000. Strategy four results in a constant amount to be replanted each year since it is based on 3 per cent of a total area which is itself fixed by assumption. Although the area replanted each year is constant the age structure of the total area at the beginning of the strategy is quite different.

The production norm calculated by strategy five is expected to be closer to reality since it gave a more accurate picture of the past output. Hence it is reasonable to accept the production norm given by this strategy as a likely event.

Table 6.9

Total Production of Rubber under 5 Strategies - Sri Lanka

Year	Strategy 1	Strategy 2	Strategy 3	Strategy 4	Strategy 5
1978	199874.490	213895.800	218076.780	225541.460	223698.730
1979	187171.770	208607.950	213836.750	218267.680	215911.590
1980	182234.480	200477.180	208450.650	211147.700	209739.890
1981	172511.600	190913.910	199676.050	200966.910	198957.350
1982	157740.340	180247.010	191954.390	190586.670	189156.990
1983	143475.160	166392.740	181737.790	180992.600	178502.390
1984	168928.310	178352.700	187001.690	175057.140	174968.640
1985	168636.800	172002.100	177393.600	168011.070	168079.360
1986	160044.570	166321.880	167099.240	162685.940	160622.000
1987	159957.970	160912.200	165353.530	160431.530	158171.460
1988	165846.700	162058.160	161014.300	159559.080	155995.470
1989	178117.540	163526.360	156869.640	159615.610	156179.030
1990	185272.510	155599.710	152416.910	160665.390	155919.460
1991	198905.080	154659.270	153349.540	161861.990	156172.520
1992	218282.180	160669.260	155082.450	163926.140	157342.810
1993	234143.020	171556.400	146800.160	166048.260	160609.760
1994	243618.640	174761.880	144309.430	166879.680	161777.150
1995	241609.810	185981.490	148278.890	168438.870	163991.020
1996	248766.260	203637.220	158766.380	171649.440	170766.790
1997	251056.980	217591.440	163673.630	174528.970	176395.560
1998	252563.070	227376.260	176142.460	177494.060	182237.380
1999	251990.320	228117.810	194488.360	180329.290	185628.580
2000	251730.190	234502.700	208126.570	183155.860	190534.830
2001	255980.980	235996.790	218355.320	185401.310	194289.540
2002	250892.970	237897.570	218832.220	187270.330	194068.130
2003	243631.160	233621.230	224088.410	188459.020	194501.660
2004	199874.490	231968.110	224928.250	188888.330	195821.030
2005	187171.770	239085.650	229130.580	189430.990	199896.770
2006	182234.480	235811.890	228721.770	189650.500	200867.900
2007	172511.600	234841.860	230857.440	189987.040	204017.210
2008	157740.340	213895.800	237747.010	190239.210	207257.800
2009	143475.160	208607.950	234656.930	190500.660	208363.040
2010	168928.310	200477.180	234049.800	190585.910	208516.650
2011	168636.800	190913.910	218076.780	190589.050	204896.070
2012	160044.570	180247.010	213836.750	190589.050	202980.400
2013	159957.970	166392.740	208450.650	190589.050	199536.300
2014	165846.700	178352.700	199676.050	190589.050	197084.200
2015	178117.540	172002.100	191954.390	190589.050	193202.660
2016	185272.510	166321.880	181737.790	190589.050	191034.060
2017	198905.080	160912.200	187001.690	190589.050	190985.800
2018	218282.180	162058.160	177393.600	190589.050	187829.640
2019	234143.020	163526.360	167099.240	190589.050	186837.850
2020	243618.640	155599.710	165353.530	190589.050	183138.470

Source: RIMP Survey data.

Under such circumstances, the projections of production presented here are simply aimed at quantifying the output norm that is likely to materialize in future, up to the year 2000, on the basis of information available. The main drawback of this simulation procedure is that it is not based on specific price assumptions. It simply assumes that the natural rubber prices will remain high enough to continue rubber production and that there will be a moderate use of chemical fertilizer and stimulants. Unless the future is very different from the past, prices will deviate around the trend and the intensity of tapping and the use of the other inputs and therefore the actual output are likely to deviate from the projected norm. The incorporation of price and other relevant variables into the model will be discussed in the conclusion.

6.3.3 <u>Comparison of Results with the Results of Other Studies</u>

In the stage of validation the output of the model was checked as being a reasonable representation of reality. The past record and the model generated values were compared and then the validity of the model was assured. It has been presumed that if the model generates values which are close to the actual records, it is also capable of predicting future production norms with accuracy.

The comparison of the model output with other results could also be treated as further validation of the model. However the other models suffer from data and methodological problems which were discussed in Chapter 4. The comparison of results is nevertheless informative and is given in Table 6.10.

It can be seen that the four different sources give four different estimates. Since the predicted values under the present model are based on the expressed intentions and expectations of the rubber farmers/planters themselves the results under the model should be taken very seriously. In particular, the relatively low values of output for the last fifteen years of this century should be noted since a modification of this is only possible with major reinvestment now. We now turn to a discussion of these and other policy implications.

Table 6.10

Comparison of Results of Different Sources (M.T.)

Year	Model Output	RRISL 1	ANRPC 2	World Bank 3
1980	209740	172636	179517	180000
1985	168080	169327	192532	185000
1990	155920	172333	174345	195000
1995	163990	201443	-	-
2000	190535	244792	-	-

Source: 1. Rubber Research Institute of Sri Lanka, 1979.
2. The Association of Natural Rubber Producing Countries, 1976.
3. World Bank/FAO, 1978.

6.3.4 Policy Implications of the Results

World natural rubber output is expected to grow at about 4 per cent per annum between 1976 and 1990, that is, slightly over one per cent per annum above the historical rate (World Bank/FAO, 1978). However, the growth path of production is likely to be quite uneven with a 5.1 per cent per annum growth in the latter part of the 1970's followed by a fall to slightly less than 4 per cent in the early 1980's and to about 3 per cent in the second half of the decade. Further, it has been predicted that production in Sri Lanka will increase at rates below those experienced from the mid 1950's to the mid 1970's. The main cause given by the World Bank for this decrease in rubber output growth was the lack of a vigorous rubber replanting policy in the 1960's and 1970's. In Sri Lanka the small average increase of 3.5 per cent of production could be ascribed to mounting political uncertainties and adverse government policies in the 1970's, and these seem likely to further depress rises in production (Barlow 1978, p. 410)

The similar pattern of growth of production in Sri Lanka can be identified from strategy 5 as shown in Table 6.9. In the latter part of the 1970's it shows around 5.8 per cent per annum growth. This pattern starts to decrease from the beginning of the next decade and it continues till the early part of the 1990's. Again there is increasing output up to the year 2000. A similar output to that given in the early 1900's would be expected from the year 2005 onwards.

In order to achieve raised production above the levels predicted and towards the targets suggested by the RRISL and the World Bank, it will be necessary to clear the back-log of over-age plantations. As mentioned in Chapter one, there are now about 88000 ha. (40 per cent of the total area) which has to be replanted. Recognising the size of this task the Sri Lankan Government, with United Kingdom technical assistance, devised a Master Plan for rubber development. Further, the FAO/World Bank Co-operative programme with the Sri Lankan Government jointly prepared a project to accelerate rubber replanting by smallholders. It was intended to cover the area of 10,000 ha over a period of five years. If this project and the Rubber Industry Master Plan Project are implemented it will indeed be possible to replant the whole of the area due for replanting. Large projects of this nature could easily replant a large slice of the area at a time (as assumed in strategies 1 and 2). As we have seen from the total production figures this has immediate repercussions. The high replanting rate would tend to reduce total production over the next 5-10 years. One possible alternative is to spread the back-log over a period of 10 or 15 years, along with the required amount of normal replanting per annum. This could help to reduce the back-log gradually and tend towards a normal replanting cycle. The advantage and practicability of this system is the lower immediate financial burden. However, the implementation of this policy mainly depends on the institutional support of the industry. At present the natural rubber industry in Sri Lanka comes under a number of institutions and has therefore no proper co-ordinating body. Further, there is considerable overlapping of functions, both regulatory and executive. However, since any policy measures for greater rubber production depend on institutional support, the form of re-organization is crucial.

Additionally, the high yield potentials of a clone may not be obtained unless the required inputs are provided. Of the inputs required, fertilizer is the most important. Generally the use of fertilizer in rubber plantation is very low, especially in smallholdings, thus the need to use more fertilizer to increase production becomes evident. It is to be hoped that the relative price of natural rubber will rise sufficiently for it to be possible to buy fertilizer at a reasonable price.

The use of yield stimulants such as ethral is also likely to be important in increasing the rate of production. In Sri Lanka this is not popular because of the high cost of ethral and the impossibility of applying it consistently because of tapping interruptions caused by rain. In order to keep up high production levels, it is necessary to do more experiments in the use of ethral stimulation to determine the quickest way of increasing production in the short run.

The supply of high yielding planting materials for the replanting programme especially for smallholders is vitally important in increasing future production since the total area under rubber is likely to increase. The present methods of supplying planting material to smallholders are not satisfactory. The supply of budded stumps is insufficient and it is necessary to increase the rubber nurseries. This could easily be achieved since the large estates are now in the hands of the state. With a small increase in the area of nurseries on estates, it would be easy to cater for smallholders' requirements. Since the clone is the most important factor affecting future production levels, breeding for new high yielding clones should be given due priority in research. Further, reducing the length of the immature period is also important for increasing production levels. Breeding for quick growth and girthing should be stepped up in order to reduce the immature period.

All of these factors depend to a greater or lesser extent on the research and development undertaken by the rubber industry. Continued research on plant breeding for new clones, experiments on tapping stimulation, plant nutrition experiments, research on disease and pests are crucial. Also possibly research on manufacturing must be increased in order to achieve higher production targets. Further, the development of central processing, marketing facilities, release of the farmers from the heavy export duty burden , are most important, to reach the maximum production capacity. The national rubber industry development plans, such as the Rubber Industry Master Plan and the Smallholder Rubber Replanting Project, will be good attempts in this respect.

In addition to the policy implications of production, the demand aspect should also be investigated. The forecast rates show an expected annual increase in consumption of both natural and synthetic rubbers of 5 per cent per year, and a maximum potential rise in natural rubber production of 4 per cent (Barlow 1978 p.1). Further, World Bank/FAO projections also emphasize that natural rubber is likely to continue to lose its share of the market during the next 15 years because of insufficient availability. Consequently the whole natural rubber industry is facing the prospect of increasingly favourable product prices. Moreover the market potential is becoming more favourable because of the rise in crude oil prices which affects future prospects for the production of synthetic rubber. Again, whilst various synthetic rubber technologies have been developed, there is no major new synthetic in view (Barlow 1979, p.2).

Finally, the government needs to ensure that all of its efforts are concentrated on measures which will realize maximum benefits to the farmers from replanting and development. Insufficient attention to replanting during the latter part of the 1960's has resulted in a lag of production behind the potential which might have been expected. This lag is also responsible for the drop in production which will occur during the 1980's. Therefore it is essential that the government take a long term view to ensure that all conditions are met which will lead to replanting at the required rate in order to clear the back-log and come into an equilibrium stage. If not, the potential benefits of natural rubber to the country will not be fully realized.

6.4 Conclusion

This study of the implications of alternative replacement strategies for the future area and production of rubber in Sri Lanka is a counterpart to the data collection made by the RIMP Study. The data collected by the RIMP Study on the age-specific area provided a basis for this study. Apart from this, the information on age, bark consumption and the remaining life of the trees supplemented information on the intensity of exploitation of the trees, and on this was based the projection of rubber area data for future years. Evidence for alternative replacement strategies was investigated in order to obtain a better understanding of the implications for the future area and production of rubber by using the process of simulation modelling. In order to estimate production figures from the mature rubber area, several yield curves were investigated. The accuracy of the model, i.e. area prediction, yield curves and a projection of production, were tested by the validation procedure of the simulation approach. Both this validation approach and a comparison of the results with other studies corroborated that the strategy based on farmers' expectations (Strategy 5) is closer to reality than the other alternatives investigated. Hence the projection of area and production of this strategy can be accepted as a reliable estimate. Since the intentions and expectations of farmers are influenced by price and other factors, this strategy takes these effects into consideration indirectly. However, the objectives laid down for this study, and time and data constraints, did not allow for the explicit inclusion of such factors as distinct variables influencing the area and production projections. This is a much needed extension of the present study and suggests the need to develop such projection models with supply response models and forecasts of future price trends.

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APPENDIX 1

The Fortran Program used for the Simulation Model

```
      PROGRAM YIELD
C
C     PURPOSE           Read 1978 rubber data and calculate the production
C                       of rubber using 3 different replanting policies:
C
C                       (i)   Replant 3% of the total area
C                       (ii)  Replant all trees older than N years.
C                       (iii) For each age group a percentage will be replanted
C                             and any tree older than 40 years will
C                             also be replanted.
C
C                       This simulation is done until we reach 2020 then
C                       a plot of the total production vs. year can be
C                       produced if required.
C
C      DATE             5-Sep-80, T. Ly, Coombs Comp. Ser.
C                       written for Premachandra  415,255 .
C
C      OPERATING INSTRUCTION
C
C                       .EX YIELD,PLTLIB 10,50 ,STRLIB 10,50
C
C-----------------------------------------------------------------------
C
      INTEGER           AGE, OLDEST, XLAB(16), YLAB(16), PLAB(16)
      DIMENSION         FRAC (9), X (45), Z (217), HECT(80)
      COMPLEX           IFILE
      INTEGER           PFILE(2)
C
      COMMON            AREA(80), Y(5,43), IYEAR1, IYEAR2,
     +                  YIELD(43)
C
      DATA              LUNI /1/, IYEAR1 /1978/, IYEAR2 /2020/
C
      DATA              LUN1 /2/, LUN2 /3/, LUNO /10/
C
C-----------------------------------------------------------------------
C
C           Print title of program
C
      TYPE 10
   10 FORMAT ( 1H0, 'YIELD CALCULATION PROGRAM' )
C
C           Set sampling fractions ( these remain constant throughout )
C           for 9 districts.
C
      FRAC(1) = 0.0701
      FRAC(2) = 0.0326
      FRAC(3) = 0.1473
      FRAC(4) = 0.0319
      FRAC(5) = 0.0470
      FRAC(6) = 0.0320
      FRAC(7) = 0.0520
      FRAC(8) = 0.1864
      FRAC(9) = 0.1270
C
C           Store year values in vector X (for plotting).
C
      DO 15 IY = IYEAR1, IYEAR2
         IX = IY - IYEAR1 + 1
```

```
         X(IX) = IY
   15 CONTINUE
C
C             Calculate sampling fraction for the whole 9 areas
C             (i.e. Sri Lanka); also include the factor to convert from
C             acres to hectares.
C
      F = 0.0
      DO 20 I = 1, 9
         F = F + FRAC(I)
   20 CONTINUE
      F = 9.0 / (F*2.471054)
C
C             Initialize area data
C
      DO 25 J = 1, 80
         AREA(J) = 0.0
   25 CONTINUE
C
C             Input data from a file (user-specified)
C
      TYPE 40
   40 FORMAT ( 1H0, 'Enter Input File Name : ', $ )
      ACCEPT 50, IFILE
   50 FORMAT ( 2A5 )
C
      OPEN ( UNIT=LUNI, ACCESS='SEQIN', FILE=IFILE, ERR=900 )
C
C             Loop here to read and accumulate data with respect
C             to age.
C
   60 READ ( LUNI,70,END=100 ) AREA0, AGE
   70 FORMAT ( 28X, F5.1, 18X, I2 )
      AREA0 = AREA0 * F                  ! convert AREA
      AREA(AGE+1) = AREA(AGE+1) + AREA0
      GO TO 60
C
C             End of file reached here, close input file and
C             start analysis.
C
  100 CLOSE ( UNIT=LUNI )
C
      CALL RESET ( HECT,AREA )                ! Store value of AREA in HECT
C
C              Read yield coefficient data
C
      OPEN ( UNIT=LUN1,ACCESS='SEQIN',FILE='YIELD1.DAT' )
      OPEN ( UNIT=LUN2,ACCESS='SEQIN',FILE='YIELD2.DAT' )
C
      DO 105 I = 7, 42
         READ ( LUN1,102 ) Y1
  102    FORMAT ( 24X, F5.0 )
         READ ( LUN2,102 ) Y2
         YIELD(I) = (Y1+Y2) * 0.5
  105 CONTINUE
C
      CLOSE ( UNIT=LUN1 )
      CLOSE ( UNIT=LUN2 )
C
C             Start analysis here
```

```
C
      CALL YIELD1                    ! 3% policy
C
      CALL RESET  ( AREA,HECT )
C
      DO 109 I = 1, 3
         IT = I
         CALL YIELD2 (IT)            ! replant ½ N policy
         CALL RESET  ( AREA,HECT )
  109 CONTINUE
C
      CALL YIELD3                    ! percentage policy
C
C           Plotting option here if required
C
  200 TYPE 210
  210 FORMAT ( 1H0, 'Would you like to have a plot ?', /,
     +           1X, 'Type 1 for YES, 2 for NO : ', $ )
      ACCEPT *, ITYPE
      IF ( ITYPE .LT. 1 .OR. ITYPE .GT. 2 ) GO TO 200
C
      IF ( ITYPE .EQ. 2 ) GO TO 600               ! Plotting not required
C                                                 ! we exit then
C
C           Plot production vs. year for 5 replanting
C           policies.
C
      PFILE(1) = 5HYIELD
      PFILE(2) = 4H.PLT
C
C           Pack Y into a one-dimensional vector Z
C           for calculating a general scale.
C
      DO 216 I = 1, 5
         DO 215 J = 1, 43
            K = (I-1)*43 + J
            Z(K) = Y(I,J)
  215    CONTINUE
  216 CONTINUE
C
      CALL PLOTS ( 1, PFILE )                      ! Open plot file
C
      XAXIS = 22.0                                 ! X-axis length
      YAXIS = 16.0                                 ! Y-axis length
C
      CALL SCALE ( X,XAXIS,43,1 )                  ! Get scaling factor for X
C                                                  ! axis
      CALL SCALE ( Z,YAXIS,215,1 )
      FIRSTX = X(44)
      DELTAX = X(45)
      FIRSTY = Z(216)
      DELTAY = Z(217)
C
      TYPE 230
  230 FORMAT ( 1H0, 'Enter X-axis label : ', $ )
      ACCEPT 240, XLAB
  240 FORMAT ( 16A5 )
      NXLAB = LEN (XLAB,16)                        ! No. of chars in X label
      TYPE 250
  250 FORMAT ( 1H0, 'Enter Y-axis label : ', $ )
```

```
      ACCEPT 240, YLAB
      NYLAB = LEN (YLAB,16)                          ! No. of chars in Y label
      TYPE 260
  260 FORMAT ( 1H0, 'Enter Plot label   : ', $ )
      ACCEPT 240, PLAB
      NPLAB = LEN (PLAB,16)                          ! No. of chars in label
C
      CALL AXIS ( 0.0,0.0,YLAB,NYLAB,YAXIS,90.0,FIRSTY,DELTAY )
C                                                    ! Plot Y-axis
      CALL AXSPRM ( -1.0,-1.0,-1.0,-1.0,-1,-1 )
C                                                    ! Do not plot decimal
C                                                    ! point for the next
C                                                    ! axis plot
      CALL AXIS ( 0.0,0.0,XLAB,-NXLAB,XAXIS,0.0,FIRSTX,DELTAX )
C                                                    ! Plot X-axis
C           Plot data here
C
      Z(44) = FIRSTY
      Z(45) = DELTAY
      DO 280 I = 1, 5
         DO 270 J = 1, 43
            Z(J) = Y(I,J)
  270    CONTINUE
         IT = I + I
         CALL LINE ( X,Z,43,1,1,IT )
  280 CONTINUE
C
      CALL CENTER ( YAXIS+2.0,
     + 'TOTAL PRODUCTION OF RUBBER IN SRI LANKA',39,0.3,0.0,XAXIS )
      CALL CENTER ( YAXIS+1.0,
     + 'UNDER HYPOTHETICAL YIELD CURVE GIVEN IN CHAPTER TWO',51,
     + 0.3,0.0,XAXIS )
C
C           Print plot legend
C
      XL = 20.0
      YL = 18.0
      DO 300 I = 1, 5
         IT = I + I
         CALL POINT ( XL,YL,0.2,IT,0.0,-1 )
         CALL SYMBOL ( XL+0.5,YL,0.2,'Policy ',0.0,7 )
         F = I
         CALL NUMBER ( XL+0.5+1.6,YL,0.2,F,0.0,-1 )
         IF ( I .EQ. 1 ) CALL SYMBOL ( XL+2.5,YL,0.2,'26',0.0,2 )
         IF ( I .EQ. 2 ) CALL SYMBOL ( XL+2.5,YL,0.2,'30',0.0,2 )
         IF ( I .EQ. 3 ) CALL SYMBOL ( XL+2.5,YL,0.2,'33',0.0,2 )
         IF ( I .EQ. 4 ) CALL SYMBOL ( XL+2.5,YL,0.2,'3%',0.0,2 )
         IF ( I .EQ. 5 ) CALL SYMBOL ( XL+2.5,YL,0.2,'I',0.0,2 )
         YL = YL - 0.5
  300 CONTINUE
C
C                                                     ! Plot plot-label
C
      CALL ENDPLT
C
C           Print results here
C
  600 WRITE ( LUNO,605 )
  605 FORMAT ( ///, 10X,
     + 'TOTAL PRODUCTION UNDER ALL 5 POLICIES IN SRI LANKA', / )
```

```
      WRITE ( LUNO,610 )
  610 FORMAT ( 1H0,' YEAR   POLICY 1     POLICY 2     POLICY 3',
     + '     POLICY 4     POLICY 5', / )
C
      DO 700 IY = IYEAR1, IYEAR2
         J = IY - IYEAR1 + 1
         WRITE ( LUNO,650 ) IY, ( Y(K,J),K=1, 5 )
  650    FORMAT ( I5,3X,5F12.3 )
  700 CONTINUE
C
      GO TO 1000                                      ! Exit here
C
C-----------------------------------------------------------------------
C
C           Error section
C
  900 TYPE 910
  910 FORMAT ( 1H+, '?File not found', / )
C
 1000 STOP
      END
      SUBROUTINE RESET ( A, B )
C
      DIMENSION A (80), B (80)
C
      DO 10 J = 1, 80
         A(J) = B(J)
   10 CONTINUE
C
      RETURN
      END
      SUBROUTINE YIELD1
C
C     PURPOSE          Calculate the rubber production of Sri-Lanka
C                      with the policy of replanting 3% of the
C                      total area every year.
C
C     DATE             5-Sep-80, T. Ly, Coombs Comp. Ser., ANU
C
C-----------------------------------------------------------------------
C
      INTEGER OLDEST
C
      COMMON AREA(80), Y(5,43), IYEAR1, IYEAR2, YIELD(43)
C
      DATA LUNO /11/
C
C-----------------------------------------------------------------------
C
      IYIELD = 4
C
C           Calculate the oldest age group index
C
      DO 10 I = 80, 1, -1
         K = I
         IF ( AREA(I) .NE. 0.0 ) GO TO 20
   10 CONTINUE
   20 OLDEST = K
C
C           Calculate replanting area
```

```
C
      REP = 0.0
      DO 30 I = 1, OLDEST
         REP = REP + AREA(I)
   30 CONTINUE
      REP = REP * 0.03                        ! Replanting area
C
C           Start analysis here
C
      DO 110 IY = IYEAR1, IYEAR2
         I = OLDEST + 1
         REP0 = 0.0
   40    I = I - 1
         REP0 = REP0 + AREA(I)
         IF ( REP0 .LT. REP ) GO TO 40     ! Continue accumulation
            IF ( REP0 .GT. REP ) GO TO 70
C
C                Zero all areas replanting, shift everything down,
C                increment zero-area entry by REP = REP0
C
              DO 50 K = I, OLDEST
                 AREA(K) = 0.0
   50         CONTINUE
C
              DO 60 K = I-1, 1, -1
                 AREA(K+1) = AREA(K)
   60         CONTINUE
C
              AREA(1) = REP
              OLDEST  = I
              GO TO 100
C
C                We exceed the replanting area quota here, zero
C                all areas replanted, keep backlog, shift everything
C                down, reset zero-area by REP
C
   70       BACK = REP0 - REP
C
            DO 80 K = I+1, OLDEST
               AREA(K) = 0.0
   80       CONTINUE
C
            AREA(I) = BACK
            DO 90 K = I, 1, -1
               AREA(K+1) = AREA(K)
   90       CONTINUE
C
            AREA(1) = REP
            OLDEST  = I + 1
C
  100    IXY = IY - IYEAR1 + 1
C
C                Calculate total yield for end of year IY
C
         SUM = 0.0
         DO 101 K = 7, 43
            SUM = SUM + YIELD(K)*AREA(K)
  101    CONTINUE
         Y(IYIELD,IXY) = Y(IYIELD,IXY) + SUM/1000.0
C
```

```
  110    CONTINUE
  150 CONTINUE
C
C
      RETURN
      END
      SUBROUTINE YIELD2 ( IT )
C
C     PURPOSE         Calculate the production of rubber planting area
C                     with the policy of replanting all trees older than
C                     N years.
C
C     DATE            24-Jul-80, T. Ly, Coombs Comp. Ser., ANU
C
C-----------------------------------------------------------------
C
      INTEGER IAGE(3)
C
      COMMON AREA(80), Y(5,43), IYEAR1, IYEAR2, YIELD(43)
C
      DATA IAGE /26,30,33/
C
C-----------------------------------------------------------------
C
C           Start analysis here
C
      N = IAGE(IT) + 1
C
      DO 110 IY = IYEAR1, IYEAR2
         REP = 0.0
         DO 50 K = N, 80
            REP = REP + AREA(K)
   50    CONTINUE
C
         DO 60 K = N-1, 1, -1
            AREA(K+1) = AREA(K)
   60    CONTINUE
C
         DO 90 K = N+1, 80
            AREA(K) = 0.0
   90    CONTINUE
C
         AREA(1) = REP
C
         IXY = IY - IYEAR1 + 1
C
C                 Calculate total yield
C
            SUM = 0.0
            DO 100 K = 7, N
               SUM = SUM + YIELD(K)*AREA(K)
  100       CONTINUE
            Y(IT,IXY) = Y(IT,IXY) + SUM/1000.0
C
  110 CONTINUE
  800 CONTINUE
C
C
      RETURN
      END
```

```
      SUBROUTINE YIELD3
C
C     PURPOSE         Calculate the production of rubber planting area
C                     with the policy of replanting a percentage of the
C                     total area every year and all trees older than 40 years.
C
C     DATE            24-Jul-80, T. Ly, Coombs Comp Ser., ANU
C
C-------------------------------------------------------------------
C
      INTEGER OLDEST
      REAL PC(41)
C
      COMMON AREA(80), Y(5,43), IYEAR1, IYEAR2, YIELD(43)
C
      DATA LUNI /10/
C
C-------------------------------------------------------------------
C
C           Input percentages from a file
C
      OPEN ( UNIT=LUNI, ACCESS='SEQIN', FILE='PRCENT.DTA' )
      DO 30 I = 1, 41
         READ ( LUNI,* ) P
         PC(I) = P / 100.0
   30 CONTINUE
      CLOSE ( UNIT=LUNI )
C
C           Start analysis here
C
      IYIELD = 5
C
C           Determine the oldest rubber tree area for 1978
C
      DO 10 I = 80, 1, -1
         K = I
         IF ( AREA(I) .NE. 0.0 ) GO TO 20
   10 CONTINUE
   20 OLDEST = K
C
      DO 110 IY = IYEAR1, IYEAR2
         M = OLDEST
         AZERO = 0.0
         IF ( M .LT. 42 ) GO TO 70
         DO 40 K = M, 42, -1
            AZERO = AZERO + AREA(K)
            AREA(K) = 0.0
   40    CONTINUE
   70    DO 80 K = 1, 41
            REP = AREA(K) * PC(K)
            AZERO = AZERO + REP
            AREA(K) = AREA(K) - REP
   80    CONTINUE
         DO 90 K = 42, 2, -1
            AREA(K) = AREA(K-1)
   90    CONTINUE
         AREA(1) = AZERO
         OLDEST  = 42
C
         IF ( M .LT. 41 ) OLDEST = M + 1
```

```
         IXY = IY - IYEAR1 + 1
C
C                 Calculate total yield
C
         SUM = 0.0
         DO 300 K = 7, 43
            SUM = SUM + YIELD(K)*AREA(K)
  300    CONTINUE
         Y(IYIELD,IXY) = Y(IYIELD,IXY) + SUM/1000.0
  110 CONTINUE
 1000 CONTINUE
C
C
      RETURN
      END
      PROGRAM BACK
C
C     PURPOSE           Read 1978 rubber data and calculate the production
C                       of rubber using 2 different replanting policies:
C
C                       (i)  Replant all trees older than N years.
C                       (ii) For each age group a percentage will be replanted
C                            and any tree older than 40 years will
C                            also be replanted.
C
C                       This simulation is done until we reach 1950.
C
C      DATE             5-Sep-80, T. Ly, Coombs Comp. Ser.
C                       written for Pr^machandra  415,255 .
C
C      OPERATING INSTRUCTION
C
C                       .EX BACK
C
C------------------------------------------------------------------------
C
      INTEGER           AGE, OLDEST
      DIMENSION         FRAC (9), HECT(80), Y1(5), Y2(5)
      COMPLEX           IFILE
C
      COMMON            AREA(80), Y(5,43), IYEAR1, IYEAR2,
     +                  YIELD(5,42)
C
      DATA              LUNI /1/, IYEAR1 /1978/, IYEAR2 /1950/
C
      DATA              LUN1 /2/, LUN2 /3/, LUNO /10/
C
C------------------------------------------------------------------------
C
C            Print title of program
C
      TYPE 10
   10 FORMAT ( 1H0, 'YIELD CRANKING BACK CALCULATION PROGRAM' )
C
C            Set sampling fractions ( these remain constant throughout )
C
      FRAC(1) = 0.0701
      FRAC(2) = 0.0326
      FRAC(3) = 0.1473
      FRAC(4) = 0.0319
```

```
      FRAC(5) = 0.0470
      FRAC(6) = 0.0320
      FRAC(7) = 0.0520
      FRAC(8) = 0.1864
      FRAC(9) = 0.1270
C
C           All indices specify a particular region (i.e. there are
C           9 regions). Calculate sampling fraction for the whole
C           9 area (i.e. Sri-Lanka).
C
      F = 0.0
      DO 20 I = 1, 9
         F = F + FRAC(I)
   20 CONTINUE
      F = 9.0 / (F*2.471054)
C
C           Initialize area data
C
      DO 25 J = 1, 80
         AREA(J) = 0.0
   25 CONTINUE
C
C           Input data from a file (user-specified)
C
      TYPE 40
   40 FORMAT ( 1H0, 'Enter Input File Name : ', $ )
      ACCEPT 50, IFILE
   50 FORMAT ( 2A5 )
C
      OPEN ( UNIT=LUNI, ACCESS='SEQIN', FILE=IFILE, ERR=900 )
C
C           Loop here to read and accumulate data with respect
C           to age.
C
   60 READ ( LUNI,70,END=100 ) AREA0, AGE
   70 FORMAT ( 28X, F5.1, 18X, I2 )
      AREA0 = AREA0 * F
      AREA(AGE+1) = AREA(AGE+1) + AREA0
      GO TO 60
C
C           End of file reached here, close input file and
C           start analysis.
C
  100 CLOSE ( UNIT=LUNI )
C
      CALL RESET ( HECT,AREA )           ! Store value of AREA in HECT
C
C             Read yield coefficient data
C
      OPEN ( UNIT=LUN1,ACCESS='SEQIN',FILE='YIELD1.DAT' )
      OPEN ( UNIT=LUN2,ACCESS='SEQIN',FILE='YIELD2.DAT' )
C
      DO 105 I = 7, 42
         READ ( LUN1,102 ) (Y1(J),J=1,5)
  102    FORMAT ( F4.0, 3F5.0, 5X, F5.0 )
         READ ( LUN2,102 ) (Y2(J),J=1,5)
         DO 103 J = 1, 5
            YIELD(J,I) = (Y1(J)+Y2(J)) * 0.5
  103    CONTINUE
  105 CONTINUE
```

```
C
      CLOSE ( UNIT=LUN1 )
      CLOSE ( UNIT=LUN2 )
C
C            Start analysis here
C
      CALL BACK2
C
      CALL RESET ( AREA,HECT )
C
      DO 109 I = 1, 3
         IT = I
         CALL BACK1 (IT)
         CALL RESET ( AREA,HECT )
  109 CONTINUE
C
C
C            Print results here
C
      TYPE 210
  210 FORMAT ( ' Enter Output File Name : ', $ )
      ACCEPT 50, IFILE
C
      OPEN ( UNIT=LUNO,ACCESS='SEQOUT',FILE=IFILE )
C
      WRITE ( LUNO,605 )
  605 FORMAT ( ///, 10X,
     + 'TOTAL PRODUCTION UNDER ALL 4 (CRANKING BACK) ',
     + 'POLICIES IN SRI-LANKA', / )
      WRITE ( LUNO,610 )
  610 FORMAT ( 1H0,' YEAR   POLICY 1     POLICY 2     POLICY 3',
     + '     POLICY 4     POLICY 5', / )
C
      DO 700 IY = IYEAR1, IYEAR2, -1
         J = IYEAR1 - IY + 1
         WRITE ( LUNO,650 ) IY, ( Y(K,J),K=1, 5 )
  650    FORMAT ( I5,3X,5F12.3 )
  700 CONTINUE
C
      CLOSE ( UNIT=LUNO )
      GO TO 1000                                      ! Exit here
C
C-----------------------------------------------------------------------
C
C            Error section
C
  900 TYPE 910
  910 FORMAT ( 1H+, '?File not found', / )
C
 1000 STOP
      END
      SUBROUTINE RESET ( A, B )
C
      DIMENSION A (80), B (80)
C
      DO 10 J = 1, 80
         A(J) = B(J)
   10 CONTINUE
C
      RETURN
```

```
      END
      SUBROUTINE BACK1 (ITYPE)
C
C     PURPOSE        Calculate the production of rubber planting area
C                    backward from 1978 to 1950 using the policy of
C                    replanting all trees older than N years.
C
C     DATE           29-Aug-80, T. Ly, Coombs Comp. Ser., ANU
C
C-------------------------------------------------------------------
C
      COMMON            AREA(80), Y(5,43), IYEAR1, IYEAR2,
     +                  YIELD(5,42)
      INTEGER IAGE(3)
C
      DATA IAGE / 26,30,33 /
C
C-------------------------------------------------------------------
C
      N = IAGE(ITYPE)
C
C          Start analysis here
C
      N = N + 1                            ! Get index for agegroup N
C
C                Group areas where trees ½= N
C                and store result in AREA(N)
C
      REP = 0.0
      DO 40 I = N, 80
         REP = REP + AREA(I)
   40 CONTINUE
      AREA(N) = REP
C
C
C                Let's go
C
      DO 100 IY = IYEAR1, IYEAR2, -1
         REP = AREA(1)
         DO 50 I = 1, N-1
            AREA(I) = AREA(I+1)
   50    CONTINUE
         AREA(N) = REP
         SUM = 0.0
         DO 70 I = 7, 42
            SUM = SUM + YIELD(ITYPE,I) * AREA(I)
   70    CONTINUE
         IXY = IYEAR1 - IY + 1
         Y(ITYPE,IXY) = SUM / 1000.0
  100 CONTINUE
C
      RETURN
      END


      SUBROUTINE BACK2
C
C     PURPOSE        Calculate the production of rubber planting area
C                    from 1978 to 1950.  The replant policy is
```

```
C                 to replant a percentage of each age group and
C                 all areas where trees' age ½ 40.
C
C    DATE         19-Aug-80, T. Ly, Coombs Comp. Ser., ANU
C
C----------------------------------------------------------------
C
      REAL PC(41)
C
      COMMON          AREA(80), Y(5,43), IYEAR1, IYEAR2,
     +                YIELD(5,42)
C
      DATA LUNI /10/
C
C----------------------------------------------------------------
C
      ITYPE1 = 4
      ITYPE2 = 5
C
C          Input percentages from a file
C
      OPEN ( UNIT=LUNI,ACCESS='SEQIN',FILE='PRCENT.DTA' )
      DO 10 I = 1, 41
         READ ( LUNI,* ) P
         PC(I) = P / 100.0
   10 CONTINUE
      CLOSE ( UNIT=LUNI )
C
C          Group all trees older than 40 years old
C          and store result in AREA(41)
C
      REP = 0.0
      DO 20 I = 41, 80
         REP = REP + AREA(I)
   20 CONTINUE
      AREA(41) = REP
C
C
C          Start analysis here
C
      DO 100 IY = IYEAR1, IYEAR2, -1
         P = 0.0
         REP = AREA(1)
         DO 70 I = 1, 40
            TEMP = AREA(I+1) / (1.0-PC(I))
            P = P + TEMP*PC(I)
            AREA(I) = TEMP
   70    CONTINUE
         R = 0.0
         IF ( P .LT. REP ) R = REP - P
         AREA(41) = R
         SUM1 = 0.0
         SUM2 = 0.0
         DO 80 I = 7, 42
            SUM1 = SUM1 + YIELD(ITYPE1,I)*AREA(I)
            SUM2 = SUM2 + YIELD(ITYPE2,I)*AREA(I)
   80    CONTINUE
         IXY = IYEAR1 - IY + 1
         Y(ITYPE1,IXY) = SUM1 / 1000.0
         Y(ITYPE2,IXY) = SUM2 / 1000.0
```