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Effects of Yield Stimulation on Profitability and Rubber Production Hypersurface in the Estate Sector

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The effects of yield stimulant technology on rubber production-profitability and rubber production-hypersurface in estates were examined. The overall effect of yield stimulant technology on the profitability of rubber production per hectare indicated that the differences in the mean operating profits per hectare between stimulated and non-stimulated fields of different technological strata were rather substantial. The margin of difference between the mean operating profits of the stimulated and non-stimulated fields within each tapping panel was higher in the older tapping panels. Production function analysis on the effect of yield stimulation indicates that there is a general upward shift of the production hypersurface. However, the extent of these upward shifts of production hypersurfaces for different technological strata are not even and non-neutral in nature. Further analysis using a non-neutral production function model reveals that there is no consistent pattern by which the adoption of yield stimulant technology will affect the derived demand of any input factors more than another.

Stimulation of rubber trees with 2-chloroethyl-phosphonic acid, commonly known as ethephon, has been claimed to substantially increase rubber output under commercial conditions[1]. Yield stimulant technology has been widely adopted in the estate sector, but it is not popular with the smallholder sector. There is continuing debate on the effects of yield stimulation on rubber trees particularly in the long run. Results of long-term ethephon stimulation experiments conducted by the Rubber Research Institute of Malaysia (RRIM)[2] indicated that high peak response to yield stimulation was obtained only for the first few rounds of stimulation, with decline in response for the later rounds of stimulation. Furthermore, little is known about the inter-relationship between yield stimulation on the one hand and the level of embodied technology and all other factors of production on the other.

This paper analyses some of the available data on yield stimulant technology and provides some knowledge on its effects in the rubber production process in estates. It outlines some brief developments of yield stimulant technology, the economic analysis of its effect on the profitability of rubber production, the analytical approach adopted to study changes in the production hypersurface resulting from the effect of yield stimulant technology, the empirical results of the production hypersurface analysis and the implications and conclusions of the empirical results.

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DEVELOPMENT OF YIELD STIMULANTS

The use of yield stimulants to increase rubber production has been an important technological development in the Malaysian rubber-growing industry. Research into the use of various stimulants suitable for rubber has a long history. The earliest attempt at yield stimulation was by periodic scraping of the bark below the tapping groove. Stimulation experiments conducted by the RRIM during 1929-30 used a mixture of cattle manure, wood ash and other minor ingredients such as sulphate of iron and permanganate of potash. The yield increases recorded in these experiments provided incentives for the scientists to pursue the subject further. Chapman[3] and Blackman[4] reported that early work using plant hormones like auxins affected cell elongation and promoted meristematic activities connected with wound healing. This led to the belief that the early practice of scraping the bark below the tapping groove caused the production of certain plant hormones which resulted from wound healing responses of the tree. The plant hormones were believed to prolong latex flow and hence led to higher productivity. Subsequent developments in yield stimulation experiments led to the discovery of a few modestly effective yield stimulants[5].

The conventional yield stimulants used in the estate sector during the 1950s included the substituted phenoxyacetic acids 2,4-D and 2,4,5-T and other similar derivatives. However, it was only during the late 1960s that scientists discovered the significance of ethylene which acts as an agent for the continuous flow of latex from vessels. In other words, ethylene was the most important factor in delaying the coagulation or 'plugging' of the latex vessels (Abraham *et al.*[6] Abraham *et al.*[7] and Dickenson *et al.*[8]). This established the fact that earlier yield stimulants always included 'ethylene inducers'.

The yield stimulant now widely recommended to the industry is essentially an ethylene inducer and consists of 2-chloroethyl-phosphonic acid and palm oil, commonly known as ethephon. Ethephon liberates ethylene gas through the latex vessels, which will then delay the plugging of the latex vessels and is capable of boosting yields by 50%–80% in well-kept trees which have been tapped for more than fifteen years[9]. An earlier method of applying ethephon was to paint a thin layer of it on renewing bark above the tapping cut at two-monthly intervals. Nowadays, ethephon is usually applied to the tapping groove or to a strip of lightly scraped bark below the tapping cut with a flat paint brush. The frequency of application is normally once a month on the groove and once in two months on scraped bark.

DATA SOURCES AND LEVELS OF TECHNOLOGY

The data used in this study were collected from estates throughout Peninsular Malaysia. The basic sampling unit was a field of rubber trees. A field is a plot of land planted with rubber trees within an estate. An estate consists of a number of fields of different sizes, each planted with trees of different ages.

The basic sources of data were the annual surveys of estates conducted by the Costing and Management Group of RRIM. The data were collected during the period 1977-8 but related to the 1976 production year. Stratified random samples were selected from the estates in Peninsular Malaysia. One major problem encountered was that the data collected by the Costing and Management Group did not constitute a complete random sample required in the present study. To overcome the problem of obtaining a biased sample, the remaining sampling

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units were collected from two other sources. First, data were collected from the Commercial Registration Unit of RRIM. Second, the author undertook a separate survey of sample estates to extract the relevant data from the remaining sample fields. All in, data from a total of 619 fields were collected and used in the present analysis.

Preliminary investigations of the historical development of the industry identified three distinct levels of embodied technology co-existing in the 1976 production year. As the most important technological feature of each level or stratum was the class of cultivars involved and the associated package of improved techniques used during the immature phase, the three technological strata have been labelled HYM 1, HYM 2 and HYM 3. A more detailed classification of the technological strata is included in *Appendix A*.

EFFECTS OF YIELD STIMULATION ON PROFITABILITY

Reports from stimulation experiments conducted by RRIM[11] using one year's data showed that responses from different cultivars varied considerably and that higher returns could be obtained from a longer length of cut and higher tapping intensity. It appears that responses from trees given ethephon stimulation varied considerably according to such factors as cultivar, tapping frequency, length of cut, age of the trees, soil type, ethephon concentration and method of application[12]. In a study by Lim[13], it was reported that the monthly income of an estate tapper could be doubled while at the same time tapping cost per kilogramme of output incurred by the estates could be reduced when ethephon was used.

To examine the extent to which stimulants have resulted in yield increases under commercial conditions, the mean yields from the stimulated and non-stimulated fields for the 1976 data set were compared. The empirical results are indicated in *Table 1*. The mean yield response to stimulation generally varied with different tapping panels, conforming with results obtained from RRIM large-scale trials. In the present analysis, the mean yield response to stimulation (for all the cultivars pooled together) ranged from 22% to 57%. The general pattern for pooled response of each tapping panel was that the second renewal bark (*Panels E* and *F*) gave higher response to stimulation. Although *Panels A* and *B* are generally not recommended for stimulation, it can be observed that seventy-seven sample fields or about 12% of the total number of the sample fields in *Panel A* and *Panel B* tapping were being stimulated in the estate sector in 1976. The mean yield responses to stimulation for trees in *Panel A* and *Panel B* tapping were 27% and 22% respectively. The highest mean yield response to stimulation (pooled response within each panel) of 57% was obtained from trees in *Panel F* tapping. The overall yield response or pooled response to stimulation for all tapping panels in 1976 was 32%.

The effects of yield stimulation on the mean operating profits of estate rubber production were also compared. *Figures 1, 2* and *3* show the overall mean effects of yield stimulation on the mean operating profits per hectare for fields with HYM 1, HYM 2 and HYM 3 technological strata respectively. The overall effect of yield stimulant technology on the profitability per hectare of production in estates was clearly shown. For all tapping panels, there were large differences in the mean operating profits per hectare between the stimulated and non-stimulated fields for the HYM 1, HYM 2 and HYM 3 technological strata. It can be observed

TABLE 1. MEAN YIELD RESPONSE TO STIMULATION FOR ALL CULTIVARS IN 1976

Tapping panel	Stimulation	Number of fields	Mean annual yield (kg/ha)	Yield increase (%)
A	No	93	1 294 (336)	27
	Yes	23	1 641 (486)	
B	No	131	1 542 (322)	22
	Yes	54	1 878 (514)	
C	No	20	1 642 (214)	31
	Yes	93	2 146 (314)	
D	No	9	1 436 (392)	38
	Yes	73	1 983 (174)	
E	No	16	1 211 (241)	39
	Yes	51	1 688 (301)	
F	No	8	984 (134)	57
	Yes	48	1 544 (288)	
All	No	277	1 493 (387)	32
	Yes	342	1 977 (276)	

Figures within brackets are standard deviations.

'Yes' refers to 100% stimulation, that is, all trees were stimulated.

that for all cases, the curves for stimulated fields were always higher than those for non-stimulated fields, indicating that stimulation always gave higher levels of mean operating profits per hectare in rubber production. Another feature noted was that the difference between mean operating profits per hectare of the

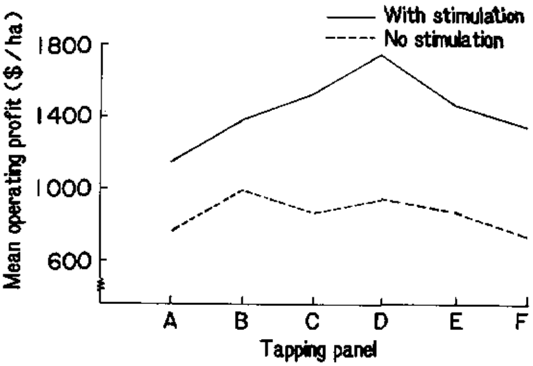

Figure 1. Variation of mean operating profits between stimulated and non-stimulated fields, HYM 1 (1976).

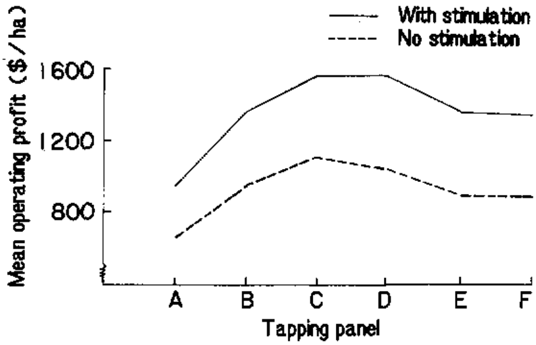

Figure 2. Variation of mean operating profits between stimulated and non-stimulated fields, HYM 2 (1976).

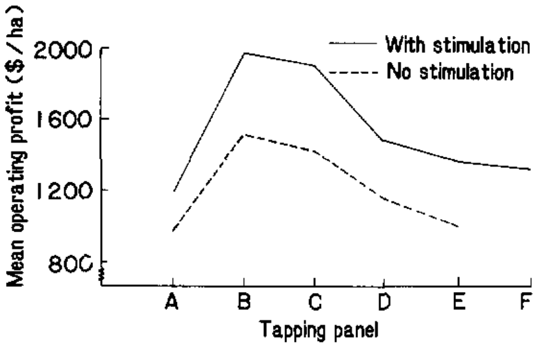

Figure 3. Variation of mean operating profits between stimulated and non-stimulated fields, HYM 3 (1976).

stimulated and non-stimulated fields was larger for fields with older trees (*i.e.* fields under *Panel D, E* and *F* tapping). The larger difference in the levels of profitability per hectare for fields with older trees suggests that the effect of stimulation is greater for fields with older trees.

CHANGES IN PRODUCTION HYPERSURFACE WITH YIELD STIMULANT TECHNOLOGY

The production function approach is used to estimate the change or shift in the production hypersurface resulting from the application of yield stimulant technology. Generally, the production functions for stimulated and non-stimulated fields in each of the HYM 1, HYM 2 and HYM 3 technological strata can be described as follows:

$$Y_{ST,\,t} = f(x_1 \,.....\, x_i \,.....\, x_n)_{ST} \qquad ...\ 1$$

$$Y_{NST,\,t} = f(x_1 \,.....\, x_i \,.....\, x_n)_{NST} \qquad ...\ 2$$

where Y is the output of a particular field
x_i are the input factors
ST represents stimulated fields
NST represents non-stimulated fields

If an assumption is made that in any particular production year t, the managers of the estates applied the most recent technology to all fields, then a comparison of the estimated production functions for those fields with and without stimulation should reveal the nature and degree of shift in the production hypersurface due to the explicit effect of yield stimulant technology.

After extensive testing of a range of functional forms suitable to the Malaysian estate sector, the multiplicative Cobb-

Douglas function was selected for subsequent empirical analysis of the above general models. Detailed analysis of the appropriateness of various functional forms was reported by Yee[10]. The basic form of the function estimated can be written as:

$$Y = \alpha_o . N^{\alpha_1} . T^{\alpha_2} . F^{\alpha_3} . E^{\alpha_4} . MP^{\alpha_5} . e^{(\delta_j + \mu)} \quad ... 3$$

where Y is the annual rubber output per field measured in thousand kilogrammes of ribbed-smoked sheet (RSS 1) equivalent

N is the harvesting labour measured in total number of tappings

T is the total index value for tappable trees per field (corrected for age effect as outlined in *Appendix B*)

F is the total amount (kilogrammes) of fertilisers applied per field per year

E is the other input expenditure measured in Malaysian Ringgit

MP is the management proxy in terms of gross-profit to total expenditure ratio for a particular field

α_o is the constant or intercept term

α_i is the coefficient of independent variables

α_j is the coefficient of j dummy which is designed to capture the shift of the function

μ is the random disturbance term independently distributed with zero mean and finite variance.

PRODUCTION HYPERSURFACES FOR STIMULATED AND NON-STIMULATED FIELDS

This section deals with the quantitative effects of yield stimulant technology on the overall rubber production hypersurfaces for the three high-yielding technological strata (*i.e.* HYM 1, HYM 2 and HYM 3). The results of regression analysis using *Models 1* and *2* fitted to the data from stimulated and non-stimulated fields for the HYM 1, HYM 2 and HYM 3 technological strata are presented in *Tables 2, 3* and *4* respectively.

All the coefficients of the variables representing harvesting labour *(N)*, fertilisers *(F)* and other inputs *(E)* increased with stimulation given HYM 1 *(Table 2)* and HYM 2 *(Table 3)* technologies. The implication is that stimulation raised the marginal productivities of these inputs. On the other hand, stimulation reduced the partial coefficient on the tree variable *(T)* for both the HYM 1 and HYM 2 functions. Therefore, except for changes in the coefficient of the management variable *(MP)*, the impact of stimulation on the hypersurfaces for HYM 1 and HYM 2 appeared to be rather similar.

The response to stimulation given HYM 3 embodied technology however, appears tö be markedly different. In particular, the partial regression coefficient for labour *(N)* diminished with stimulation while there was a substantial increase in the coefficient for the tree variable *(T)*.

The observed difference in the response to yield stimulation for labour and tree inputs between the most recent technological stratum, HYM 3 and the older technological strata, HYM 1 and HYM 2 could be due to a number of reasons. First, there is a probability that the genetic make-up of the HYM 1 and the HYM 2 cultivars were sufficiently different from that of the HYM 3 cultivars to result in a significantly different response to yield stimulants. Secondly, the greater response from HYM 3 could be due to the different tapping systems adopted in the HYM 3 fields when compared with the HYM 1 and HYM 2 fields.

TABLE 2. COBB-DOUGLAS PRODUCTION FUNCTION ESTIMATES FOR STIMULATED, NON-STIMULATED AND POOLED HYM 1 TECHNOLOGICAL STRATUM, 1976 SAMPLE

Input variable	Stimulated (R2.1)	Non-stimulated (R2.2)	Pooled (2.3)	Pooled (R2.4)
Harvesting labour (N)	0.3684** (0.0656)	0.2891** (0.1432)	0.3413** (0.0593)	0.3453** (0.0586)
Tree (T)	0.3448** (0.0799)	0.5260** (0.1766)	0.3264** (0.0728)	0.3563** (0.0731)
Fertilisers (F)	0.1503** (0.0264)	0.0937** (0.0339)	0.1338** (0.0397)	0.1267** (0.0394)
Other input expenditure (E)	0.1206** (0.0299)	0.1113** (0.0341)	0.1960** (0.0427)	0.1674** (0.0439)
Management proxy (MP)	0.4111** (0.0308)	0.2132** (0.0411)	0.0717** (0.0066)	0.2134** (0.0807)
Stimulation technology dummy (S)				0.3669** (0.0184)
Intercept	0.1661	0.2217	−1.4379	−1.4157
Adjusted R^2	0.9316	0.9635	0.9360	0.9375
SEE	0.2321	0.1966	0.2309	0.2283
Overall F-statistic	*461.5083***	*143.5147***	*577.4271***	*491.8174***
Returns to scale	0.9841	1.0201	0.9975	0.9957
F-statistic	1.01	0.47	0.19	1.14
No. of fields	71	37	108	108

Figures within brackets are standard errors of coefficients.

Stimulation technology dummy (S) has the value of one for stimulated fields and zero otherwise.

Standard errors of estimates (SEE) are in natural logarithms of rubber output (Y)

Returns to scale is measured by the sum of conventional inputs of N, T, F and E.

F-statistic is calculated to test the hypothesis of constant returns to scale.

**Significant at 1% level

The trees in most of the fields with HYM 3 technologies were younger than those with HYM 1 and HYM 2 technologies. More intensive tapping systems were adopted for older trees and less intensive tapping systems for younger trees. Thirdly, the frequency of application and the concentration of yield stimulants applied to the younger trees (such as those in the HYM 3 fields) might have been different from those of the older trees (such as those in the HYM 1 and HYM 2 fields). Experiments indicated that different responses to yield stimulants are obtained with different frequencies and concentrations of the yield stimulants[6,7,8]. In addition, the method of application might have given different output responses.

The analysis of covariance suggested by Johnson[14] was used to determine whether there were any changes in the

TABLE 3. COBB-DOUGLAS PRODUCTION FUNCTION ESTIMATES FOR STIMULATED, NON-STIMULATED AND POOLED HYM 2 TECHNOLOGICAL STRATUM, 1976 SAMPLE

Input variable	Stimulated (R3.1)	Non-stimulated (R3.2)	Pooled (R3.3)	Pooled (R3.4)
Harvesting labour (N)	0.3425** (0.0701)	0.3099** (0.0921)	0.3231** (0.0617)	0.3256** (0.0671)
Tree (T)	0.4988** (0.0611)	0.6076** (0.2179)	0.5254** (0.0727)	0.5329** (0.0791)
Fertilisers (F)	0.1477** (0.0427)	0.0892* (0.0539)	0.1033** (0.0425)	0.1177** (0.0329)
Other input expenditure (E)	0.1033** (0.0563)	0.0826 (0.0876)	0.0971* (0.0564)	0.1055** (0.0413)
Management proxy (MP)	0.1426** (0.0376)	0.1931** (0.0303)	0.1574** (0.0611)	0.1238** (0.0371)
Stimulation technology dummy (S)				0.2931** (0.0271)
Intercept	0.4504	−0.0949	−1.4921	−0.4797
Adjusted R^2	0.9377	0.9647	0.9586	0.9592
SEE	0.1755	0.1574	0.1706	0.1694
Overall F-statistic	412.3171**	137.4716**	543.2714**	459.6231**
Returns to scale	1.0923	1.0893	1.0489	1.0817
F-statistic	1.12	0.41	0.71	0.24
No. of fields	151	73	224	224

Figures within brackets are standard errors of coefficients.

Stimulation technology dummy (S) has the value of one for stimulated fields and zero otherwise.

Standard errors of estimates (SEE) are in natural logarithms of rubber output (Y).

Returns to scale is measured by the sum of conventional inputs of N, T, F and E.

F-statistic is calculated to test the hypothesis of constant returns to scale.

*Significant at 5% level

**Significant at 1% level

production hypersurfaces between the stimulated and non-stimulated fields in each of the three technological strata (*Tables 2, 3* and *4*). To this end, pooled regressions were estimated for each of the technological strata. These were indicated in the third and fourth columns of *Tables 2, 3* and *4*. Results of the analysis of covariance are summarised in *Table 5* (*see Appendix C* for details of F_1, F_2 and F_3 tests). All the F values were found to be significant at the 1% level in all the three analyses. Therefore, the data support the hypothesis that yield stimulant technology shifts the production hypersurface upwards in a non-neutral fashion irrespective of the level of embodied technology.

TABLE 4. COBB-DOUGLAS PRODUCTION FUNCTION ESTIMATES FOR STIMULATED, NON-STIMULATED AND POOLED HYM 3 TECHNOLOGICAL STRATUM, 1976 SAMPLE

Input variable	Stimulated (R4.1)	Non-stimulated (R4.2)	Pooled (R4.3)	Pooled (R4.4)
Harvesting labour (N)	0.1825** (0.0726)	0.2103** (0.0827)	0.2411** (0.0564)	0.2365** (0.0567)
Tree (T)	0.6692** (0.0821)	0.5857** (0.0711)	0.5928** (0.0735)	0.6044** (0.0733)
Fertilisers (F)	0.1178** (0.0427)	0.1027** (0.0341)	0.1138* (0.0617)	0.1031** (0.0221)
Other input expenditure (E)	0.1082* (0.0400)	0.0927** (0.0417)	0.1014* (0.0714)	0.0779* (0.0417)
Management proxy (MP)	0.4077** (0.0726)	0.4143** (0.0614)	0.2911** (0.0432)	0.3371** (0.0573)
Stimulation technology dummy (S)				0.2281** (0.0691)
Intercept	–0.9584	–0.5161	–0.4921	–1.6743
Adjusted R^2	0.9615	0.9478	0.9544	0.9549
SEE	0.1625	0.1612	0.1642	0.1632
Overall F-statistic	495.3214**	451.6168**	911.2977**	788.2765**
Returns to scale	1.0777	0.9914	1.0491	1.0219
F-statistic	0.91	1.28	1.31	0.41
No. of fields	120	167	287	287

Figures within brackets are standard errors of the coefficients.
Stimulation technology dummy (S) has the value of one for stimulated fields and zero otherwise.
Standard errors of estimates (SEE) are in natural logarithms of rubber output (Y).
Returns to scale is measured by the sum of conventional inputs of N, T, F and E.
F-statistic is calculated to test the hypothesis of constant returns to scale.
*Significant at 5% level
**Significant at 1% level

Results of Non-neutral Model

For the purpose of examining the nature and extent of non-neutral shift between the production hypersurfaces of the stimulated and non-stimulated fields, the non-neutral version of *Equation 3* was formulated *(Equation4)* and fitted to the 1976 data for each of the three HYM technological strata:

$$Y = \alpha_o . N^{(\delta_j + \alpha_2)} . T^{(\delta_j + \alpha_2)} . F^{(\delta_j + \alpha_3)} . E^{(\delta_j + \alpha_4)} . MP^{(\delta_j + \alpha_5)} . e^{(\delta_j + \mu)} \quad \ldots 4$$

The results of the regression analysis are given in *Table 6.* These results confirm the significant increase in the coefficient of labour variables for both the HYM 1

TABLE 5. SUMMARIES OF COVARIANCE ANALYSIS FOR STIMULATED AND NON-STIMULATED FIELDS, 1976 SAMPLE

Technological stratum	Degree of freedom (n_1, n_2)	F value
HYM 1 *(Table 2)*	1, 101	F_1 = 24.76**
	5, 96	F_2 = 14.33**
	6, 96	F_3 = 7.62**
HYM 2 *(Table 3)*	1, 217	F_1 = 39.76**
	5, 212	F_2 = 8.14**
	6, 212	F_3 = 13.29**
HYM 3 *(Table 4)*	1, 280	F_1 = 17.44**
	5, 275	F_2 = 6.52**
	6, 275	F_3 = 13.76**

**Significant at 1% level

and the HYM 2 technological strata as discussed earlier. However, in the case of the HYM 3 stratum, despite the decrease in the coefficient of the labour variables as observed in *Table 4*, the non-neutral model *(Table 6)* showed that the decrease in the labour input coefficient was not significantly different from zero as indicated by the coefficient of the interaction term *(S.* ln*N)* in the HYM 3 function *(Table 6)*. Similar results were observed with respect to the tree variable. Although the tree partial elasticity diminished for stimulated fields in the case of both the HYM 1 and HYM 2 strata, these decreases were not significant at the 5% level. The non-neutral model indicated that there was a significant increase in the coefficient of the tree variable in the HYM 3 function as expected, given the earlier results of regression (R4.1) in *Table 4*.

On the interaction between sitmulation and fertilisers, and between stimulation and other input expenditure variables, the results in the non-neutral model as indicated by *Table 6* reveal that the HYM 1 and the HYM 3 technological strata showed an increase in the fertiliser input coefficient while the HYM 2 showed no significant results. This is indicated by the coefficients of the interaction term *(S.* ln*F)* for all the three HYM technological strata. Similar results were also observed for the other input expenditure variable *(E)*.

Overall, the results in *Tables 2, 3, 4* and *6* indicate that there is no consistent pattern by which yield stimulants will increase or decrease the marginal productivities (and hence the derived demand) for the other inputs. The impact of yield stimulants on the production function for rubber growing is non-neutral and uneven, and depends upon the level of embodied technology involved.

YIELD STIMULANT TECHNOLOGY AND TECHNICAL EFFICIENCY

Since the difference in the production hypersurfaces between the stimulated and non-stimulated fields is non-neutral in nature, the degree of technical efficiency will vary over the whole range of the production functions. Thus, there is no

TABLE 6. ESTIMATES OF NON-NEUTRAL MODEL (4) FOR POOLED STIMULATED AND NON-STIMULATED HYM 1, HYM 2 AND HYM 3 TECHNOLOGICAL STRATA, 1976 SAMPLE

Input variable	Pooled technological stratum		
	HYM 1 (R6.1)	HYM 2 (R6.2)	HYM 3 (R6.3)
Harvesting labour (N)	0.2991** (0.1081)	0.2941** (0.0914)	0.2824** (0.0370)
Tree (T)	0.5882** (0.0716)	0.6608** (0.2287)	0.5019** (0.0914)
Fertilisers (F)	0.1438** (0.0392)	0.1038** (0.0413)	0.1421** (0.0531)
Other input expenditure (E)	0.1655** (0.1011)	0.1032** (0.0276)	0.1417** (0.0331)
Management proxy (MP)	0.3117** (0.0632)	0.2137** (0.0519)	0.1411** (0.0539)
Stimulation technology dummy (S)	0.2326** (0.0171)	0.1947** (0.0322)	0.2871** (0.0493)
S. 1n N	0.0699** (0.0213)	0.0821* (0.0474)	0.0911 (0.0891)
S. 1n T	0.2397 (0.2179)	–0.1665 (0.2674)	0.1633** (0.0697)
S. 1n F	0.1087** (0.0413)	0.0827 (0.0915)	0.0895 (0.0531)
S. 1n E	0.0109** (0.0067)	0.0793 (0.1008)	0.0446* (0.0281)
S. 1n MP	0.0049 (0.0047)	0.0947* (0.0593)	0.0087 (0.0074)
Intercept	–4.4601	–2.3764	–1.4793
Adjusted R^2	0.9433	0.9328	0.9489
SEE	0.1911	0.2014	0.1894
Overall F-statistic	274.5861**	291.3217**	471.2800**
No. of fields	108	224	287

Figures within brackets are standard errors of coefficients.

Stimulation technology dummy (S) has the value of one for stimulated fields and zero otherwise.

Standard errors of estimates (SEE) are in natural logarithms of rubber output (Y) measured in thousand kilogrammes of RSS1 equivalent rubber.

*Significant at 5% level

**Significant at 1% level

single measure which can express the relative average technical efficiency of the two groups of fields. Under these circumstances, one could proceed by estimating a frontier function for stimulated and non-stimulated fields. These functions would then enable a comparison to be made between technical efficiency of stimulated and non-stimulated fields given any particular combination of levels of input for the other factors of production. However, such a comparison would be 'at the frontier' and not a comparison of 'on average' technical efficiency. While there are merits in 'frontier' as opposed to 'average' comparisons, the method adopted in this study was to utilise the 'average' production functions already in hand.

The production functions in *Tables 2, 3* and *4* have been used to determine the isoquants shown in *Figures 4, 5* and *6* respectively. The stimulated and non-stimulated field isoquants in *Figure 4* are derived from production functions given by regressions R2.1 and R2.2 *(Table 2)* respectively. Similarly, the stimulated and non-stimulated field isoquants in *Figures 5* and *6* are derived from production functions given by regressions R3.1 and R3.2 *(Table 3)*, and R4.1 and R4.2 *(Table 4)* respectively. The isoquants for both the stimulated and non-stimulated fields have the output level *(Y)*, fertiliser *(F)*, other input expenditure *(E)* and management proxy *(MP)* fixed at the per hectare geometric means of the stimulated fields for each of the HYM technological strata. The diagrams are thus two-dimensional, depicting the shape of the isoquants at various levels of harvesting labour and tree index value. In each of the three cases, it is observed that the isoquant for the sitmulated fields lies entirely below the isoquant of the non-stimulated fields thus indicating that for all input levels of harvesting labour and tree index value, the non-stimulated fields require higher levels of

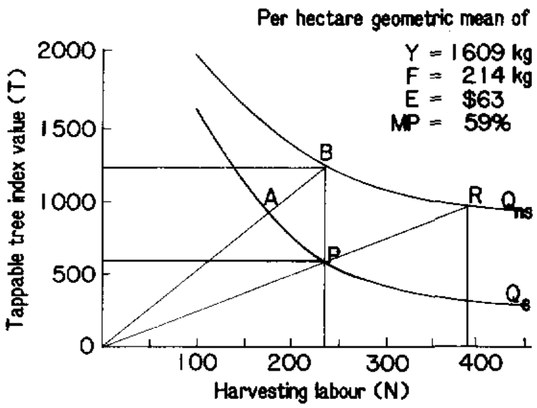

Figure 4. Isoquants of stimulated (Q_s) and non-stimulated (Q_{ns}) fields, HYM 1 stratum.

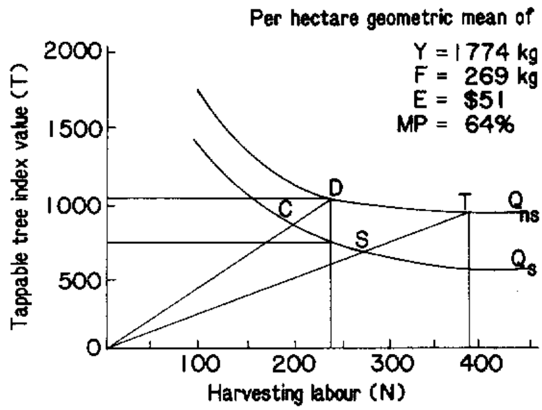

Figure 5. Isoquants of stimulated (Q_s) and non-stimulated (Q_{ns}) fields, HYM 2 stratum.

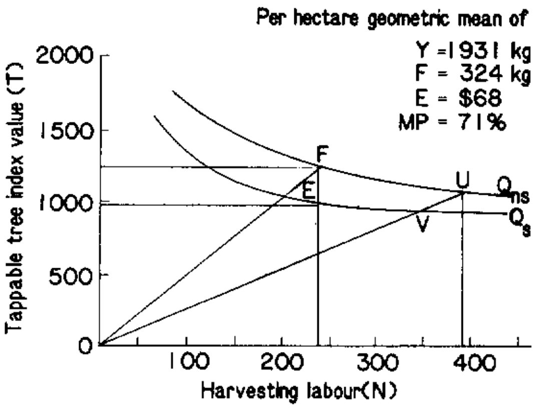

Figure 6. Isoquants of stimulated (Q_s) and non-stimulated (Q_{ns}) fields, HYM 3 stratum.

inputs than the stimulated fields to produce the same level of output. For example, in the case of HYM 1 technological stratum, taking an arbitrary harvesting labour of 233 man-days, the stimulated HYM 1 fields need a tree index of 590 to produce an output of 1609 kg of rubber, while fertiliser, other input expenditure and management proxy variables are fixed at 214 kg, \$63 and 59% respectively. At the same harvesting labour input, a tree index of 1192 is needed to produce the same output of 1609 kg of rubber for the non-stimulated HYM 1 fields. An additional tree index value of 602 (*i.e.* 1192 minus 590) is needed for the non-stimulated HYM 1 fields to give the same output (1609 kg). Similar illustrations can be made for the HYM 2 and HYM 3 cases where the output, fertiliser usage, other input expenditures and management variables are fixed at their respective geometric means per hectare.

Another feature noted is that the gap between the isoquants of stimulated (Q_s) and non-stimulated (Q_{ns}) fields for the HYM 1 and HYM 2 strata is widened as one increases the harvesting labour input. This indicates that when a higher tapping frequency is applied, that is, increasing the harvesting labour input, the differences in productivity between the stimulated and non-stimulated fields of the HYM 1 and HYM 2 strata become larger. However, a different pattern is noted for the isoquants of the HYM 3 stratum. The gap between the isoquants of stimulated (Q_s) and non-stimulated (Q_{ns}) fields in HYM 3 stratum narrows as one increases the harvesting labour input. Such a contrasting response to stimulation is largely due to different genetic components of the HYM 3 cultivars and the associated package of improved technology for the HYM 3 stratum. Nevertheless, the diagram illustrates the finding of the previous section which indicated that the response to yield stimulation was different for the HYM 3 stratum compared to the HYM 1 and HYM 2 strata. In any event, there is a limit to which trees can be tapped. In the long-term interest of tree growth, the use of too high or too low tapping intensities is not a common practice in the estate sector. Thus, within the range of 100 man-days and 250 man-days per hectare and at the usual levels of harvesting labour stimulation significantly contributes to higher productivity for all three technological strata.

As mentioned earlier, the fact that technological changes between the stimulated and non-stimulated fields are non-neutral for all three HYM technological strata means that any technical efficiency index designed to rank stimulated and non-stimulated fields will vary according to the levels of inputs used. By arbitrarily fixing the harvesting labour levels at 233 man-days and 389 man-days for all three HYM technological strata, the level of technical efficiency for each arbitrary resource combination can be calculated (*Table 7*). It can be seen that at the arbitrary resource combination of 233 man-days of harvesting labour and 1192 tree index value, the relative technical efficiency for the non-stimulated fields of HYM 1 stratum is computed as being 73% while at the other arbitrary resource combination of 389 man-days of harvesting labour and a tree index value of 989, the relative technical efficiency is 60%. Similar comparisons can be made for the HYM 2 and HYM 3 strata.

The above results give some indications of the average differences in technical efficiency between stimulated and non-stimulated fields. While the precise difference depends upon many factors, it is clear that stimulants greatly enhance technical efficiency for all HYM technological strata for all reasonable combinations of the other input factors.

TABLE 7. TECHNICAL EFFICIENCY ASSOCIATED WITH DIFFERENT TECHNOLOGICAL STRATA AND AT DIFFERENT RESOURCE COMBINATIONS

Technological stratum	Technical efficiency at	
	233 man-days	389 man-days
HYM 1	$\frac{OA}{OB} = 0.73$	$\frac{OP}{OR} = 0.60$
HYM 2	$\frac{OC}{OD} = 0.83$	$\frac{OS}{OT} = 0.71$
HYM 3	$\frac{OE}{OF} = 0.87$	$\frac{OU}{OV} = 0.89$

OA, OB, OC, OD, OE, OF, OP, OR, OS, OT, OU and OV are as shown in *Figures 4, 5* and *6.*

CONCLUSION

Yield stimulant technology has been successfully applied in the Malaysian rubber industry, particularly in the estate sector. Empirical results using cross-sectional data from the estate sector indicate the effectiveness of stimulants in raising yield levels. The overall mean yield (pooled) response to stimulation was recorded to be 32% in 1976. Closer examination of the results indicated that the highest mean pooled response to yield stimulation (within each tapping panel) was recorded in the oldest tapping panel (*i.e. Panel F*). On the whole, the mean yield increase resulting from yield stimulation increased from the younger tapping panels to the older tapping panels.

The effect of yield stimulant technology on the mean operating profits of the estate sector was also analysed. Mean operating profits per hectare was relatively higher for the stimulated fields compared to the non-stimulated fields. The margin of difference between the mean operating profits of the stimulated and non-stimulated fields within each tapping panel, was found to be higher as one moved towards the older tapping panels.

The analysis on the effect of yield stimulant technology on the rubber production hypersurface indicates that there is a general upward shift of the production hypersurface. However the nature of upward shift for the rubber production hypersurface of estates was found to be non-neutral irrespective of the level of embodied technology. Further analysis using a non-neutral production function model indicates that there is no consistent pattern by which yield stimulation will affect the derived demand of any input factor more than another.

The development of yield stimulant technology during the last decade will play an important role in putting the Malaysian rubber industry on a competitive footing in the world elastomer market. Although production cost increases with yield stimulation, the increase in yield, particularly in the older tapping panels, often offsets the increase in production cost and hence a higher level of operating profits can be derived. However, the study does not provide any indication of the long-term effect of yield stimulant to the trees. Nevertheless, it has demonstrated the profitability of yield stimulant technology, at least in the short run, for rubber production in the estate sector.

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APPENDIX A

CLASSIFICATION OF TECHNOLOGICAL STRATA

In the course of the technological evolution of the Malaysian rubber-growing industry, four time periods can be differentiated. These are the periods associated with the planting of:

- Unselected seedlings (before 1930)
- First group of high-yielding materials (1930–42)
- Second group of high-yielding materials (1945–59)
- Recent group of high-yielding materials (since 1960).

Preliminary enquiries from twenty-seven estate managers and field assistants indicated that it was not possible to obtain detailed input-output data from individual production fields of the estates for years prior to 1960*. The majority of the managers indicated that they did not retain records of production after the fields had been replanted. Thus long-term time-series data were not available from fields using technologies associated with the earlier periods. The level of technology available during these earlier periods must be examined indirectly.

This study classifies different technological strata based on detailed information derived from cross-sectional surveys about the types of rubber cultivars and their associated package of inputs introduced during various time periods. Due to the perennial nature of rubber trees, it is possible to obtain data from cross-sectional surveys covering rubber cultivars recommended and planted in a range of time periods.

Work done on the breeding and selection of cultivars began to produce new high-yielding materials in the early 1900s. These high-yielding cultivars have been introduced to the industry by RRIM on the basis of *Class 1*, *Class 2* and *Class 3* materials. *Class 1* materials are recommended for planting on a large scale (*i.e.* up to 80% of the planted area). *Class 2* materials are recommended for planting on a moderate scale (*i.e.* usually up to 20% of the total planted area). *Class 3* materials are recommended for planting in experimental plots only. New plantings and replantings in the estate sector generally follow the RRIM recommendations for large-scale planting and hence fields are mostly planted with *Class 1* materials. For this study the *Class 1* materials were grouped into different technological strata. *Table A1* summarises the various new *Class 1* materials recommended to the industry at different time periods. It must be noted that *Class 1* materials which continue to be recommended to the industry have not been included in the list for subsequent periods in *Table A1*. This is because when the cultivars (and hence their associated package of input factors during the planting time) were first recommended to the industry, they embodied the state of technology at the time of their recommendations, *i.e.* they were vintage-specific. Their continued recommendations as *Class 1* materials in the subsequent period do not embody any new technology.

Based on the information in *Table A1*, *Class 1* cultivars have been classified into four technological strata each representing one state of technology for the four time periods discussed above. The four technological strata representing the above time periods are, respectively, USM,

*These enquiries were made in 1977 when a group of estate managers and field assistants from throughout Malaysia attended an estate management and planning course conducted by RRIM at its Kuala Lumpur headquarters.

TABLE A1. NEW CLASS 1 PLANTING MATERIALS RECOMMENDED BY RRIM AT DIFFERENT PERIODS

Period	Clone	Seedling family
Before 1930		Unselected seedlings
1930s	Tjir 1 Tjir 16 PB 86 Pil B84 PB 25	
1940s	GL 1	
1950s	RRIM 501 RRIM 513 PR 107	PBIG/C PBIG/D PBIG/E PBIG/F PBIG/G PBFB/A PBFB/B Ch IG/B Ch IG/E Tjir 1M Tjir 1 illegitimate
Since 1960	RRIM 600 RRIM 605 RRIM 623 PB 5/51 GT 1	PBIG/GG1 PBIG/GG2

Unselected seedlings are not recommended materials but are indicated here as the original material used in the rubber industry.

HYM 1, HYM 2 and HYM 3. USM represents the original planting materials and their associated package of input factors. It must be noted that USM represents the oldest technology and the cultivar, *i.e.* unselected seedling material, is not a *Class 1* material as listed in *Table A1*. HYM 1 represents the technology embodied in *Class 1* cultivars and their associated package of input factors introduced during the period 1930-42. HYM 2 represents the technology embodied in the next group of *Class 1* cultivars and their associated package of input factors introduced during the period 1945-59. This is the immediate period after the Second World War in Malaysia. HYM 3 represents the technology embodied in the most recent group of *Class 1* rubber cultivars recommended since 1960. The grouping of cultivars into different technological strata is summarised in *Table A2*.

TABLE A2. CLASSIFICATION OF RUBBER CULTIVARS INTO DIFFERENT TECHNOLOGICAL STRATA

Technological stratum	Rubber cultivar	Characteristics
USM	Unselected seedlings	Original technology introduced to the Malaysian rubber industry
HYM 1	Tjir 1, Tjir 16, PB 86, Pil B84, PB 25	Pre-World War II high-yielding technology (1930–42)
HYM 2	RRIM 501, RRIM 513, PR 107, GL 1, PBIG/C, PBIG/D, PBIG/E, PBIG/F, PBIG/G, PBFB/A, PBFB/B, Ch IG/B, Ch IG/E, Tjir 1M, Tjir 1 illegitimate	Immediate post-war high-yielding technology (1945–59)
HYM 3	PB 5/51, GT 1, RRIM 600, RRIM 623, RRIM 605 PBIG/GG1, PBIG/GG2	Recent high-yielding technology (since 1960)

APPENDIX B

The number of tappable rubber trees within a productive field is an important capital input factor in the production process. The cultivation of rubber trees requires an initial high capital investment and careful nurturing during their immature phase. In other words, the initial and subsequent capital input costs are transferred into a stock of trees which produce rubber during the mature phase.

A mature rubber tree normally has an economically productive life span of about thirty years. *Figure B1* exhibits

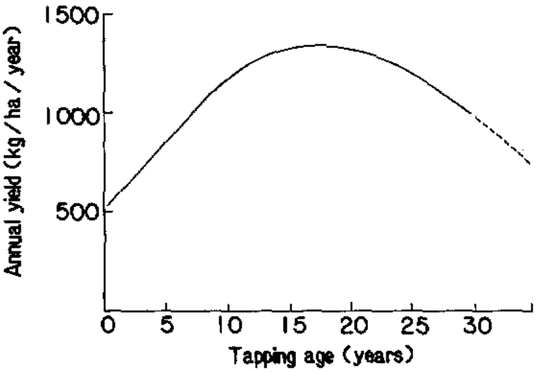

Figure B1. A hypothetical yield curve.

a typical yield profile of a hectare of trees. The yield curve normally shows a rapid rise during the first fifteen years of tapping which flattens out and subsequently declines during the last ten years or so of its productive life span. Thus, the effect of age on tree productivity must be accounted for when the number of tappable trees is used as a variable in the regression analysis.

The proposed measure of tree input in the present study is a flow variable representing the weighted measure of the number of tappable trees in the field. This incorporates weights to allow for the different ages of trees in different fields based on their yield performances. Age in the present context refers to the number of years a tree has been tapped or harvested. A tree index value for each age (years of tapping) based on the yield profile of the particular cultivar is derived as follows. First, a yield curve from the pooled 1964, 1970 and 1976 data sets is constructed for each cultivar. The productivity of the trees q_t, for each age, t, can then be derived from the computed yield curve. The tree index value, V_t, is then computed using the formula,

$$V_t = \frac{\sum_{t=1}^{30} q_t - \sum_{t=1}^{t} q_t}{30}$$

The total index value of tappable trees is then computed as

= number of tappable trees in a field X V_t.

APPENDIX C

ANALYSIS OF COVARIANCE

The analysis of covariance adopted in this study is based on the procedure outlined by Johnston[14] The method of this analysis is briefly summarised here.

Consider a simple model given by

$$y = X\beta + \mu \qquad \text{... C1}$$

where y is a $(n \times 1)$ column vector made up of p sub-vectors which are the sample observations on y for each of the p classes. X is the $(n \times k)$ matrix and β is the $(k \times 1)$ vector of coefficients, β contains a first column of ones to allow for a single intercept term for each class.

Consider another model incorporating dummy variables, which is given as

$$y = D\alpha + X\beta + \mu \qquad \text{... C2}$$

where y, X and β are defined as above and α is a $(p - 1)$ element column vecto., *i.e.* $\alpha = [\alpha_2, \alpha_3 \ldots \alpha_p]$ and D is a $[mp \times (p-1)]$ matrix of dummy variables.

Applying least-squares to *Equation C1*, the following result is obtained:

$$y = X\hat{\beta} + s \qquad \text{... C3}$$

where $\hat{\beta} = (X'X)^{-1}\ X'Y$ and s is the vector of least-squares residuals.

Partitioning *Equation C3*, the following is obtained,

$$y'y = \hat{\beta}'X'X\hat{\beta} + s's + 2\hat{\beta}'X's$$
$$y'y = \hat{\beta}'X'y + s's \qquad \text{... C4}$$

since $X's = X'y - X'X\hat{\beta} = 0$

and $\hat{\beta} = (X'X)^{-1}X'y$

Similarly for *Model C2*, application of least-squares gives

$$y = D\alpha + X\beta + e \qquad \text{... C5}$$

where $\begin{bmatrix} \hat{\alpha} \\ \hat{\alpha} \end{bmatrix} = \begin{bmatrix} D'D & D'X \\ X'D & X'X \end{bmatrix}^{-1} \begin{bmatrix} D'y \\ X'y \end{bmatrix}$

A similar partitioning to *Equation C4* gives

$$y'y = \hat{\alpha}D'y + \hat{\beta}'X'y + e'e \qquad \text{... C6}$$

In using the data matris *(D X)*, one allows only the intercept terms to vary but imposes a single set of slope coefficients on all classes. To allow both the intercepts and slope coefficients to vary, a separate regression should be run for each class. The least-squares regression of y_i on x_i may be written as

$$y_i = x_i b_i + r_i \qquad i = 1, \ldots, p \qquad \text{... C7}$$

where b_i is the estimated vector of k coefficient (both intercept and slopes) for i^{th} class and r_i is the vector of least-squares residuals.

Defining a block-diagonal matrix Z as

$$Z = \begin{bmatrix} X_1 & O & \ldots & O \\ O & X_2 & \ldots & O \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ O & O & & X_p \end{bmatrix}$$

the set of p regressions is written as

$$y = Zb + r \qquad \text{... C8}$$

where b is the $(pk \times 1)$ column vector consisting of b_i as sub-vectors and r is the $(mp \times 1)$ column vector with the r_i as sub-vectors. The residual sum of square from *Equation C8* is $r'r$.

The complete analysis of covariance is given in *Table C1*.

Test of differential intercepts between classes is ascertained by the F_1 value.

Test of differential slope vectors is ascertained by the F_2 value.

Test of overall homogeneity of different classes is ascertained by the F_3 value.

TABLE C1. ANALYSIS OF COVARIANCE

Source	Sum of squares	Degree of freedom	Mean squares	F – ratios
X (pooled sample)	$s's = y'y - \hat{\hat{\beta}}'X'y = S$	mp – k		
	$e'e = y'y - \hat{\hat{\alpha}}'D'y - \hat{\hat{\beta}}'X'y = S_2$	mp – p – k + 1	$S_2/(mp - p - k + 1)$	
X and D (dummy adjustment)	Differential intercepts			$F_1 = \dfrac{S_1/(p-1)}{S_2/(mp - p - k + 1)}$
	$s\,s - e'e = \hat{\hat{\alpha}}'D'y + \hat{\hat{\beta}}'X'y - \hat{\beta}'X'y = S_1$	p – 1	$S_1/(p-1)$	
	$r'r = y'y - b'Z'y = S_4$	p(m – k)	$S_4/p(m-k)$	
	Differential slope vectors			$F_2 = \dfrac{S_3/(pk - p - k + 1)}{S/p(m-k)}$
	$e'e - r'r = b'Z'y - \hat{\hat{\alpha}}'D'y - \hat{\hat{\beta}}'X'y = S_3$	pk – p – k + 1	$S_3/(pk - p - k + 1)$	
Z (overall)	$s\,s - r'r = b'Z'y - \hat{\beta}'X'y = S_5$	k(p – 1)	$S_5/k(p-1)$	$F_3 = \dfrac{S_5/k(p-1)}{S_4/p(m-k)}$