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Variation in Stimulation Response in Yield of a Hevea *Clone. II. A Regression Model*

C.S. CHOW and H. TAN

A regression model was used to study the short- and long-term variation in yield response of clone RRIM 605 to stimulation with ethephon (2-chloroethyl phosphonic acid) and 2,4,5-T (2,4,5-trichlorophenoxyacetic acid). The short-term fluctuation for a given tapping system was found to be the most significant source of variation in yield response to ethephon. Cycle and trend fluctuations resulted in negative responses even in early periods of stimulation. Negative correlation between yield response to stimulation and control yield was observed for most tapping systems. Tapping frequency was negatively correlated with random variation. Autocorrelation probably reflected the net effect of tapping system and stimulation in the short term.

A study on the short- and long-term variations in yield response to stimulation with ethephon and 2,4,5-T in clone RRIM 605 based on component variance analyses[1] showed that:

- Variation within stimulation periods (cyclical or short-term variation) constituted the major variation in stimulated yield.
- The magnitude of the short-term variation for ethephon stimulated yield (36% of total variance) was very much larger than that for 2,4,5-T stimulated yield (5% of total variance).
- Ethephon stimulated yield declined much more rapidly from the first to the subsequent cycles for each particular stimulation period than the 2,4,5-T stimulated yield.
- The variation in yield for different tapping cut lengths was reduced while the reverse was found for different tapping frequencies upon stimulation.

Based on these findings, was derived the favourable choice of shorter tapping cut length and appropriate tapping frequency and methods of stimulation (including type and concentration of stimulant, frequency, timing and perhaps method of application).

This paper presents another statistical approach – regression model, to examine the nature of the yield data used in the earlier paper[1]. The regression model describes the systematic variations from the stochastic variations as well as the environmental disturbances in yield response to stimulation.

STATISTICAL CONSIDERATIONS

The following regression model was considered. Let Y_{st} be the observed response (difference between stimulated and unstimulated yield) to stimulation in gramme per tree per tapping at the s^{th} cycle (four cycles in each stimulation period) of the t^{th} period (bi-monthly application of stimulant known as a period); where $s = 1, 2, 3, 4$; $t = 1, 2, 3 \ldots 24$. D_{st} is the dummy variable for cycle s, taking value 1 for the observation in cycle s and zero otherwise (e.g. $D_{1t} = 1, 0, 0, 0, 1, 0 \ldots\ldots$). If T'_{it} is the i^{th} order orthogonal polynomial function of t ($i = 1$ for linear, 2 for quadratic and 3 for cubic) and T'_{ist} is such that $T'_{ist} = T'_{it}$ for each s, then $T_{ist} = T'_{ist} \times D_{st}$ is the i^{th} order trend variable for the s^{th} cycle. Similarly, if C'_{st} is the trend-removed yield of control corresponding to the s^{th} cycle of the t^{th} period of stimu-

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lation (in stimulated trees), then $C_{st} = C'_{st} \times D_{st}$ are the control variables for the four cycles. The regression equation may be formulated as follows:

$$Y_{st} = a + \sum_{s=1}^{3} d_s D_{st} + \sum_{i=1}^{3} \sum_{s=1}^{4} b_{is} T_{ist} + \sum_{s=1}^{4} c_s C_{st} + u_{st} \qquad \ldots 1$$

where *a, b, c* and *d* are regression coefficients to be determined and u_{st}, the deviations from expected trend.

Model 1 may be regarded as being composed of four polynomial trend equations for each of the four cycles. For example, the trend for the first cycle (that immediately after each stimulation) is given by

$$Y_t = a + d_1 + b_{11} T_{11t} + b_{31} T_{31t}$$

The use of the (quadratic) trend-removed control variable accounts for response variations which are common to those of the control. When *Equation 1* was estimated by the ordinary least squares method, autocorrelation was found to be highly significant. This implies that high sampling error in the regression coefficients and biased standard errors invalidate the result of significance testing. Therefore, an autoregressive model was adopted.

To *Equation 1* is added the first-order autoregressive scheme,

$$u_{st} = r u_{st-1} + e_{st},$$

here e_{st} is assumed to be independent and normally distributed. By fitting $Y_{st} - ry_{st-1}$ on $D_{st} - rD_{st-1}$, *etc* (*i.e.* each variable is transformed using the estimated r and the lag variables by the least squares method), the autocorrelation in the residuals can be removed[2].

The regression coefficients of the parameters studied were estimated using the model described *(Tables 1* and *2)*. The cyclical and trend variations for individual tapping systems were depicted by computing expected values from the regressions using the trend and dummy variables but ignoring the control variables *(Figure 1)*. These expected values of yield response not only eliminated random and certain environmental variations but also excluded extreme responses that normally occurred in the first cycle of the early stimulation period. Since the independent variables were to a great extent uncorrelated, the sum of squares explained by variables in the regression model were estimated (approximately) by repeated fitting of the regressions with partial inclusion of variables.

RESULTS AND DISCUSSION

The major variations expected in the long and short term are shown in *Figure 1*. The cycle variation was in general most salient in the pattern of yield response especially with ethephon stimulation. The sum of squares accounted by cycle variation was about 55%–75% for the individual tapping systems in response to ethephon but only 4%–36% with 2,4,5-T stimulation *(Table 3)*. These may be compared with the lower percentages in terms of component variances obtained in the earlier analysis[1]. The differences are probably due to variations in cyclical patterns among the tapping systems and over stimulation periods. In general, there was a pronounced difference in yield stimulation response between the first and the fourth cycle[1] particularly in cases where maximum response was observed. The second cycle yield response to ethephon was usually less than half of the first cycle. In 2,4,5-T stimulation, the declining yield response from one cycle to another was generally more gradual *(Figure 1)*.

TABLE 1. REGRESSIONS FOR YIELD RESPONSE TO ETHEPHON STIMULATION

Tapping system	Partial regression coefficients											
	T_{11}	T_{12}	T_{13}	T_{14}	T_{21}	T_{22}	T_{23}	T_{24}	T_{31}	T_{32}	T_{33}	T_{34}
S/2.d/2 100%	−1.81c	−0.68c	−0.53b	−0.41a	−0.05a	−0.03n	−0.03n	−0.02n	0.01a	0.00n	−0.00n	−0.00n
S/2.d/3 67%	−2.06c	−1.01c	−0.71b	−0.51a	−0.06n	0.04n	0.03n	0.02n	0.01b	0.03n	−0.00n	−0.01n
S/2.d/4 50%	−1.93c	−1.89c	−1.07b	−0.80a	−0.09n	0.04n	0.06n	0.08n	0.01b	0.00n	−0.01n	−0.01n
S/R.d/2 150%	−1.45c	−0.34n	0.19n	−0.12n	0.03n	0.01n	0.01n	0.01n	−0.01b	−0.01n	−0.01n	−0.01n
S/R.d/3 100%	−2.00c	−1.11c	−0.61a	−0.46n	0.04n	0.05n	0.03n	0.04n	−0.01n	−0.00n	−0.01n	−0.01n
S/R.d/4 75%	−2.78c	−1.96c	−1.28c	−0.98c	0.10b	0.12c	0.11c	0.12c	−0.01b	−0.01n	−0.01b	−0.01b
S/1.d/2 200%	0.51b	0.72c	0.61c	0.45b	−0.11c	−0.09c	−0.08c	−0.06c	0.00n	0.00n	0.00n	0.00n
S/1.d/3 133%	−0.03n	0.70b	0.52a	0.50a	0.02n	0.04n	0.02n	0.04n	−0.01n	−0.00n	−0.00n	−0.00n
S/1.d/4 100%	0.10n	−0.09n	0.04n	−0.38n	−0.11c	−0.02n	−0.01n	0.03n	0.00n	0.00n	0.00n	−0.01n
S/2.d/2(2×2d/4) 100%	−0.32n	0.16n	−0.00n	−0.10n	0.02n	0.01n	0.00n	0.01n	−0.01b	−0.00n	−0.01a	−0.01a
S/2.d/3(2×3d/6) 67%	−1.22s	−0.72c	−0.60b	−0.61c	0.07b	0.08c	0.06b	0.06b	−0.01n	−0.00n	−0.01a	−0.01b
S/2.d/4(2×4d/8) 50%	−2.71c	−1.53c	−1.18c	−1.05c	0.06n	0.06n	0.07a	0.08a	0.00n	−0.00n	−0.00n	−0.01n
3S/8.d/2(2×2d/4) 75%	−1.75c	−0.74c	−0.54b	−0.47b	0.04a	0.07c	0.05b	0.05b	0.00n	−0.00n	−0.00n	−0.01n
3S/8.d/3(2×3d/6) 50%	−2.10c	−1.17c	−0.96c	0.77a	−0.01n	0.03n	0.04n	0.05a	0.00n	0.00n	−0.01n	−0.00n
3S/8.d/4(2×4d/8) 37.5%	−1.95c	−1.50c	−1.27c	−1.00b	0.01n	0.03n	0.04n	0.05n	0.00n	0.00n	−0.01n	−0.00n

TABLE 1. REGRESSIONS FOR YIELD RESPONSE TO ETHEPHON STIMULATION (CONTD.)

Tapping system	Partial regression coefficients							Intercept	Auto-correlation	R^2	Durbin-Watson statistic
	D_1	D_2	D_3	C_1	C_2	C_3	C_4				
S/2.d/2 100%	65.64c	21.00c	7.83b	−0.44n	−0.67n	−0.25n	−0.06n	− 2.86	0.43	0.93	1.99
S/2.d/3 67%	105.07c	37.82c	11.68b	0.46n	0.09n	−0.15n	−0.28n	3.94	0.37	0.92	1.91
S/2.d/4 50%	107.11c	50.42c	13.42a	0.63n	0.97a	0.19n	−0.10n	7.94	0.57	0.87	1.86
S/R.d/2 150%	74.74c	24.08c	8.00b	−0.34n	−0.51n	−0.27n	−0.25n	−11.22	0.37	0.90	1.96
S/R.d/3 100%	92.55c	36.42c	12.28c	0.00n	−0.17n	−0.24n	−0.34n	−14.40	0.44	0.90	1.91
S/R.d/4 75%	106.87c	45.28c	13.61c	0.27n	0.18n	−0.04n	−0.28n	− 5.94	0.37	0.93	1.93
S/1.d/2 200%	38.98c	12.61c	3.38n	−0.03n	−0.48a	−0.53a	−0.31n	− 0.02	0.54	0.90	2.10
S/1.d/3 133%	74.77c	26.70c	7.69a	−0.15n	−0.23n	−0.13n	−0.24n	− 6.92	0.50	0.89	2.02
S/1.d/4 100%	67.28c	27.59c	6.48b	−0.22n	−0.02n	−0.23n	−0.34a	0.50	0.62	0.92	1.94
S/2.d/2(2 × 2d/4) 100%	47.65c	17.67c	5.77b	−0.50c	−0.31n	−0.42a	−0.61c	−10.36	0.45	0.90	2.03
S/2.d/3(2 × 3d/6) 67%	71.94c	25.87c	9.74c	−0.64c	−0.44b	−0.44b	−0.47c	− 7.09	0.43	0.93	2.01
S/2.d/4(2 × 4d/8) 50%	87.27c	36.45c	11.24c	−0.15n	−0.12n	0.39b	−0.18n	− 2.39	0.62	0.93	1.88
3S/8.d/2(2 × 2d/4) 75%	69.39c	23.96c	8.24c	−0.33n	−0.26n	−0.16n	−0.31n	2.25	0.52	0.94	2.08
3S/8.d/3(2 × 3d/6) 50%	89.31c	32.03c	11.15c	−0.05n	−0.17n	−0.26n	−0.36a	− 0.53	0.41	0.94	1.92
3S/8.d/4(2 × 4d/8) 37.5%	92.02c	38.89c	12.80c	1.67c	1.25b	0.90a	0.62n	8.86	0.51	0.90	1.83

T_{ij} (trend variables) the i^{th} order orthogonal polynomial for the j^{th} cycle (i = 1 for linear, 2 for quadratic and 3 for cubic)
D_i = Dummy variables for cycle i
C_j = (Trend-removed) control variable for cycle j
n = Not significant at $P < 0.05$
a = $P < 0.05$
b = $P < 0.01$
c = $P < 0.001$
R^2 = Coefficient of multiple determination

TABLE 2. REGRESSIONS FOR YIELD RESPONSE TO 2,4,5-T STIMULATION

Tapping system	Partial regression coefficients											
	T_{11}	T_{12}	T_{13}	T_{14}	T_{21}	T_{22}	T_{23}	T_{24}	T_{31}	T_{32}	T_{33}	T_{34}
S/2.d/2 100%	−0.62c	−0.73c	−0.53c	−0.33a	−0.05a	−0.03n	−0.02n	−0.01n	0.01b	0.00n	0.00n	0.00n
S/2.d/3 67%	0.10n	−0.07n	−0.04n	−0.01n	−0.08b	0.04a	−0.02n	−0.03n	0.01a	0.00n	0.00n	−0.00n
S/2.d/4 50%	−0.27n	−0.29a	−0.25a	−0.14n	−0.02n	−0.01n	−0.01n	0.01n	0.01c	0.01n	0.00n	0.00n
S/R.d/2 150%	−1.02c	−0.70c	−0.47c	−0.37b	0.04a	0.04a	0.04a	0.05b	−0.00n	−0.01b	−0.01b	−0.01c
S/R.d/3 100%	−1.75c	−1.61c	−1.33c	−1.07c	−0.02n	0.03n	0.04n	0.05n	0.00n	0.00n	−0.01n	−0.01n
S/R.d/4 75%	−0.94c	−0.66c	−0.56b	−0.35n	−0.03n	−0.02n	0.00n	0.02n	0.00n	0.00n	0.00n	0.00n
S/1.d/2 200%	0.34b	0.48c	0.52c	0.43c	−0.05c	−0.03a	−0.03b	0.02n	0.01a	−0.00n	−0.00n	−0.00n
S/1.d/3 133%	0.70n	0.72a	0.86b	0.76a	0.00n	0.01n	0.01n	0.02n	0.00n	−0.00n	−0.00n	−0.01n
S/1.d/4 100%	−0.67b	−0.64b	−0.55a	−0.55b	0.04n	0.06a	0.06a	0.07b	0.01n	−0.00n	−0.00n	−0.01n
S/2.d/2(2×2d/4) 100%	−0.17n	−0.03n	0.08n	0.06n	−0.00n	0.01n	−0.01n	0.00n	−0.00n	−0.01a	−0.00n	−0.00n
S/2.d/3(2×3d/6) 67%	−1.04c	−1.05c	−0.78c	−0.74c	0.01n	0.00n	0.02n	0.02n	0.00n	0.00n	−0.00n	−0.00n
S/2.d/4(2×4d/8) 50%	−0.21n	0.05n	−0.02n	−0.01n	−0.09c	−0.07b	−0.05a	−0.05a	0.00n	0.00n	0.01n	0.00n
3S/8.d/2(2×2d/4) 75%	−0.19n	−0.20n	−0.10n	−0.02n	−0.02n	−0.01n	−0.00n	−0.00n	0.01a	0.00n	0.00n	0.00n
3S/8.d/3(2×3d/6) 50%	−0.62a	−0.42n	−0.39n	−0.21n	−0.05n	−0.02n	−0.03n	−0.01n	0.01c	0.01n	0.01a	0.06n
3S/8.d/4(2×4d/8) 37.5%	0.24n	−0.08n	−0.00n	−0.05n	−0.10c	−0.08c	−0.08c	−0.08c	0.01c	0.01a	0.00n	0.01n

TABLE 2. REGRESSIONS FOR YIELD RESPONSE TO 2,4,5-T STIMULATION (CONTD.)

Tapping system	Partial regression coefficients							*Intercept*	Auto-correlation	R^2	Durbin-*Watson* statistic
	D_1	D_2	D_3	C_1	C_2	C_3	C_4				
S/2.d/2 100%	17.74c	16.99c	7.70c	−0.24n	0.01n	0.07n	−0.23n	2.88	0.53	0.80	1.85
S/2.d/3 67%	20.40c	13.67c	6.54c	−0.03n	0.03n	−0.17n	−0.12n	2.00	0.61	0.71	1.89
S/2.d/4 50%	10.42c	9.81c	3.67b	−0.16n	−0.09n	−0.11n	−0.27a	− 1.75	0.59	0.71	1.71
S/R.d.2 150%	22.48c	13.92c	5.30b	−0.39a	−0.44a	−0.54b	−0.52a	10.73	0.42	0.82	1.63
S/R.d/3 100%	29.55c	20.73c	8.32c	0.00n	0.27n	0.01n	−0.05n	− 0.01	0.67	0.88	1.83
S/R.d/4 75%	23.29c	15.76c	5.69a	0.09n	−0.08n	−0.14n	−0.30a	− 1.75	0.50	0.70	1.76
S/1.d/2 200%	13.09c	9.65c	3.05b	0.06n	−0.32b	−0.29a	−0.15n	− 1.01	0.57	0.87	1.92
S/1.d/3 133%	18.87c	12.49c	4.25a	−0.27a	−0.33b	−0.43b	−0.53c	− 4.01	0.76	0.83	1.90
S/1.d/4 100%	19.86c	15.30c	8.53c	−0.11n	−0.05n	−0.16n	0.28a	− 1.12	0.63	0.76	2.01
S/2.d/2(2 × 2d/4) 100%	12.28c	7.96c	3.09a	−0.43c	0.61c	−0.41c	−0.53c	− 5.68	0.59	0.79	1.70
S/2.d/3(2 × 3d/6) 67%	18.95c	10.10c	3.24a	0.09n	0.02n	−0.12n	−0.11n	0.45	0.68	0.85	1.98
S/2.d/4(2 × 4d/8) 50%	10.01c	6.63c	2.11n	−0.10n	−0.17a	−0.25c	−0.22b	0.08	0.69	0.78	2.05
3S/8.d/2(2 × 2d/4) 75%	13.14c	8.10c	3.96b	−0.23a	−0.04n	−0.34a	−0.27a	2.69	0.62	0.73	1.77
3S/8.d.3(2 × 3d/6) 50%	17.93c	11.15c	3.19n	−0.01n	−0.11n	−0.21n	−0.25a	0.61	0.64	0.76	1.85
3S/8.d/4(2 × 4d/8) 37.5%	4.70a	2.22n	−0.30n	0.76c	0.49a	0.95c	1.07c	10.69	0.55	0.73	1.72

T_{ij} (trend variables) = the i^{th} order orthogonal polynomial for the j^{th} cycle (i = 1 for linear, 2 for quadratic and 3 for cubic)
D_i = Dummy variables for cycle i
C_j = (Trend-removed) control variable for cycle j
n = Not significant at $P<0.05$
a = $P<0.05$
b = $P<0.01$
c = $P<0.001$
R^2 = Coefficient of multiple determination

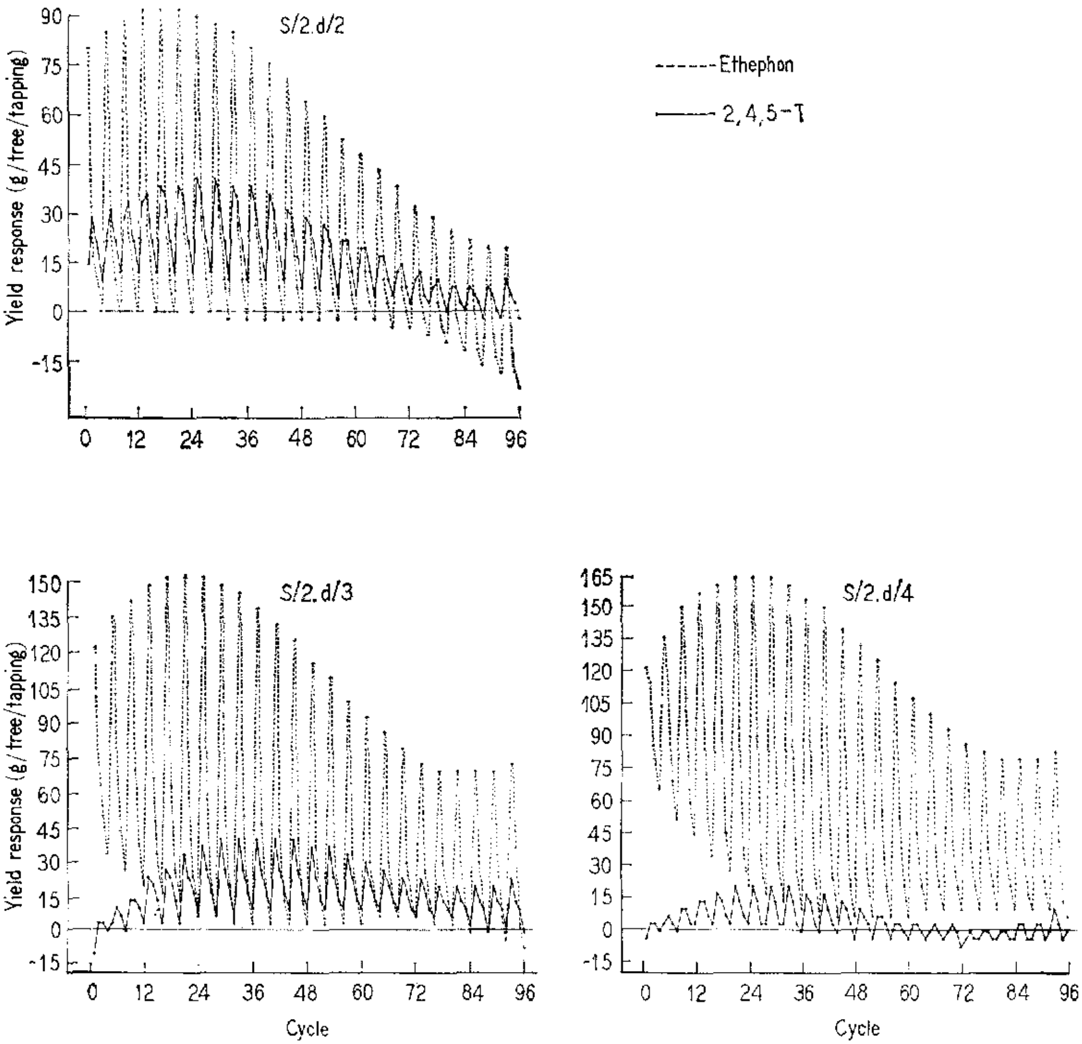

Figure 1. Expected trend for total yield response over individual cycles of different tapping systems.

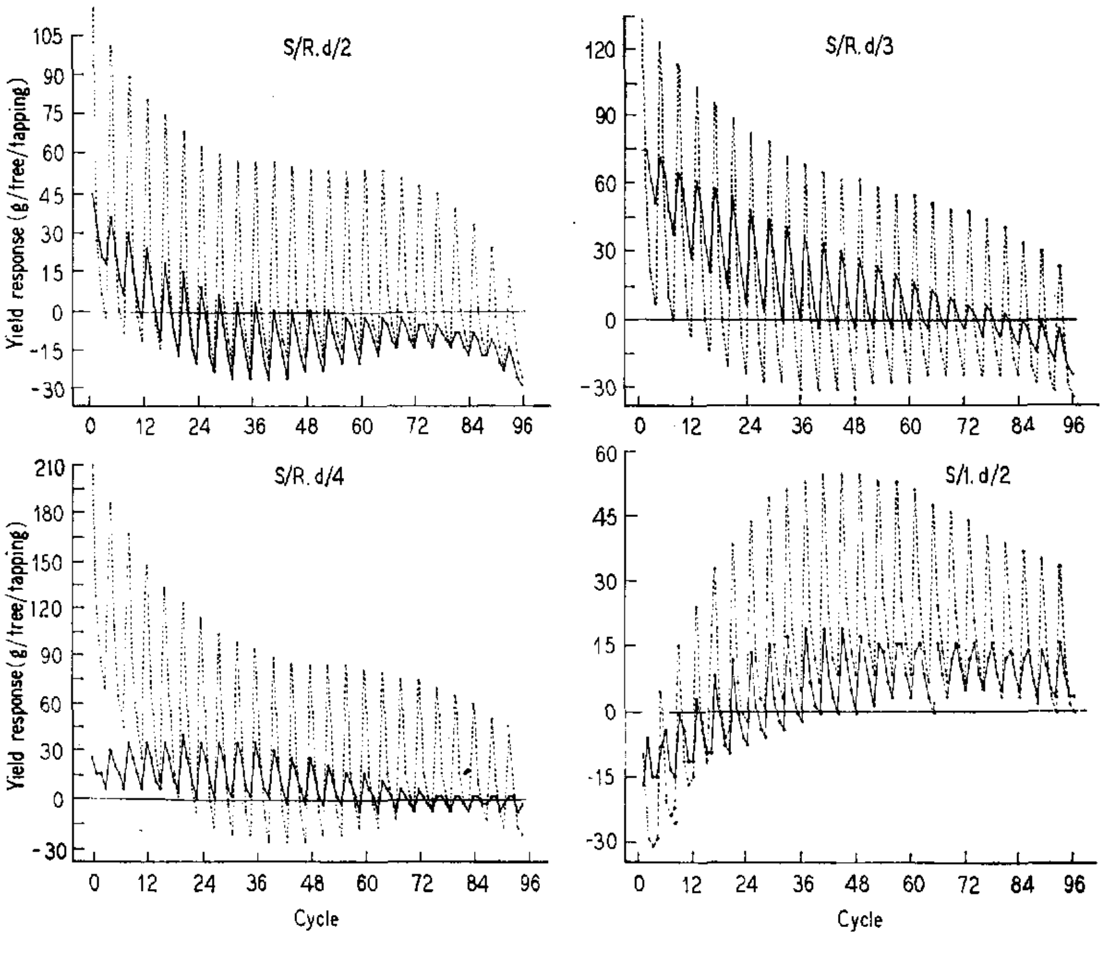

Figure 1. Expected trend for total yield response over individual cycles of different tapping systems (contd.).

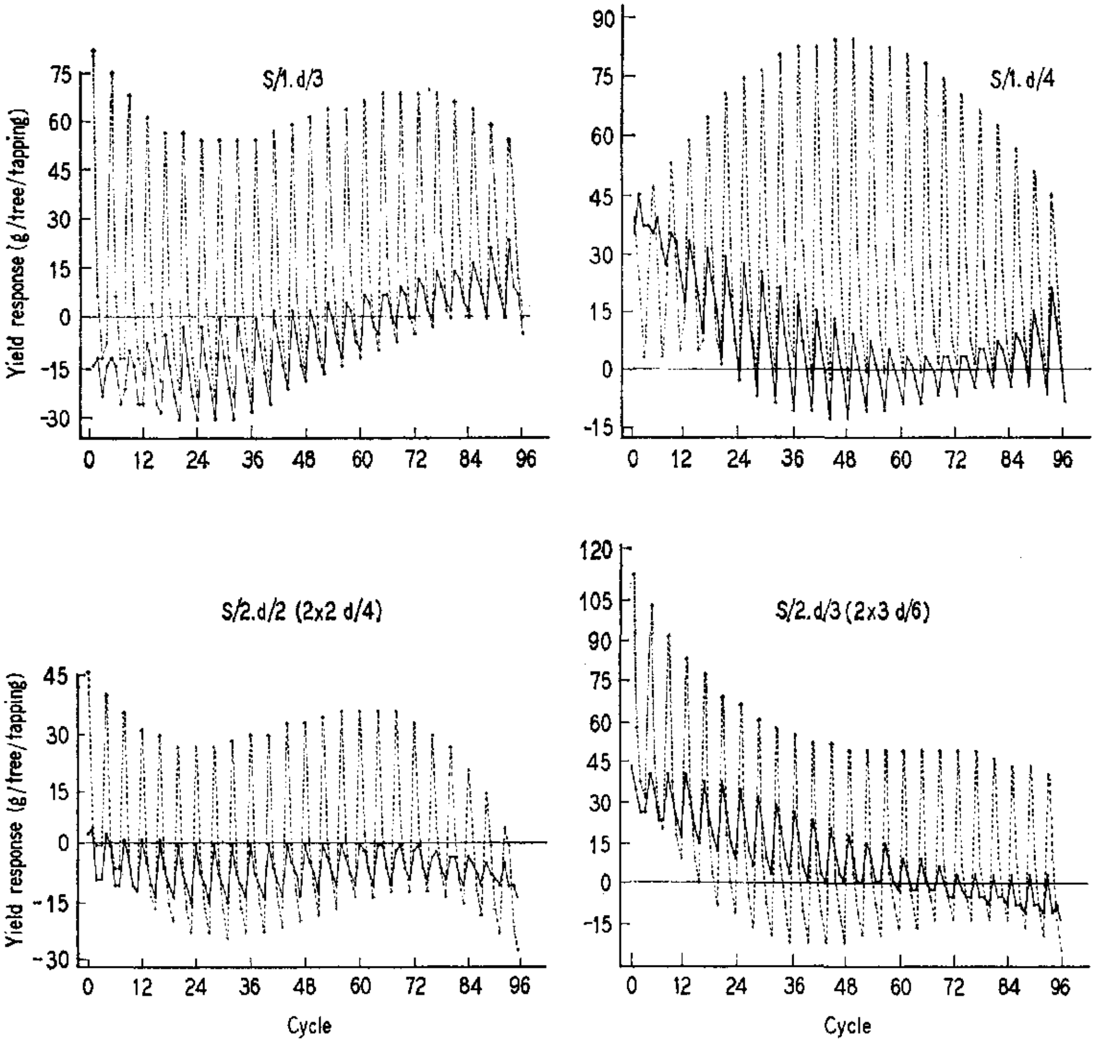

Figure 1. Expected trend for total yield response over individual cycles of different tapping systems.

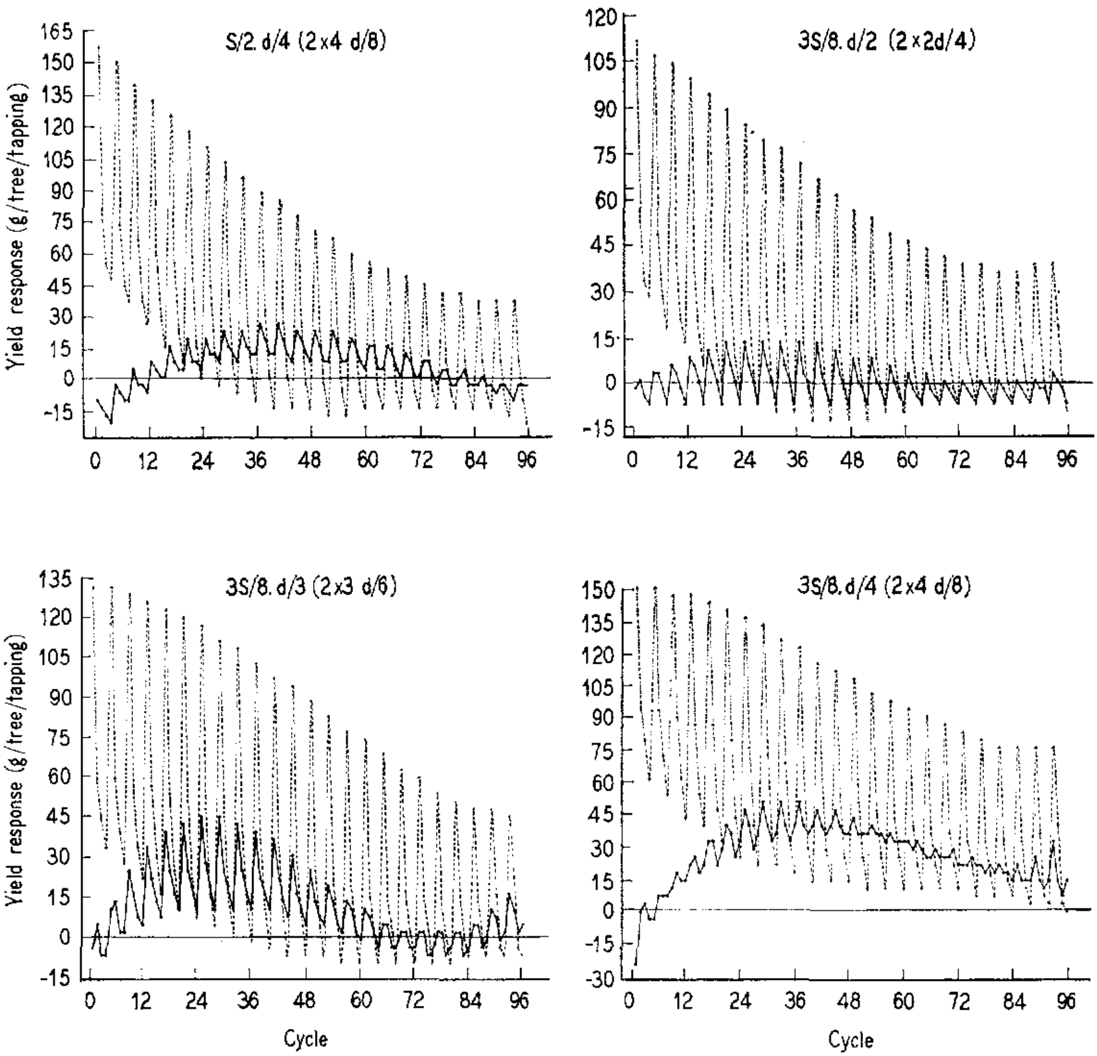

Figure 1. Expected trend for total yield response over individual cycles of different tapping systems (contd.).

TABLE 3. SUM OF SQUARES EXPLAINED BY VARIABLES IN REGRESSIONS FOR YIELD RESPONSE TO ETHEPHON AND 2,4,5-T STIMULATION

Tapping system	Trend		Cycle		Control		Auto-correlation		Error		Total SS
	SS	%	SS	%	SS	%	SS	%	SS	%	
Ethephon stimulation											
S/2.d/2 100%	22 627	23.7	64 172	67.1	342	0.4	1 610	1.7	6 893	7.2	95 645
S/2.d/3 67%	32 712	15.2	161 621	75.2	1 047	0.5	2 831	1.3	16 757	7.8	214 968
S/2.d/4 50%	60 290	21.3	164 300	58.0	7 258	2.6	14 402	5.1	36 816	13.0	283 066
S/R.d/2 150%	13 768	12.9	80 267	75.1	372	0.3	2 144	2.0	10 267	9.6	106 818
S/R.d/3 100%	32 901	19.2	117 677	68.5	141	0.1	4 365	2.5	16 690	9.7	171 773
S/R.d/4 75%	88 211	33.3	151 599	57.1	2 790	1.1	4 091	1.5	18 673	7.0	265 465
S/1.d/2 200%	6 858	13.9	26 961	54.8	2 211	4.5	8 283	16.8	4 930	10.0	49,243
S/1.d/3 133%	12 191	10.2	85 261	71.0	2 750	2.3	6 208	5.2	13 664	11.4	120 074
S/1.d/4 100%	5 977	5.7	75 785	72.4	4 857	4.6	9 450	9.0	8 567	8.2	104 635
S/2.d/2 (2 × 2d/4) 100%	8 880	14.7	37 078	61.4	5 298	8.8	3 207	5.3	5 959	9.9	60 421
S/2.d/3 (2 × 3d/6) 67%	24 857	21.7	75 897	66.2	3 914	3.4	1 965	1.7	7 942	6.9	114 576
S/2.d/4 (2 × 4d/8) 50%	62 190	31.6	108 772	55.3	2 878	1.5	9 138	4.6	13 883	7.1	196 861
3S/8.d/2 (2 × 2d/4) 75%	23 560	23.2	69 021	68.0	280	0.3	2 419	2.4	6 175	6.1	101 455
3S/8.d/3 (2 × 3d/6) 50%	33 884	21.0	115 653	71.6	658	0.4	2 053	1.3	9 369	5.8	161 616
3S/8.d/4 (2 × 4d/8) 37.5%	40 124	20.5	113 483	58.1	14 189	7.3	7 477	3.8	20 161	10.3	195 434
2,4,5-T stimulation											
S/2.d/2 100%	8 709	41.0	5 848	27.6	208	1.0	2 263	10.7	4 193	19.8	21 221
S/2.d/3 67%	2 438	13.3	6 616	36.0	208	1.1	3 801	20.7	5 330	29.0	18 393
S/2.d/4 50%	2 214	23.5	2 582	27.4	273	2.9	1 644	17.4	2 709	28.8	9 422
S/R.d/2 150%	13 515	49.2	6 796	24.7	1 037	3.8	1 223	4.4	4 919	17.9	27 490
S/R.d/3 100%	40 470	63.6	6 819	10.7	1 064	1.7	7 722	12.1	7 539	11.9	63 614
S/R.d/4 75%	8 186	25.8	8 733	27.5	976	3.1	4 408	13.9	9 432	29.7	31 735
S/1.d/2 200%	1 760	13.3	3 977	30.0	1 536	11.6	4 280	32.3	1 694	12.8	13 246
S/1.d/3 133%	8 597	23.1	6 053	16.2	3 885	10.4	12 240	32.9	6 482	17.4	37 258
S/1.d/4 100%	9 553	35.4	6 052	22.4	273	1.0	4 615	17.1	6 480	24.0	26 974
S/2.d/2 (2 × 2d/4) 100%	1 919	16.6	2 530	21.8	2 960	25.6	1 759	15.2	2 414	20.8	11 582
S/2.d/3 (2 × 3d/6) 67%	16 677	56.8	4 626	15.7	526	1.8	3 203	10.9	4 353	14.8	29 385
S/2.d/4 (2 × 4d/8) 50%	6 103	32.0	2 012	10.5	1 838	9.6	4 855	25.4	4 286	22.4	19 094
3S/8.d/2 (2 × 2d/4) 75%	1 167	13.9	2 821	33.5	371	4.4	1 812	21.5	2 251	26.7	8 422
3S/8.d/3 (2 × 3d/6) 50%	8 194	28.2	7 148	24.6	835	2.9	5 773	19.9	7 067	24.4	29 017
3S/8.d/4 (2 × 4d/8) 37.5%	8 517	35.5	904	3.8	2 527	10.5	5 510	23.0	6 523	27.2	23 981

SS = Sum of squares

For a given tapping cut studied, the trend patterns for different tapping frequencies appeared to be similar in most cases. However, the patterns differed considerably among the tapping cuts *(Figure 1)*. The significant curvilinear regression coefficients and the negative linear regression coefficients in most cases suggested a general downward trend of yield responses *(Tables 1* and *2)*. Total trend variation accounted for about 6%–33% of the total sum of squares in response to ethephon but 13%–64% in the case of 2,4,5-T stimulation *(Table 3)*. These percentages agree with those in terms of component variance[1]. Hence, trend (long-term) variation was higher than the cycle (short-term) variation in response to 2,4,5-T compared with ethephon stimulation.

As a result of the cycle and trend fluctuations, negative responses in yield were observed even in early periods of stimulation. It may therefore be useful to investigate the minimum number of stimulations which would give the first negative and last positive responses over the twenty-four stimulation periods for the various tapping systems and stimulants studied. *Figure 2* and *Table 4* summarise the results of the investigation. It was observed that 2,4,5-T stimulation generally resulted in more and earlier negative responses than ethephon stimulation. Six out of the fifteen tapping systems did not give negative response over the first twenty-four periods of stimulation with ethephon, but there was only one such tapping system [3S/8.d/4(2×4d/8)] in the case of 2,4,5-T stimulation. In terms of response per cycle, however, practically all the tapping systems with both the stimulants, except S/2.d/4 and 3S/8.d/4(2×4d/8) with ethephon stimulation, gave negative response at one time or another for the duration of the experiment *(Figure 1)*.

Table 3 shows that, in terms of the proportion of sum of squares, control variables explained more variation in yield response to 2,4,5-T stimulation than ethephon stimulation. This implies that response to 2,4,5-T was relatively more subject to variations due to systematic environmental factors (e.g. seasons) than response to ethephon stimulation though the reverse seemed to be the case in absolute terms.

The total numbers of significant negative and positive regression coefficients of the control variables in each cycle over the twenty-four stimulation periods under various tapping systems are summarised in *Table 5*. The total number of significant negative regression coefficient in ethephon stimulation was larger than that for 2,4,5-T stimulation. For ethephon stimulation the number of significant positive coefficients dropped from 3 in the first cycle to 0 in the fourth cycle whereas that of the significant negative coefficients changed from 5 in the first cycle to 4 in the fourth cycle. In the case of 2,4,5-T stimulation, the number of significant positive coefficients remained at 1 throughout the four cycles but that of the significant negative coefficients increased from 4 in the first cycle to 9 in the fourth cycle. The predominent negative coefficients of the trend-removed control variables seemed to imply that yield response was usually relatively less when yield of the unstimulated tree was high or *vice versa*. Of the fifteen tapping systems, only 3S/8.d/4 (2×4d/8) showed consistent significant positive coefficients over the four cycles with both stimulants. The cases with positive correlation between yield response and control variable seemed to suggest some positive effects of the short-term climatic factors on yield response in the particular tapping system but such positive effects diminished over the cycles within the ethephon stimulation periods *(Table 1)*. These results conform to field observations on stimulation trials.

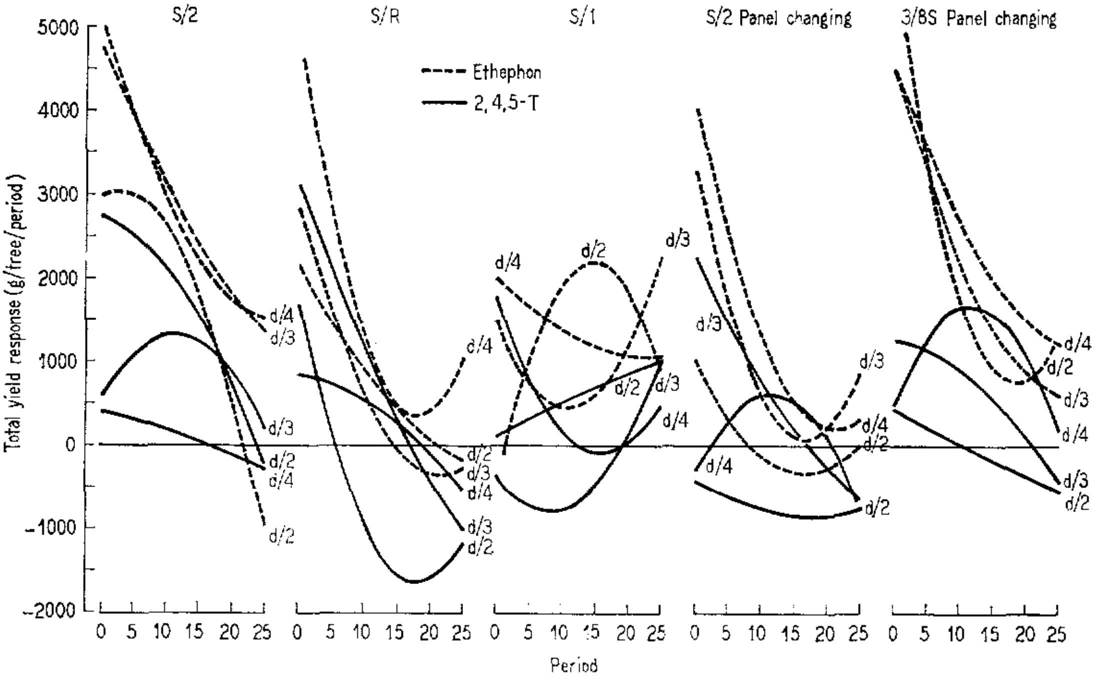

Figure 2. Total yield response for tapping systems over stimulation periods.

TABLE 4. OBSERVED AND EXPECTED NUMBERS OF STIMULATION AT FIRST NEGATIVE AND LAST POSITIVE RESPONSES OVER TWENTY-FOUR STIMULATION PERIODS

Tapping system	Ethephon				2,4,5-T			
	Observed		Expected		Observed		Expected	
	FN	LP	FN	LP	FN	LP	FN	LP
S/2.d/2 100%	20	22	22	21	21	24	24	23
S/2.d/3 67%	–	24	–	24	2	24	–	24
S/2.d/4 50%	–	24	–	24	5	24	17	16
S/R.d/2 150%	6	22	22	21	5	4	6	5
S/R.d/3 100%	7	22	12	20	12	18	18	17
S/R.d/4 75%	–	24	–	24	2	19	19	18
S/1.d/2 200%	2	24	–	24	2	24	–	24
S/1.d/3 133%	4	24	12	24	2	24	1	24
S/1.d/4 100%	–	24	–	24	8	24	13	24
S/2.d/2 (2×2d/4) 100%	2	23	5	21	2	3	1	0
S/2.d/3 (2×3d/6) 67%	9	23	12	24	15	19	18	17
S/2.d/4 (2×4d/8) 50%	17	24	–	24	3	19	1	20
3S/8.d/2 (2×2d/4) 75%	18	24	–	24	2	17	12	11
3S/8.d/3 (2×3d/6) 50%	–	24	–	24	13	24	22	21
3S/8.d/4 (2×4d/8) 37.5%	–	24	–	24	–	24	–	24

Expected values were estimated from the regression equation.
FN = First negative
LP = Last positive

TABLE 5. TOTAL NUMBERS OF NEGATIVE OR POSITIVE REGRESSION COEFFICIENTS OF CONTROL-VARIABLES FOR INDIVIDUAL CYCLES OVER TWENTY-FOUR STIMULATION PERIODS AND FIFTEEN DIFFERENT TAPPING SYSTEMS

Stimulant	Cycle 1				Cycle 2				Cycle 3				Cycle 4				All cycles			
	S		NS		S		NS		S		NS		S		NS		S		NS	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
Ethephon	3	5	2	4	2	5	2	6	1	5	2	7	0	4	1	10	6	19	8	27
2,4,5-T	1	4	2	8	1	5	4	5	1	7	2	5	1	9	0	5	4	25	8	23

NS = Not significant at P = 0.05
S = Significant at P = 0.05 − 0.001

Random variation measured in terms of residual (error) sum of squares accounted for about 6%–13% of the total sum of squares in the response to ethephon and 12%–30% in the case of 2,4,5-T stimulation *(Table 3)*. The magnitude of the random variation was therefore relatively small compared with the cycle variation with ethephon stimulation whereas they are comparable in the case of 2,4,5-T stimulation. The magnitude of the error sum of squares was negatively correlated with tapping frequency ($P < 0.001$ and 0.05 for ethephon and 2,4,5-T respectively). In fact, tapping frequency was also correlated with the total sum of squares ($P<0.01$) in yield response to ethephon but it was not significant in the case of 2,4,5-T stimulation. It therefore appears that d/4 tapping was associated with higher unexplained variation than d/3 tapping which also had higher random fluctuation than d/2 tapping in terms of yield response.

Auto-correlation or the correlation between successive observations after removal of systematic factors has accounted for about 1%–17% of the sum of squares in response to ethephon and 4%–33% in the case of 2,4,5-T stimulation. The proportion of auto-correlation sum of squares was positively correlated ($P<0.05$) with tapping intensity in ethephon stimulation, but not significant in 2,4,5-T stimulation. The significant correlation between auto-correlation sum of squares and tapping intensity in ethephon stimulation seemed to indicate that high tapping intensity had the effect of reducing the differences between successive responses. The non-significant correlation in the case of 2,4,5-T stimulation which in fact showed higher auto-correlation, appears to suggest the strong tendency of gradual decrease of yield response from one cycle to another. Since the environmental effects have been explained to certain extent by the control variables, the auto-correlation in yield response may in fact reflect the net effect of tapping system and stimulation effect in the short term. In the present context, significant auto-correlation could imply a more drastic decline in yield response than would be expected from the estimated regression model.

CONCLUSION

For the given tapping systems studied, the sum of squares attributable to short-term (cycle) fluctuation amounted to 55%–75% of the total sum of squares in yield response to ethephon. This constitutes the most significant source of variation in the data studied. The dramatic fluctuation among the cycles in ethephon response was usually found where the maximum responses were observed. Trend variation which accounted for 13%–64% of the total sum of squares was found to be the major source of variation in yield response to 2,4,5-T stimulation. The cycle and trend fluctuations resulted in negative responses even in early periods of stimulation especially in the case of 2,4,5-T stimulation.

The predominent negative regression coefficients of the trend-removed control variables suggest that yield response (difference between the stimulated and unstimulated yields) to stimulation was generally low when yield of the unstimulated (control) trees was high or *vice versa*. However, in one exceptional case involving a shorter cut length and reduced tapping frequency, positive regression coefficients of the trend-removed control variables were observed, suggesting some positive effects of the short-term climatic factors on yield response. These results agree with field observations on stimulation trials.

Random fluctuation in yield response to ethephon was relatively low compared with cycle variation. However, if these two sources of variations were combined, they absorbed about 60%–90% of the total sum of squares. In the case of 2,4,5-T stimulation, random variation was comparable to cycle variation. The higher tapping frequency tended to associate with a lower random error and *vice versa* in yield response to the stimulants.

Auto-correlation probably reflects the net effect of tapping system and stimulation effects in the short term. This net effect appears to vary with the stimulants used.

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