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Research Article

Contributions of weather variables for specific adaptation of rubber tree (*Hevea brasiliensis* Muell.- Arg) clones

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Abstract

The specific adaptation of 15 rubber tree (*Hevea brasiliensis*) clones was assessed by analyzing yield during a normal year (1997-98) and a year (1998-99) in which the yield was exceptional. Differences in yield in response to changes in weather conditions over the years were evident with clones RRII 203, RRIM 703, PB 5/51 and PB 235 which all exhibited a negative trend with increasing wind velocity during 1997-98, these clones also exhibited a negative correlation with minimum temperature during 1998-99. The prominent yield differences across the years made selection based on both yield and stability inevitable through computing weather variables and environmental index as covariant. To determine the contribution of variable(s) to genotype-environment (GE) interactions, the GE interaction was partitioned into heterogeneity and residual GE interaction. Heterogeneity only for environmental index was highly significant (p = 0.01), meaning that stability or instability of clones was due to a linear effect of the environmental index. The non-significant values of heterogeneity for the weather variables revealed that none of these factors individually was sufficient to explain heterogeneity. A QBASIC computer program called STABLE was used to select simultaneously for yield and stability. Clones PB 235, RRII 118, RRII 203, RRIM 703 and RRIM 600 were stable over the years investigated.

Key words: rubber clones, weather variables, specific adaptation, *Hevea*, stability, environmental index.

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Introduction

The importance of using selection procedures to assess the specific adaptation of plants to moderate or marginal conditions has been discussed by Ceccarelli (1994). Estimation of specific adaptation is normally based on genotype-environment (GE) interactions, although the partitioning of genotypic effects and phenotypic plasticity effects in response to changes in the environment is debatable (Vega, 1996). Although yield is the primary attribute evaluated in agricultural GE interaction studies, it is not solely under genetic control, being modulated by genotype-genotype (GG) and genotype-environment (GE) interactions as well as physiological and biochemical processes controlled by specific genes (Blum, 1988). In rubber tree (*Hevea brasiliensis*), these processes are even more complex because yield is based on latex production.

Tripura state in Northeast India (22-24° N, 91-92° E) is a non-traditional environment for rubber cultivation with sub-optimal conditions (Rao *et al*., 1993; Priyadarshan *et al*., 1998a; Priyadarshan, 2003), where *H. brasiliensis* clones have different yields compared with traditional rubber-growing areas because of specific adaptation (Priyadarshan *et al*., 1998b). According to Priyadarshan *et al*. (2000), two yield regimes are prevalent in Tripura state, low-yielding Regime I that occurs from May to September (sub-optimal environment) and high-yielding Regime II that occurs from October to January (optimal environment). This significant difference in yield is caused by the range of latitude and longitude covered by the state, which results in areas that are sub-optimal. It is possible to control the edaphic factors at will while the climatic attributes are uncontrollable but predictable. The responses of rubber trees to this type of environment can be assessed by measuring phenotypic attributes such as the girth of the tree and/or the yield of latex and analyzing resulting GE interactions. Such ontogenetic changes occur in response to changes in the seasons and weather that prevents important stages in the development of the plant coinciding with adverse environmental conditions (Roberts *et al*., 1993). In Tripura state, selecting rubber clones that have specific adaptation traits is vital since the exceptional climate of Tripura also offers low- and high-yielding environments (Priyadarshan *et al*., 1998b). Ceccarelli (1994), states that genotypes exhibiting high yield-potential in otherwise

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low-yielding environments should be preferred when selecting for specific adaptation.

Although GE interactions can be assessed by analyzing phenotypic stability, only very few papers have been published on how weather variables affect GE interactions in perennial crops. Devi *et al*. (1998) investigated the impact of weather variables on the rubber yield of a polyclonal rubber seedling population and concluded that both temperature and evaporation influenced yield. In another study, Priyadarshan *et al.* (2000) found that minimum temperature, evaporation and wind velocities were negatively correlated with dry rubber yield under the conditions found in Tripura state. They also found that the GE interactions that occurred were of the cross-over type. The major factors (covariants) that contribute to heterogeneity (non-additivity) in GE interactions can be determined using a BASIC program developed by Kang (1988). Kang (1993) developed a statistic called YS_i or yield-stability statistic to simultaneously select for yield and stability. Kang and Magari (1995) wrote a QBASIC program that allows the calculation of the YS_i statistic. The present study evaluated the impact of weather variables (minimum temperature, wind velocity, evaporation) on the yield of rubber in Tripura during a normal year (1997-98) and an exceptionally high-yielding year (1998-99) in relation to changed macro-environmental attributes.

Table 1 - Details of the clones investigated.

Country/clone	Parentage
Indian	
RRII 5	Primary
RRII 105	Tjir 1 x Gl 1
RRII 118	Mil 3/2 x Hil 28
RRII 203	PB 86 x Mil 3/2
Malaysian	
G l 1	Primary
PB 5/51	PB 56 x PB 24
PB 86	Primary
PB 235	PB 5/51 x PB S/ 78
RRIM 600	Tjir 1 x PB 86
RRIM 605	PB 49 x Tjir 1
RRIM 703	RRIM 600 x RRIM 500
Indonesian	
GT 1	Primary
Sri Lankan	
RRIC 52	Primary
RRIC 105	Tjir 1 x RRIC 52
Liberian	
Harbel 1	Primary

Material and Methods

The experiment was conducted at the Regional Research Farm of the Rubber Research Institute of India at Taranagar (Tripura State, North East India - 23°53' N; 91°15' E; 30 m above sea level (a.s.l.). For this research, yield data of dry rubber during a normal year (1997-98) and an exceptionally high-yielding year (1998-99) was used. Yielding period for rubber in Tripura is from May to January. The trial involved 15 clones from different geographic origins (Table 1), which had been planted during 1979 in a completely randomized design using a 5 x 5 m spacing between plants. Initially 40 trees per clone were planted that were multiplied by bud grafting. Latex was collected from each tree of each clone once a month, coagulated, squeezed through rollers to remove excess water, dried in a smoke house, weighed and mean dry rubber yield in grams per tree per tap (g tree^{-1} tap^{-1}) calculated. Data on three weather variables (minimum temperature, wind velocity and evaporation) were collected each day using standard meteorological methods (Rao *et al*., 1993).

Analysis of variance and other statistical calculations were done using standard procedures (Snedecor and Cochran, 1980). Genotype-environment (GE) interaction was partitioned into σ_i^2 components that were assigned to each genotype using Kang's BASIC program (Kang, 1988). The σ_i^2 is Shukla's stability variance statistic (Shukla, 1972). The program calculates stability variance (σ_i^2) prior to and after the use of a covariant (s_i^2) and analysis can be used to determine the major factor (covariant) that contributes to heterogeneity in the GE interactions. In this case, weather variables were used as covariants and an analysis was also made using environmental index (Xj – X.., where Xj is the mean yield of all clones in environment j and X.. is the mean of all clones across all environments) as a default covariant to remove heterogeneity (non-additivity or a linear effect of a covariant) from the GE interaction (Kang and Gorman, 1989). The program STABLE was used to simultaneously select for yield and stability (Kang, 1993; Kang and Magari, 1995), which is based on σ_i^2 of Shukla (1972).

Results and Discussion

This investigation was conducted not only to compare the yield of clones during a year (1997-98) when the yield was normal and a year (1998-99) when the yield was exceptionally high but also to gauge the stability of yield of the different clones. Since the edaphic factors (soil type, texture, drainage etc.) remained the same during the two years, it is probable that the exceptional yield during 1989-99 was due to a favorable macro-environment (*e.g.*, climatic conditions). An earlier study on the yielding trends of these clones established that minimum temperature, wind velocity and evaporation were the key attributes contributing to fluctuations in rubber yield in Tripura (Priyadarshan *et al.*, 2000). In any year, yields are lower during May to September (Regime I) and higher during October to January (Regime II), high yields being mainly due to the lower temperatures (23-26 °C) during the cooler winter months of October to January because lower temperatures stimulate prolonged latex flow, it having been established by Shuochang and Yagang (1990) that temperatures in the range of 18-24 °C are conducive to higher latex flow.

Effect of climatic variables on yield

The monthly mean values of minimum temperature, wind velocity and evaporation are given in Table 2. A variety of relationships was evident from the calculated correlations between yield and weather variables. For example, during 1997-98 none of the clones exhibited a correlation between yield and evaporation but almost all clones showed a significant negative correlation between yield and wind velocity (*i.e.*, the higher the wind velocity, the lower the yield), with clones RRII 203, RRIM 703, PB 5/51 and PB 235 giving highly significant correlations (Table 3). When we examined the 1998-99 data, RRII 105, RRII 118, RRIM 605, RRIC 52, RRIC 105 and Gl 1 exhibited significant negative correlations between yield and minimum temperature, *i.e.*, the lower the temperature the higher the yield. Although the relationship between yield and wind velocity was not as important as in 1997-98 (Table 4).

These differences in yield should be seen in the light of the effects that climatic variables have on the micro-environment, the lower yields during 1997-98 probably being caused by the higher minimum temperature and stronger winds that reduced atmospheric vapor pressure and hence the higher turgour pressure, being directly proportional to the osmotic pressure of the laticifers that control latex flow (Jacob *et al.*, 1998). On the other hand, lower wind velocities during 1998-99 assisted in enhancing yield.

Table 3 - Yield in grams per tree per tap (g tree^{-1} tap^{-1}) correlated to Minimum temperature, wind velocity evaporation during 1997-98.

	Correlation coefficients		
Clones	Minimum temperature	wind velocity	evaporation
RRII 5	-0.216	-0.875^{**}	-0.106
RRII 105	-0.645	-0.908^{**}	-0.449
RRII 118	$0.055^{\#}$	-0.767^{*}	-0.193
RRII203	-0.179	-0.938^{***}	-0.273
RRIM 600	-0.485	-0.913^{**}	-0.268
RRIM 605	-0.897^{**}	-0.804^{*}	-0.568
RRIM 703	-0.644	-0.945^{***}	-0.453
PB 5/51	-0.504	-0.975^{***}	-0.432
PB 86	-0.751^{*}	-0.868^{**}	-0.618
PB 235	-0.152	-0.945^{***}	-0.117
RRIC 52	-0.517	-0.888^{**}	-0.502
RRIC 105	-0.587	-0.899^{**}	-0.361
GT 1	-0.634	-0.900^{**}	-0.639
Gl 1	-0.903^{**}	-0.590	-0.700
HARBEL 1	-0.513	-0.898^{**}	-0.25

Significant at: *5%; **1%; 0.1%. # = high degree of independence.

Simultaneous selection for yield and stability

The differences in yield over months and seasons mean that it is important to select cultivars based on both yield and stability (Figure 1), in other words stability of yield should be taken into consideration as well as high yield. In our trials, the year 1998-99 was exceptional in regard to yield, such high yields not having been recorded during the preceding 10 years.

The weather variables and environmental index were used as covariants when analyzing the yield data to determine the variable that contributed to heterogeneity in the GE interactions. The heterogeneity caused by environmental index was highly significant (Tables 5 and 6), wind

Table 2 - Monthly mean values of weather attributes

Months	1997-98			1998-99		
	Min. temp. (°C)	Wind velocity (km/h)	Evaporation (mm)	Min. temp. (°C)	Wind velocity (km/h)	Evaporation (mm)
May	23.6	5.1	2.9	24.5	3.8	2.6
June	24.8	6.1	3.2	25.3	7.2	2.8
July	25.5	5.3	2.0	25.6	7.1	2.2
August	25.6	4.8	2.1	25.8	5.9	2.2
September	24.7	3.8	2.6	25.8	2.6	2.3
October	21.2	1.2	2.3	24.4	1.7	2.1
November	17.7	1.2	1.9	19.8	1.4	1.6
December	13.6	1.0	1.5	13.2	0.95	1.5
January	11.5	1.3	1.3	10.6	1.3	1.2

velocity and other climate variables causing only non-significant heterogeneity in GE interaction.

The yield stability statistic (YS_i) can be used to select clones that can adapt to normal and exceptional years (Tables 7 and 8). While eight clones (RRII 118, RRII 203, RRIM 600, RRIM 703, PB 235, RRIC 52 and RRIC 105) were stable during the normal-yielding year, only seven clones (RRII 105, RRII 118, RRII 203, RRIM 600, RRIM 703, PB 235 and GT 1) were stable during the exceptional-yielding year. When the cultivars were ranked in order of yield (highest-yielding clones first) the rank-order for 1998-99 was PB 235, RRII 203, RRIM 703, RRIM 600 and RRII 118, while the rank order (again starting with the highest-yielding clones) for 1997-98 was PB 235, RRII 203, RRII 118, RRIM 703 and RRIM 600, although these all gave lower yields than the highest-yielding clones for 1998-99. Calculation of yield-stability using the YS_i statis-

Table 4 - Yield in grams per tree per tap (g tree^{-1} tap^{-1}) correlated to Minimum temperature, wind velocity evaporation during 1998-99.

	Correlation coefficients		
Clones	Minimum temperature	wind velocity	evaporation
RRII 5	-0.412	-0.820**	-0.520
RRII 105	-0.839**	-0.696	-0.799*
RRII 118	-0.788*	-0.811*	-0.773*
RRII203	-0.029	-0.540	-0.290
RRIM 600	-0.671	-0.809*	-0.566
RRIM 605	-0.893**	-0.846**	-0.765*
RRIM 703	-0.558	-0.890**	-0.576
PB 5/51	-0.570	-0.833**	-0.527
PB 86	-0.567	-0.814*	-0.476
PB 235	-0.438	-0.683	-0.480
RRIC 52	-0.911**	-0.695	-0.889**
RRIC 105	-0.915**	-0.797*	-0.864**
GT 1	-0.672	-0.749*	-0.735*
Gl 1	-0.743*	-0.798*	-0.690
HARBEL 1	-0.669	-0.716*	-0.749*

Significant at: *5%; **1%; 0.1%.

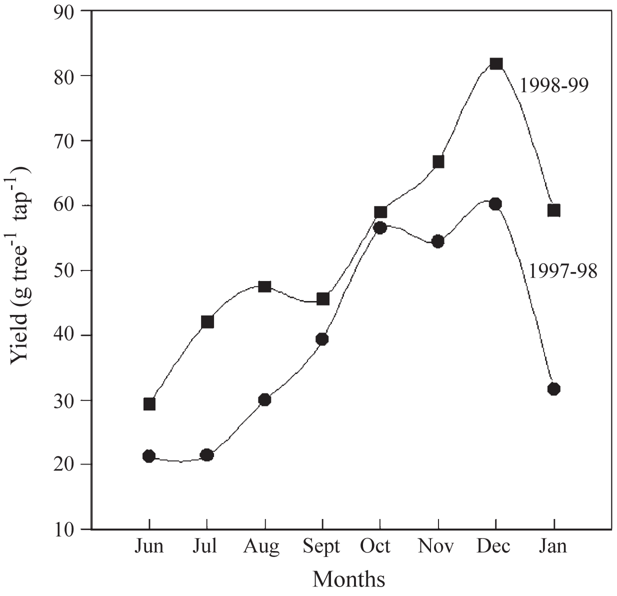

Figure 1 - Yield (environmental mean) over months during 1997-98 and 1998-99.

Table 5 - ANOVA showing heterogeneity removed from G *vs.* E interaction via each listed 1997-98 environmental covariant using Kang's program (1988).

Source	Degrees of freedom (df)	Environmental index	Minimum temperature	Wind velocity	Evaporation
G x E	98	1572.1**	1572.1**	1572.1**	1572.1**
Heterogeneity	14	4126.2**	228.9	883.6	110.6
Residual GxE	84	1146.4**	1795.9**	1686.8**	1815.7**
Pooled error	2128	324.1	324.1	324.1	324.1

** Significant at p = 0.01.

Table 6 - ANOVA showing heterogeneity removed from G *vs.* E interaction via each listed 1998-99 environmental covariant using Kang's program (1988).

Source	Degrees of freedom (df)	Environmental index	Minimum temperature	Wind velocity	Evaporation
G x E	98	1397.4**	1397.4**	1397.4**	1397.4**
Heterogeneity	14	2839.8**	264.8	700.4	141.6
Residual GxE	84	1157.0**	1586.1**	1513.5**	1606.8**
Pooled error	2128	360.7	360.7	360.7	360.7

** Significant at p = 0.01.

Table 7 - Simultaneous selection for yield and stability during 1997-98 using Kang and Magari's STABLE program (1995).

Clone	Yield	Yield rank	Adjustment to rank	Adjusted rank	Stability Y	Stability variance	YS (i)$^{\blacklozenge}$ rating $^{\#}$
RRII 5	33.0	4	-2	2	1090.9	-8	-6
RRII 105	38.4	10	-1	9	2078.6	-8	1
RRII 118	58.1	13	3	16	3545.0	-8	8+
RRII 203	60.5	14	3	17	2073.8	-8	9+
RRIM 600	42.7	11	2	13	667.5	-4	9+
RRIM 605	33.4	6	-2	4	1517.6	-8	-4
RRIM 703	47.6	12	3	15	2863.1	-8	7+
PB 5/51	30.4	3	-3	0	290.3	0	0
PB 86	34.5	7	-2	5	687.4	-4	1
PB 235	63.1	15	3	18	3267.8	-8	10+
RRIC 52	35.8	8	-2	6	566.6	0	6+
RRIC 105	37.9	9	-1	8	490.1	0	8+
GT 1	33.4	5	-2	3	639.8	0	3+
Gl 1	15.7	1	-3	-2	2898.3	-8	-10
HARBEL 1	25.0	2	-3	-1	904.2	-8	-9
Mean	39.3						2.2

LSD (p = 0.05)+ = 3.3. Key: + = selected genotype; $^{\#}$ -4, -8 σ^2_i at p = 0.05 or 0.1; 0 = non-significant; ♦ selected genotypes must have a value more than the mean YS*i* value.

Table 8 - Simultaneous selection for yield and stability during 1998-99 using Kang and Magari's STABLE program (1995).

Clone	Yield	Yield rank	Adjustment to rank	Adjusted rank	Stability Y	Stability variance	YS (i)$^{\blacklozenge}$ rating $^{\#}$
RRII 5	51.2	7	-1	6	1185.3	-8	-2
RRII 105	55.8	10	1	11	2335.0	-8	3+
RRII 118	57.1	11	1	12	274.2	0	12+
RRII 203	80.1	14	3	17	3838.4	-8	9+
RRIM 600	64.2	12	3	15	1220.2	-8	7+
RRIM 605	42.6	3	-3	0	2069.5	-8	-8
RRIM 703	64.3	13	3	16	1225.7	-8	8+
PB 5/51	42.6	4	-3	1	526.9	0	1
PB 86	51.9	8	-1	7	1179.9	-8	-1
PB 235	81.3	15	3	18	1773.9	-8	10+
RRIC 52	48.8	6	-2	4	1245.6	-8	-4
RRIC 105	48.5	5	-2	3	1115.0	-8	-5
GT 1	52.0	9	-1	8	603.2	0	8+
Gl 1	27.0	1	-3	-2	1734.0	-8	-10
HARBEL 1	38.1	2	-3	-1	633.9	0	-1
Mean	53.7						1.8

LSD (p = 0.05) = 3.4. Key: + = selected genotype; $^{\#}$ -4, -8 σ^2_i at p = 0.05 or 0.1; 0 = non-significant ; ♦ selected genotypes must have a value more than the mean YS*i* value.

tic showed that clones PB 235, RRII 118, RRII 203, RRIM 703 and RRIM 600 were stable in yield during both the years (these cultivars can therefore be considered as showing adaptation under specific environments) while the same statistic showed that clones RRII 118 needed an exceptional climate to produce a high yield.

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