GENETIC DIVERGENCE, PREPOTENCY AND INBREEDING DEPRESSION IN PARA RUBBER

(*Hevea brasiliensis* Muell. Arg.)

By

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THESIS

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D E C L A R A T I O N

I hereby declare that this thesis entitled "Genetic divergence, prepotency and inbreeding depression in para rubber (Hevea brasiliensis Muell. Arg.)" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar titles of any other University or Society.

Vellayani,

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CERTIFICATE

Certified that this thesis entitled "Genetic divergence, prepotency and inbreeding depression in para rubber (*Hevea brasiliensis* Muell. Arg.)" is a record of research work done independently by Smt. KAVITHA K. MYDIN under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

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INTRODUCTION

INTRODUCTION

Rubber (*Hevea brasiliensis* Muell. Arg.) in India is grown over an area of 4.5 lakh ha with 3.1 lakh ha under tapping and an annual production of 3.3 lakh metric tonnes. The mean yield at the national level is 1076 kg ha^{-1} (Anon., 1991a). The theoretical maximum yield estimated is to the tune of 9,500 kg ha^{-1} (Templeton, 1969). The reasons for this dismal gap between the potential and the realised yields are many, the insufficiency of environment specific planting material being one among them. The perennial nature of the crop, the long juvenile period, the heterozygous nature of clones and the large area required for a statistical layout of breeding experiments are mainly responsible for the slow progress in *Hevea* breeding work. In spite of these limitations, considerable progress has been achieved and improved clones have already played a major role in bringing about a ten-fold increase in rubber yields. From a meagre 300 kg ha^{-1} for unselected seedlings, rubber yields could be raised to the level of about 3000 kg ha^{-1} in experimental plantings within a span of 70 years. Rubber breeding in South East Asia has been described as one of the outstanding success stories of plant breeding and has been shown to be so in formal economic terms (Pee and Khoo, 1976). But in recent years, significant yield increases have not been possible and productivity has remained more or less stagnant.

Since rubber is grown under diverse agro-climatic and soil conditions, the genetic plasticity conferring adaptation deserves more attention. Besides wide scale planting in the traditional tracts of Kerala and Kanyakumari district in Tamil Nadu, rubber cultivation in India is being extended to new environments like the non-traditional zones of Karnataka, Maharashtra, Orissa, West Bengal and the North Eastern States which are exposed to a wide range of biotic and abiotic stresses. In such circumstances, heterogeneity in the planting material is likely to give greater stability of population performance. Socio-economic considerations of such marginal areas also demand the generation of planting material which can be handled with ease and require a lower level of managerial expertise.

Hybridization and clonal selection is the most important method of Hevea breeding in India. Though clones predominate, synthetic seedling populations produced from polycrosses of clonal parents have long been planted on a substantial scale. Such polycrosses are effected in polyclonal seed gardens. As self pollination cannot be prevented in rubber, inbreeding is minimised by interplanting several parents in a polycross seed garden with the objective of producing a more or less random array of hybrids between good parents (Simmonds, 1979).

Polycross seed material obtained from specially designed polyclonal seed gardens have the significance that they are composed of a wide array of gene combinations derived from superior selected clones. The heterogeneity in such seed lots guarantees stability under adverse environments. As compared to monoclonal stands, seedling populations face less risk of a wipe out in the event of stress calamities. Polyclonal seeds can therefore be used for raising plantations in non-conventional areas of rubber cultivation. These seedling stands can later yield superior ortets which could be identified and cloned.

High yield, disease tolerance, good seed bearing capacity and synchrony in flowering are some pre-requisites to be considered while selecting clonal components of a polyclonal seed garden. Genetic divergence, prepotency/general combining ability and inbreeding depression are the three important genetic parameters which determine the suitability of clones for use as components of a polyclonal seed garden.

The existing polyclonal seed gardens have been planted with selected clones, some of which are becoming obsolete. Moreover, the gardens were constructed using phenotypically superior clones rather than proven genetically superior ones. Realising the need for newer seed gardens and the potential uses to which superior seed material could be put, the present study was undertaken to:

* evaluate a set of clones for genetic variability for yield and other economic characters,
* estimate biometric parameters like heritability and genetic advance,
* determine the association of yield with major yield components through correlation and path analysis,
* estimate genetic divergence among selected clones,
* assess prepotency of promising clones through seedling progeny analysis and
* estimate inbreeding depression of the clones assessed for prepotency.

The final objective of the study is to identify a set of clones as components of a polyclonal seed garden based on superiority in phenotype combined with high genetic divergence, prepotency and inbreeding depression so that superior heterogenous seedling stands could be generated.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Numerous reports on studies pertaining to the components of variance and associations among economic traits of rubber are available, but reports relating to genetic divergence, prepotency and inbreeding depression are few and scattered. The present review attempts to examine pertinent research reports on these topics in other tree crops with a similar breeding system in relation to the situation in rubber.

2.1. Components of variance

The choice of a suitable breeding method for improvement of yield and its components in any crop largely depends on the genetic variability, associations between characters, heritability and value of expected genetic advance under selection. In the case of quantitatively inherited characters which are controlled by a large number of minor genes with cumulative but small individual effects it becomes impossible to assess the contribution of each and every gene to the total variance. Genetic variation so essential for response to selection, is however, not directly accessible for measurement. Only the external expression of genetic values as modified by the environment is measurable as phenotypic values. The variability available in a population could be partitioned into heritable and non-heritable components with the aid of genetic parameters such as genotypic coefficient of variation (G.C.V.), phenotypic coefficient of variation (P.C.V.), heritability (H^2) and genetic advance (G.A.) which serve as a basis for selection.

Selection acts on genetic differences and the gains from selection for a specific character depend largely on the heritability of the character (Allard, 1960). The degree to which the variability for a quantitative character is transmitted to the progeny is called 'heritability'. Heritability can be defined as that proportion of total variation in a progeny which is the result of genetic factors and may be transmitted.

The determination of heritability is one of the first objectives in the genetic study of a metric character since it enters into almost all the important formulae connected with breeding methods and many practical decisions about procedure depend on its magnitude. It acts as an index of transmissibility of characters from one generation to the next and gives a measure of the value of selection for different attributes.

The term 'heritability' was first introduced and defined by Fisher (1918) as the ratio of the fixable genetic variance to the total genetic variance. Lush (1937) defined heritability in the 'broad sense' as the proportion of total genotypic variance to the total or phenotypic variance and in the 'narrow sense' as the ratio of the additive genetic variance to the total variance. Robinson et al.

(1949) defined it as "the additive genetic variance in per cent of the total variance".

Hanson et al. (1956) proposed the mathematical relationship of various estimates on computation of heritability. It is estimated either as a variance ratio or as an offspring-on-parent regression. The latter is more precise. The variance ratio may take two forms viz. narrow sense heritability which is the additive genetic variance divided by phenotypic variance (V_A/V_P) and broad sense heritability which is the total genetic variance divided by the phenotypic variance (V_G/V_P). Heritability is favoured by a high genetic variance and low environmental variance (V_E).

Coefficient of variation is used to compare the relative variables where different metric traits are measured in different units. Dividing the standard deviation of the trait by mean renders the coefficient of variation independent of the unit of measurement.

Lush (1937) and Johnson et al. (1955) devised an accurate and easily manageable procedure for the calculation of the genetic advance under a specified intensity of selection, which in metric traits largely depends on the heritability, phenotypic variability of the trait under selection and the selection differential expressed as phenotypic standard deviation. Genetic advance is favoured by a high genetic variability and high heritability of the trait selected for.

A review of reports pertaining to genetic variation in rubber, coconut and arecanut is presented.

2.1.1. Rubber

Gilbert *et al*. (1973) was the first to report on the application of biometrical analysis to rubber progeny data. They concluded that inheritance of yield and girth are additive and so phenotypic selection and family prediction would be effective.

Nga and Subramaniam (1974) reported high genetic variance for yield and girth. Heritability estimates for mean yield over five years and over fifteen years were 56 per cent and 47.8 per cent respectively and for girth at opening and after five years of tapping were 47.2 per cent and 55.9 per cent respectively.

Tan *et al*. (1975) examined a large number of progenies of diverse origin for inheritance of yield, girth, girth increment and thickness of virgin and renewed bark. Unlike the previous methods, male and female variance components were estimated and then expressed in terms of heritabilities based on the male (h^2_M), female (h^2_F) and male plus female (h^2_{M+F}) variance components. Results showed that h^2_F were generally higher than h^2_M for most of the characters studied. They suggested the existence of dominance variance also in rubber. Earlier reports (Simmonds, 1969; Gilbert *et al*., 1973; Nga and Subramaniam, 1974) have indicated more of additive gene effects.

Tan (1979) reported on heritabilities of biometrical characters viz. mean yield over five years (0.29-0.47), virgin bark thickness (0.17-0.46) and renewed bark thickness (0.27-0.28). Liang et al. (1980) obtained a heritability estimate of 0.42 for yield in seedling progenies involving eight cross combinations while Liu et al. (1980) obtained a low broad sense heritability for yield. Alika (1982) also obtained a heritability estimate of only 0.21 for yield over four years. Alika and Onokpise (1982) estimated heritability for yield, girth and bark thickness in rubber from a single pair mating design. The annual heritability estimates for dry rubber yield were 0.23, 0.24, 0.16 and 0.02 for the first to fourth years of tapping respectively. A heritability estimate of 0.30 was obtained for bark thickness while genotypic variation for girth was negligible.

Markose (1984) obtained high phenotypic and genotypic coefficients of variation for yield of dry rubber, volume of latex and number of latex vessel rows. Dry rubber content showed comparatively low genotypic coefficient of variation. Broad sense heritability was high for dry rubber yield (0.82), volume of latex (0.77), number of latex vessel rows (0.93) and virgin bark thickness (0.75).

Genetic variance, heritability and genetic gain from selection with respect to rubber yield and morphological characters were studied by Alika (1985). Heritability was reported to be highest for stem form and moderately low for yield. Application of a 10 per cent intensity of selection resulted in a genetic gain of 10.87 per cent over the mean.

Variability and associations of certain bark anatomical traits in Hevea were studied by Premakumari et al. (1987). Comparatively high phenotypic coefficient of variation for all the anatomical traits signified the involvement of environment in the expression of the traits. Broad sense heritability was very high for all the traits except for ray width for which it was medium. High heritability and low genetic advance for most of the traits indicated predominant involvement of non-additive gene effects in the expression of these traits.

The striking feature, according to Simmonds (1989), is that heritabilities of economic characters in rubber are generally very high and therefore progeny performances are more or less predictable. This is probably a reflection of the youth of the crop which is still at an early stage of selection and genetic variance is still largely additive.

2.1.2. Coconut

Heritability estimates worked out for different yield groups of coconut have indicated that the estimates were high for number of female flowers, yield of nuts and percentage set of nuts (Nambiar and Nambiar, 1970). Studies on the pattern of genetic variation for reproductive characters and its impact on yield potential have shown that selection of genotypes with low variance of distribution of female flowers and more number of spikes with one female flower tend to reduce instability in production and increase productivity (Nambiar et al., 1970; Nambiar and Ravindran, 1974). Louis (1981) studied the phenotypic and genotypic variability in 25 varieties and hybrids and found number of leaves produced per year, number of leaves on the crown, number of spathes per year, number of female flowers per palm, setting percentage and number of nuts to have high genetic advance and recommended consideration of these characters for exercising selection.

2.1.3. Arecanut

Bavappa and Ramachander (1967a) observed that heritability for yield in arecanut is very low (0.20) and hence practically no improvement in yield could be achieved by direct selection for this character. The age at first bearing, the percentage of inflorescences to leaves shed and number of inflorescences produced showed high heritability. Percentage of nuts set had relatively low heritability. Bhagavan et al. (1981) also reported low heritability values for the number of nuts and weight of nuts.

2.2. Associations between yield and its components

Plant breeding programmes by and large are based on an understanding of correlations between yield and various yield determining factors. An ideal situation would be direct selection for yield itself, but this is not readily feasible particularly in a perennial crop. Selection is hence practised on several simple characters which explicitly show correlated responses with yield. Hence the study of correlations is a preliminary requirement in a breeding programme.

The idea of correlation of variables was first conceived by Galton (1889). Fisher (1918, 1954) developed the method of applying the theory of correlation of variables in understanding their influence in biological systems. Burton (1952) introduced a convenient procedure for the calculation of the phenotypic and genotypic coefficients of correlation.

The association between two characters is a part of a complicated pathway in which other traits are also interwoven. Wright (1921, 1934) introduced the path coefficient analysis. The theory of causation and effect is made applicable in this method. The ultimate dependant variable is referred to as the 'effect', and the components which by themselves may or may not be dependant on other variables as the 'causes'. Path coefficients are standardised partial regression coefficients (Dewey and Lu, 1959). Path analysis measures the direct influence of one variable upon another and permits the separation of the correlation coefficient into components of the direct and indirect effects of causal factors on the effect. This is applied only when we have a linearly related closed system of variables, which could predominantly be assumed to be responsible for the expression of the final end product. Durate and Adams (1972) emphasised the identification and the classification of the components (causes) to different orders (first, second, third etc.) and the importance of the formulation of the causal scheme in path analysis studies. The implications and significance of this technique have been stressed by Bhatt (1973). The technique of path analysis has since been extensively used by different workers in a large number of crop plants.

2.2.1. Correlations

2.2.1.1. Rubber

Rubber yield in *Hevea brasiliensis* is a manifestation of various morphological, anatomical, physiological and biochemical characters of the tree (Pollinere, 1966). These factors are ultimately manifested in the volume of latex obtained on tapping and the quantum of rubber it contains.

Morphological components of yield

Girth is considered as the most important parameter of growth vigour in rubber. Yield and vigour in the crop are hardly separable (Simmonds, 1989). Early opening and good early yield are only possible in a tree which grows very vigorously when young. The normal growth pattern of a free growing Hevea tree follows an S' curve (Vollema and Dijkman, 1939). The increase in girth during the first three years is relatively small but is greatly accelerated once the tree branches and the crown takes shape (Dijkman, 1951; Anon., 1973a). The trees are brought under tapping when they attain sufficient girth. On opening for tapping, photosynthate is partitioned between two competing sinks: latex offtake and tree growth. Accordingly, growth rate tends to decline under tapping and the breeder's task is to maximise latex yield in a tree which is still growing vigorously enough to sustain an upward yield trend for many years (Wycherley, 1975, 1976). Ramaer (1929) indicated that growth vigour is genetically controlled and Ferwerda (1940) and De Jong (1941) confirmed this. There is marked clonal variation with regard to girth increment under tapping.

The innumerable correlations worked out among various economic traits of rubber have contributed to the present understanding that vigour and yield are related to each other. Correlation for both attributes among successive growth stages and between yield and girth are generally positive though widely variable in actual magnitude (Lee and Tan, 1979; Liang et al., 1980). On the contrary, Wycherley (1969) reported that in the first year of tapping, girth and yield among clones are positively correlated but as exploitation advances this correlation disappears and may even become negative. Napitapulu (1973) found a positive correlation between yield and girth within clones but not between clones. This could be due to the varying response of different clones to tapping. Latex yield in adult trees of Hevea is consistently correlated with bark thickness and girth increment (Narayanan et al., 1974). Yield and girth increment under tapping tend to be negatively correlated (Ho, 1976). Positive correlations of rubber yield with girth, number of latex vessels and bark thickness have been reported by Dijkman and Ostendorf (1929), Gilbert et al. (1973), Liu et al. (1980) and Hamzah and Gomez (1982). Fernando and de Silva (1971) reported a positive correlation between latex content and growth in rubber. Nazeer et al. (1986) reported that high yield tends to be associated with low girth increment under tapping.

Physiological and biochemical components of yield

Latex is a hydrosol and rubber occurs as dispersed, discrete particles (Bonner and Galston, 1947). Besides rubber, latex contains various substances like carbohydrates, proteins, resins, inorganic salts etc. (Archer et al., 1963; Archer and Audley, 1967; Archer, 1980). Latex is the cytoplasm of the cells constituting the latex vessels, which in Hevea brasiliensis are of the articulated, anastomosing and coenocytic type (Bobilioff, 1923; Milanez, 1946;

Andrews and Dickenson, 1960; Panikkar, 1974). While latex synthesis occurs within the laticifers as long as they are active, its free movement within them is not normal. The flow of latex starts only after injuring the bark and thereby opening the latex vessels. During the process of tapping, thin shavings of the bark are removed simultaneously opening the latex vessels (Ridley, 1897). As a result the latex contained in the laticifers exudes, which in turn is collected and processed. Field latex usually contains 30 to 45 per cent rubber (Sethuraj and Usha Nair, 1980).

There is an inherent clotting mechanism within the latex vessels which is responsible for the cessation of latex flow (Southorn, 1966). This process of flocculation of latex particles causing the plugging of latex vessels is brought about by the rupture of lutoid particles in the latex (Southorn and Edwin, 1968; Southorn and Yip, 1968). Milford et al. (1969) proposed an index - the plugging index - for measuring the extent of plugging. The initial rate of flow of latex gives an indication of the velocity of flow. A higher initial rate of flow per se can result in a lower plugging index (Sethuraj et al., 1974) presumably because the rubber flocs that are formed inside the latex vessels are swept out with the surge of high flow rate (Chua, 1965; Pakianathan et al., 1966). The initial flow rate and plugging index are therefore two important physiological components determining latex yield (Sethuraj, 1977).

There are several steps in the biochemical pathway that leads to the formation of polyisoprene (natural rubber). The whole synthesis requires three essential components: Acetyl CoA as the building block, NADP as the reducing factor and ATP as the energy source, all three of which are generated by carbohydrate metabolism. Therefore in situ carbohydrate metabolism in Hevea is an important factor in rubber biosynthesis (Tata, 1980). Nucleic acids and proteins also play an important role in rubber synthesis (Tupy, 1969). Biochemical mechanisms are also involved in latex vessel plugging, of which the activity of the enzyme acid phosphatase is important (Pujarniscle et al., 1970). Low (1978) noted a positive correlation between total cyclitols in C-serum and plugging index and suggested that the higher osmotic pressure associated with higher cyclitol concentration could lead to a faster and greater dilution on tapping and hence to increased lutoid damage and faster plugging. Rubber particles are strongly protected by a complex film of protein and lipid material. Subramaniam (1976) and Sherief and Sethuraj (1978) found a negative correlation between plugging index of clones and neutral lipid content in the rubber phase. These findings suggest that in addition to the effect of lutoid behaviour, plugging is influenced by the degree to which rubber particles are 'protected' by lipids. The flocculation of rubber particles is also influenced by inorganic cations like Na^{+}, K^{+}, Mg^{++} and Ca^{++}. Yield is also determined by the rate of rubber biosynthesis. The balance between latex withdrawal and rubber regeneration is reflected in the dry rubber content of the latex (Paardekooper, 1989).

Yield in rubber has been found to be positively correlated to the initial flow rate (Paardekooper and Samosorn, .1969) and negatively correlated to plugging index (Milford et al., 1969) and dry rubber content (Grantham, 1925; Heusser and Holder, 1931). Saraswathyamma and Sethuraj (1975) explained seasonal variation in yield to be related to clonal variation in the plugging index during different seasons. A low plugging index and high initial flow rate contributed to high yield. The volume of latex, as reported by Sethuraj (1977) is dependant on the rate and duration of flow. Lee and Tan (1979) found a close association between daily latex volume and yield of rubber.

Anatomical components of yield

Structural components also play a major role in determining rubber yield. Latex from which the commercial product, natural rubber is obtained, is synthesised by and contained in the latex vessels which occur in almost all parts of the tree except the pith and wood (Bobilioff, 1918, 1923; Aggelen-Bot, 1948; Schweizer, 1949). Under plantation practices latex is obtained by tapping the bark of the trunk. The bark is delimited from the wood by the layer of cambium which, by repeated divisions, adds up new tissues towards the wood and bark. The mature bark has an outermost corky zone (the periderm), an innermost soft zone and an intermediate hard zone. The intermediate hard zone comprises groups of stone cells in addition to latex vessels and other secondary phloic tissues. Towards the outer portion of this hard zone, the latex vessels, sieve tubes etc. become discontinuous due to senescence. The innermost soft bark contains most of the functional tissues of the secondary phloem like the sieve tubes, companion cells, phloic rays, latex vessels etc. Latex vessels are more concentrated in the bark near the cambium (Bobilioff, 1923; Dijkman, 1951; De Jong and Warrier, 1965). The latex vessels are produced in discrete rows and appear as concentric rings in cross section. The vessels belonging to the same ring are tangentially interconnected. The laticifers are generally oriented in an anticlockwise direction, the angle of inclination varying from three to five degrees to the vertical.

Correlation studies have established the positive association of bark thickness and the number of latex vessel rows with yield of clones (Gomez et al., 1973; Ho et al., 1973; Narayanan et al., 1974). A positive correlation between initial rate of latex flow and the number of latex vessel rows has also been reported (Sethuraj et al., 1974).

Sethuraj (1981), through a theoretical analysis of yield components of Hevea brasiliensis represented the effect of the major yield components by the formula $y = \frac{F.l.Cr}{p}$ where, y = rubber yield; F = initial flow rate per unit length of tapping cut; l = length of the tapping cut; C_r = percentage rubber content, and p = plugging index. These relationships indicate that the yield of rubber from a tree per tap is proportional to the initial flow rate, the length of the tapping cut and the rubber content of the latex and inversely proportional to the plugging index. All the internal and external factors influencing yield must exert their effects through one of the above components. This is supported by the various experimental evidences cited.

2.2.1.2. Coconut

Patel (1937) noted that in coconut palm, characters like girth and number of leaves were positively and significantly correlated with yield. Pankajakshan and George (1961) observed that girth at collar is positively correlated with height and number of leaves in coconut. Height of the palm and number of functioning leaves were positively correlated with yield in the West Coast Tall variety (Satyabalan et al., 1972).

Correlations between yield and its components have been utilized to draw valuable inferences on exercising selection in coconut. Studies on West Coast Tall palms comprising low, medium and high yielders showed a high positive correlation between the total yield of copra and yield of nut and copra content per nut in all the yield groups.

The relationship was linear and high even when the above three groups were combined. The copra content per nut was not related to the yield of nuts (Anon., 1975). In West Coast Tall, the mean yield of nuts was significantly and positively correlated with annual out turn of both copra and oil, whereas with mean copra content per nut, the correlation was significant and negative. The oil percentage in copra was not significantly related to the yield of nuts. Studies on the relationship between yield of nuts, copra content per nut, total yield of copra and yield of oil per palm in West Coast Tall showed that the mean copra content per nut although negatively correlated with yield did not affect the annual out turn of copra per palm. A similar relationship was found to exist for yield of nuts and annual out turn of oil also indicating the necessity for exercising selection pressure towards weight of copra per nut and oil percentage in addition to the number of nuts (Bavappa and Sukumaran, 1976).

2.2.1.3. Arecanut

In arecanut, age at first bearing has a high negative correlation with yield (Bavappa and Ramachander, 1967b). The percentage of inflorescences to leaves shed and the number of inflorescences produced have only a low genotypic correlation with yield. Percentage of nuts set has a high positive correlation with yield. Eventhough the mean weight of nut was found to be negatively correlated with yield, in the absence of a threshold value, the total weight of nuts produced increased with the number of nuts and this negative correlation did not set a limit to the possible yield improvement (Anon., 1969).

2.2.1.4. Other crops

Reports on other tree species indicate the importance of vegetative vigour in determining yield potential.

Nayar et al. (1981) studied the relationship of height, girth and spread with yield in cashew and found these three traits to be positively correlated with yield. They established that plant vigour has got a profound influence on yield and each growth parameter was found to contribute independently and jointly in enhancing yield.

Teaotia et al. (1970) calculated the relationship between yield and vigour expressed as trunk diameter, tree spread and height in Dashehari mango. They reported that tree spread was positively correlated with fruit yield.

In apple, Warning (1920) obtained a close correlation between trunk circumference and yield of fruits in several varieties. Sudds and Anthoney (1929) also reported that girth of trunk was directly correlated with yield of apples.

2.2.2. Path analysis

Yield, a complex character is dependant on a number of components as evidenced by the correlation estimates discussed. The direct and indirect effects of each of the components on yield are, however, not revealed by correlation studies. Path analysis provides information on such causal factors. Cause and effect studies in perennial crops are meagre.

The cause and effect relationship of important traits with rubber yield was studied by Markose (1984) from data on twenty clones. Volume yield had the highest positive direct effect on dry rubber yield. The number of latex vessel rows showed a very low positive effect on dry rubber yield even though the correlation was very high. The significant positive correlation of yield with the number of latex vessel rows and virgin bark thickness was suggested to be manifested through volume of latex.

Path coefficient analysis for yield and yield attributes in coconut (Sukumaran et al., 1981) showed that the major contributing characters which influenced yield directly or indirectly were average number of female flowers, number of functioning leaves at the age of nineteen years and internodal distance at a fixed mark. These characters were found to influence yield indicating their value in selection.

2.3. Genetic divergence

The extent of genetic distance among populations is referred to as genetic divergence. In any breeding programme inclusion of genetically diverse parents is essential in order to create new reservoirs of genetic variability which in turn would help in recombining genes from diverse sources. Information about genetic divergence is helpful in crop improvement programmes since divergent parents, on crossing, are known to produce hybrids with high heterosis.

The importance of genetic diversity in plant breeding programmes has been emphasised by several workers (Hayes and Johnson, 1939; Hayes et al., 1955). Many statistical procedures have been developed to measure divergence between populations. Among them multivariate analysis has proved to be a potent tool (Sokal, 1965). Multivariate analysis permits the simultaneous statistical treatment of several characters.

2.3.1. D^2 statistic

The concept of a measure of divergence between populations was first introduced and further developed on the theoretical side by Mahalanobis (1925). A measure of group distance based on multiple characters was given by Mahalanobis (1928). Mahalanobis (1936) suggested the generalized distance which has become the standard measure of distance between two populations when all the observed characters are quantitative. The approximate generalizations of the D^2 statistic in the case of more than two populations and suitable statistic to test the equality of means of each character for a given number of populations were given by Fisher (1939). Mahalanobis' D^2 is intimately related to the linear discriminant function (Fisher, 1936) being in fact the distance between population means along the axis of the discriminant function. This permits significance tests to be performed on the distances. Everitt (1980) summarised many methods for clustering objects into groups. Arunachalam (1981) made an exposition of the theoretical concepts behind the genetic distance.

The D^2 statistic has been used extensively in classificatory problems in tree species. Hughes (1959) used this technique in the study of oak scrubs occurring in two different kinds of soil. Nair and Mukherjee (1960) used it in the classification of natural and plantation teaks (*Tectona grandis*) grown in different regions.

Employing the D^2 statistic, Bavappa and Mathew (1982) estimated the genetic distances between thirteen cultivars of *Areca catechu* and four ecotypes of *Areca triandra* using 24 characters recorded in the productive phase for two years. They found that the pooled data for both these years were more or less consistent. The cultivars could be grouped into six clusters in both the years and into five for the pooled data. A comparison of the groupings obtained during the two different years showed that the widely divergent clusters remained distinct in both the years whereas in the case of the less divergent groups there was slight deviation in the clustering pattern. They concluded that detection of genetic divergence is possible in the early years of the productive phase, but estimation of genetic divergence in the juvenile phase in arecanut may not give the correct picture. The results obtained from canonical analysis were also in broad agreement with the clustering pattern from D^2 analysis. The clustering pattern revealed that geographic diversity need not always be related to genetic diversity in arecanut.

Markose (1984), from a study on twenty clones of Para rubber, concluded that girth of trees, girth increment, dry rubber yield, dry rubber content, bark thickness, number of latex vessel rows and volume yield of latex contribute to genetic divergence. Maximum divergence was shown by girth, followed by branching height, girth increment, dry rubber yield and dry rubber content. The least divergence was with respect to volume of latex per tree per tap. The 20 clones studied were grouped into eight clusters based on intra and inter cluster distances. The intra cluster D values ranged from 0 to 2.71 and inter cluster D values ranged from 3.82 to 25.10. Clones of Indian, Malaysian, Indonesian, Liberian and Brazilian origin came under the same cluster showing no association between geographical diversity and genetic diversity.

D^2 analysis using data from twenty four cultivars of coconut (Balakrishnan and Namboodiri, 1987) also showed no association between geographical diversity and genetic diversity. The cultivars were grouped into six clusters based on their genetic distances. Cultivars of the same place of origin were found to fall into different clusters. The study showed that multivariate analysis could help to detect the diverse lines in genetically heterogeneous but phenotypically similar populations like coconut and choose the divergent parents for specific crosses to exploit hybrid vigour. Characters like the number of female flowers in an inflorescence, contributed maximum towards total divergence whereas the weight of husked nut, weight of unhusked nut, thickness of meat and girth of the stem at 1 m from ground level contributed minimum to total divergence.

D^2 analysis has also been effectively employed for identification of traits contributing to genetic divergence and grouping of cultivars in vegetatively propagated crops like banana (Valsalakumari et al., 1985; Mercy and George, 1987, 1988) and sugarcane (Punia et al., 1983; Santhi, 1989).

2.3.2. Factor analysis

Factor analysis is another multivariate analysis used to explain the dependence structure of a set of variables in terms of certain common factors and principal component analysis is the most common method employed for extracting the factors of divergence. The method of factor analysis is widely used as an exploratory tool to reduce the dimensionality of multivariate data. Factor analysis can explain the causative factors responsible for inter and intra specific differentiation. The method is potent enough to distinguish the forces of natural and human selection causing divergence in a particular species.

The theory of factor analysis begins from Spearman's two factors theory, which assumes that the inter relationships of all the variables involved could be accounted for by a single underlying general factor and group the factors which are common to some of the variables but not to all of them. In addition to this, a third type factor which is peculiar to single variables alone called specific factors was also differentiated (Spearman, 1940). Bart (1952) has given a full account of tests of significance in factor analysis developed upto that time. The computation schemes of various factor analysis methods were provided by Fruchter (1954). Factor analysis is also useful in determining the number and nature of causative influences responsible for the inter correlation of variables in any population (Lawley and Maxwell, 1963). A general description of the concepts, theories and techniques of factor analysis was given by Harman (1967). Mc Donald (1970) made a theoretical comparison among the three factor score construction methods namely principal factor analysis, canonical factor analysis and alpha factor analysis.

Joreskog (1971) has given estimation procedures for factor models involving several populations.

Santhi (1989) applied factor analysis to data on various morphological and quality traits in forty eight varieties of sugarcane to identify the factors of divergence. The quality factor was identified as the main factor of divergence in sugarcane. The characters found to be more amenable to changes due to selection were pol at 12th month, C.C.S. percentage and brix at 12th month in the quality factor and cane yield per plot and shoot count in the second factor which was found to be the same in all the three clusters studied.

Hevea brasiliensis grows wild in the tropical rain forests south of the Amazon river in Brazil. In an attempt to widen the genetic base of Hevea, a major internationally supported collecting expedition was undertaken in Brazil in 1981 (Ong *et al.*, 1983). The expedition was concentrated on three chosen areas of the Amazon basin: the states of Acre, Mato Grosso and Rondonia. The collection comprised about 65,000 seeds and 1500 m of budwood from 194 selected trees thought to be potentially high yielders. Following the introduction of this new germplasm collection into the various rubber growing countries, studies to determine genetic diversity in the material through electrophoretic analysis have been attempted.

Isozyme markers were employed to study the extent of genetic diversity in Hevea germplasm through principal component analysis (Anon., 1986) and factor analysis (Chevallier, 1988). Considerable genetic diversity was observed within the new germplasm as well as among the clones of Wickham origin. Genetic distances and factor analysis showed a wide differentiation between material from Acre and Mato Grosso, with that from Rondonia falling between the two. Diversity was less within Acre and Mato Grosso and more within Rondonia. Isozyme studies have further demonstrated that the Wickham material possesses sufficient genetic diversity which can be maintained by further crossing (Chevallier, 1987). Seven enzymatic systems allowed seventy two patterns to be distinguished among the clones studied. Heterozygosity was found to be high in the Wickham clones and in certain loci it exceeded that of the new Brazilian germplasm. Legnate and Demange (1990) also established from one dimensional electrophoresis studies based on the allele frequencies for eight to ten enzyme systems that clones of Wickham origin have sufficiently high genetic diversity.

These reports reveal scope for identifying divergent clones among the germplasm generated from the original Wickham collection. Since the Wickham clones are already domesticated and of proven performance in the countries where they were evolved, the study of genetic divergence among the locally adapted clones holds promise for the identification of potential parents for further improvement programmes.

2.4. Prepotency

Charles Darwin (1859) was the first to use the word 'prepotent' which he explained as follows: "When two species are crossed, one has sometimes a prepotent power of impressing its likeness on the hybrid and so I believe it to be with varieties of plants".

According to Harland (1957) a prepotent palm is one where the gene combinations tend to 'cohere' but do not recombine resulting in the 'enbloc' transmission of parental characters to the progeny even under random mating leading to some sort of functional homozygosity. Just as the progeny of a single female parent may be superior whatever the nature of the male parent, the reverse situation also holds good, that is, the pollen of female transmitters could be used to cross with other superior female parents. He has compared the situation in coconut with other open pollinated crops like cocoa and showed that open pollinated plants differed in their capacity to transmit the higher yielding ability to their progenies. He has suggested that prepotent high yielders could be identified from a comparative study of sufficiently large number of progenies from open pollinated mothers. The concept of prepotency used by animal breeders was extended to coconut where each palm represents a gene complex.

Clausen and Hiesey (1960) elaborated on the balance between coherence and variation in evolution. It is the device of coherence that enables ecological races to function as reservoirs of potential variability. Coherence is therefore as much a part of evolution as is variation.

Allard (1960) defined prepotency as the capacity of a parent to impress characteristics on its offspring so that they resemble that parent and each other more closely than usual. Differences in prepotency depend on homozygosity, dominance, epistasis and linkage.

Ninan and Pankajakshan (1961) expressed the view that palms with genetic superiority are of two types, the first having a favourable combination of genes in the heterozygous condition or hybrid phase and the second, which are sufficiently possessed of dominant genes to ensure that their progeny are also high yielding. Those high yielders which continue to maintain sufficiently high progeny values irrespective of the type of the pollinating male are no doubt inherently superior and may be regarded as having sufficient load of dominant yield factors to be called prepotents. On the basis of seedling performance it is possible to isolate high yielders which yield superior progeny from those yielding inferior progeny. They found that some high yielders showed markedly superior progeny performance than others in the nursery.

Charles (1961) also recommended progeny testing as the most reliable method of detecting prepotent palms.

Liyanage (1972) described prepotent palms as those able to transmit the high yielding character to their progeny in spite of having been indiscriminately pollinated by miscellaneous male parents. He has mentioned prepotency to be comparable to the general combining ability phenomenon observed in tree crops.

The concept of prepotency has been further elucidated with investigations on several cross pollinated perennial species like rubber, coconut, arecanut and cashew.

2.4.1. Rubber

Rubber has many parallels in other crops like coconut, arecanut and cashew with respect to the problems associated with the perenniality of the species and the scope for exploitation of prepotency.

Wijewantha (1965), while discussing some breeding problems in *Hevea brasiliensis* has mentioned that in any modern breeding programme, the prepotency of parents is to be investigated as an initial step in the breeding of heterozygous materials and that further increases in rubber yields are anticipated with the exploitation of heterotic vigour, prepotency and natural variability in *Hevea*.

The scope for identification of prepotents through seedling progeny analysis on the basis of juvenile adult correlations in the crop needs to be examined in this context.

In addition to the magnitude of correlated responses between seedling characters and adult tree yield, the effectiveness of juvenile selection depends on the genetic source of variability (Swaminathan, 1975). It is well known that progressive selection through generations is successful only when the character selected is highly heritable and determined by additive gene action. Under such situations, selection is effective, response is rapid and continuous, family performance is predictable and there is a high correlation between parental phenotype and its breeding behaviour.

2.4.1.1. Early evaluation techniques in rubber

Interest in early evaluation techniques in Hevea began in the 1920s with the aim of culling inferior seedlings. Early workers had studied a number of parameters in relation to yield in mature plants (Summers, 1930; Gunnery, 1935). The parameters studied included girth, height, bark thickness, latex vessel number, latex vessel and sieve tube diameters and rubber hydrocarbon in the bark and petiole. The only parameter which gave a fairly consistent correlation with yield was the number of latex vessels. However, measurement of this character was tedious and required skill and elaborate facilities. Consequently other characters which showed some association with yield, for example, vigour (expressed as circumference or diameter of the trunk), though not as ideal as latex vesssel count were recommended for use in culling inferior seedlings.

Later, direct methods for yield testing were developed. Cramer (1938) adopted a system of grading young rubber plants using a special type of knife to make incisions on one to two year old plants and then made a qualitative assessment of the amount of latex exuded. This method was employed only for culling (Dijkman, 1951), due to poor association with yield of mature plants. Hamaker (1914) and Morris and Mann (1932-1938) developed another early test (known as the HMM method), consisting of successive tappings of 3-4 year old trees and weighing the latex produced. The HMM method was subsequently modified to test tap two to three year old plants (Tan and Subramaniam, 1976). Mendes (1971) described an early test tapping method for a few month old plants using a specially designed knife while Waidyanatha and Fernando (1972) reported a needle prick test for very young plants. Zhou et al. (1982) developed two methods to predict the yield potential of one year old buddings from the amount of latex oozing out from leaflets or petioles. Annamma et al. (1989) developed an incision method for determining yield of one year old seedlings. A highly significant positive correlation was obtained between yield determined from one year old seedlings by this method and subsequent yield more precise and reliable.

Gilbert *et al*. (1973) were the first to estimate G.C.A. values in *Hevea*, using an incomplete diallel model composed of unsystematic crosses. They obtained G.C.A. constants of individual parents from past data of seedling progeny trials and showed that those could be used for predicting family performance. In addition to identifying high G.C.A. parents, they were also able to identify some potential cross combinations which had been left out of earlier programmes.

Tan and Subramaniam (1976) employed a five parent diallel cross to study combining abilities of parental clones for seven characters: yield, growth vigour, bark thickness, number of latex vessels, latex vessel size, sieve tube size and plugging index. Effects due to G.C.A. were more important than G.C.A. and reciprocal effects for all the characters studied. Tan (1977, 1978a,b) confirmed the usefulness of the method and further reported that it was possible to assess parental G.C.A. using only two years of progeny yield records. A highly significant positive correlation (r = 0.71***) was found between G.C.A. estimates from seedling families and those from their corresponding clonal families (Tan, 1977). This finding justifies the choice of parents based on G.C.A. estimates for yield obtained from seedling performance. However, a similar trend was not observed for girth. In another study, Tan (1978b) reported that some of the high G.C.A. parents obtained determined on test tapping at the age of two years by the HMM method.

There have also been investigations on indirect methods of yield prediction. These include the use of (1) anatomical characters: latex vessel system in the bark (Ho, 1972, 1976, 1979) and leaf (Huang et al., 1981); (2) physiological characters: plugging index (Ho, 1972, 1976), bursting index (Dintinger et al., 1981) and photosynthetic rates (Samsuddin et al., 1986); (3) biochemical attributes: rubber hydrocarbon in petiole and leaf (Bolle-Jones, 1954); nucleic acids (Tupy, 1969), cotyledon oil (Fernando and de Silva, 1971) and pH (Dintinger et al., 1981); (4) chemical attributes: latex constitutents such as N, P, K etc. (Ho, 1976); and (5) morphological characters: leaf variation (Testam method of Amand, 1962) and number of stomata (Senanayake and Samaranayake, 1970). Among these, only plugging index and number of latex vessels or latex vessel density have shown consistent significant correlations with yield of mature trees (Ho, 1972, 1976, 1979; Huang et al., 1981).

According to Simmonds (1989) there are four correlations which are important and have potential for helping to frame economical breeding plans. These are (1) between test tapping of young budded plants and performance in subsequent clone trials (r = 0.73, rising to 0.85, Ho, 1976); (2) between test tapping of young nursery seedlings and yield in small scale trials (r = 0.3-0.5, Tan, 1987; Licy *et al*., 1990); (3) between yields in small scale clone trials and in subsequent large scale clone trials (r = 0.5-0.79 for yield and 0.63-0.72 for girth, Ong, 1981); and (4) between GCA estimates for seedlings and for the same genotypes as clones after five years of tapping (Tan, 1978a).

2.4.1.2. Variation and character associations in juvenile plants

Predominantly additive inheritance for several seedling characters observed in the nursery has been established. Heritability values estimated for yield and yield components (Paiva *et al*., 1983) in rubber at the nursery stage are encouraging. There is very high additive genetic variation particularly for early vigour and plugging index at the nursery stage. Also, this fraction of genetic variance is considerable for bark thickness, the number and size of latex vessel rows and yield (Swaminathan, 1975). Growth vigour, plugging index, number of latex vessel rows and bark thickness account for 64 per cent of the variation in nursery yields (Tan and Subramaniam, 1976). Fernando *et al*. (1970) stated that measurements of height are more important than girth as growth estimates of young plants of *Hevea*. It has been established that height and diameter of nursery seedlings of *Hevea* have a high positive correlation (Jayasekara and Senanayake, 1971). Seedling vigour measured as the height or diameter during an early stage of growth was suggested as an efficient evaluation criterion for culling. Senanayake *et al*. (1975) reported that seedlings which germinated early (12 to 22 days) always had a greater diameter at all stages of growth than those which germinated late (24 to 34 days). Growth rate of early germinators was higher than that of late germinators. Highly significant positive correlations of nursery yield with plant girth (Narayanan and Ho, 1970; Gomez et al., 1973), number of latex vessel rows, bark thickness and plant height (Licy and Premakumari, 1988) have been established.

The current practice adopted in Hevea breeding procedures (Panikkar et al., 1980; Tan, 1987) is to carry out early selection on 2-3 year old seedling progenies based primarily on yield (by the modified HMM method) and to a lesser extent on other characters (vigour, latex vessel number and density, plugging index, disease tolerance etc) for further testing. Nursery test tapping may not identify superior plants with high reliability but will give good estimates of family means (Simmonds, 1989). Selection is therefore automatically concentrated on the best families where the prospect of genetic advance is greatest.

2.4.1.3. Combining ability

Results of combining ability studies in rubber indicate scope for the exploitation of prepotency. Though reports establish predominant additive inheritance of yield and girth suggesting effectiveness of phenotypic selection of parents, selection based on genotypic values as reflected by general combining ability (G.C.A.) will be from 2-3 year old seedlings were found in the high G.C.A. parental group in the mature stage of different populations evolved through hybridization. He suggested that it was thus possible to identify good parents at an early stage.

The findings that heritability estimates based on female parents are higher, presumably due to the existence of maternal effect (Tan *et al.*, 1975) and that the variance for general combining ability is several times higher than that for specific combining ability (Tan and Subramaniam, 1976) point to the possibility that phenotypically superior female parents, if subjected to seedling progeny analysis employing the existing early evaluation procedures could lead to the identification of prepotents. Evidently there is immense scope for the exploitation of prepotency in rubber.

2.4.2. Coconut

Based on the suggestion made by Harland (1957), studies were conducted to identify prepotent palms based on progeny performance in the nursery. Earlier studies made by Ninan and Pankajakshan (1961) and Ninan *et al.* (1964) indicated that on the basis of seedling performance it is possible to isolate high yielders which yield superior progeny as the differences in growth rate and vigour of seedlings between families were highly significant in comparison with variation within families.

Liyanage (1967) explained the programme of identifying superior transmitters by noting the total number of leaves produced per plant within each family during the forty months after transplanting. Breeding values of the mother palms were then determined. The families with high mean number of leaves per plant derived from phenotypically superior parents indicated the prepotency of the parents. It was found that prepotent palms showed high phenotypic and breeding values with their open pollinated progenies being consistently high yielding with a low coefficient of variation. He obtained a significant positive correlation between leaf production of progeny and breeding value of the respective parents determined in terms of the mean yield of the adult progenies. The magnitude of the correlation was much larger when the best ten per cent of the palms were selected for progeny testing.

Satyabalan et al. (1975) conducted a study of seedling characters and yield attributes of 43 open pollinated progenies of eight high yielding West Coast Tall palms and indicated the possibility of identifying prepotent palms based on progeny performance in the nursery. Nampoothiri et al. (1975) also arrived at a similar conclusion based on the study of open pollinated progenies of some high yielding palms in the juvenile and adult stages. Results of their study on phenotypic and genotypic correlations of four seedling and four adult palm characters with yield in coconut indicated that the number of leaves and collar girth of seedlings are positively correlated with yield.

Satyabalan and Mathew (1976, 1983) have expressed the view that prepotent palms can be identified from nursery studies on the basis of growth rate and seedling vigour as measured by collar girth and leaf production. Correlation of these growth characters from the first to the ninth month with those of the tenth month indicated a high and positive correlation from the fifth month onwards thereby showing that it might be possible to identify prepotent palms of superior genetic value from the fifth month after germination. They also observed that the seedlings raised from the nuts of prepotent palms were more vigorous than those of other palms irrespective of the months of harvest and germination. Further detailed studies of progenies have shown high and positive correlation of growth characters like collar girth and leaf production from the fifth month after germination with those of later months (Satyabalan, 1984).

Prepotency studies on twenty progenies each of fiteen high yielding West Coast Tall palms indicated that only two families had high yield (Anon., 1977) showing thereby that progenies of all high yielders need not be high yielding. This corroborates the findings of Satyabalan (1982a).

Gopimony (1982), following some preliminary observations on the coconut type Komadan which showed superiority for nine quantitative characters has expressed the view that the prepotency carried by Komadan types will be transmitted to its progenies due to its self pollinated nature. It was found that 99 per cent of the Komadan population gave more than 80 nuts per palm per year while only 15 per cent of West Coast Tall gave the same yield. Komadan type also exhibited superior seedling vigour in terms of germination percentage, height, collar girth, leaf production and mean number of split leaves.

Thomas Mathew (1983) evaluated some super mother palms for their prepotent ability to produce quality seedlings. One of the palms evaluated was found to be prepotent with respect to seednut and seedling characters. Estimates on recovery of quality seedlings from total number of seednuts was found to be more reliable than the recovery from total number of seedlings as a measure of prepotency. The study revealed that all super mother palms were not necessarily prepotent.

The criteria for selection of mother palms, seednuts and seedlings established by research workers have proved helpful in producing quality planting material of the cultivar West Coast Tall (Satyabalan, 1982b; Iyer et al., 1982). Satyabalan and Rajagopal (1985) made a systematic study to establish the validity of the earlier findings so that the seedling indexing method of locating the prepotents in the natural population of West Coast Tall variety could be routinely used. An attempt was also made to ascertain whether the open pollinated second generation progenies of palms identified earlier as likely prepotents continue to maintain their superiority and whether prepotency is transmitted to all the second generation progenies. The likely prepotents showed a high rate of transmission of growth characters to their progenies and the growth of progenies of those palms were more vigorous irrespective of the months of harvest and germination. The second study on 146 F_2 open pollinated progenies derived from three high yielding prepotent palms indicated that prepotency is not transmitted to all the open pollinated second generation palms.

Shylaraj and Gopakumar (1987) tested forty Komadan palms for prepotency, classifying them into high, medium and low yielding groups. A vigour index was computed for each seedling on the basis of the principle of discriminant function. The palmwise mean value for seedling vigour index was made use of in identifying prepotent palms. The recovery of vigorous seedlings and prepotent palms were highest in the high yielding group of palms. They suggested that a rigorous selection of vigorous seedlings coupled with the outright rejection of the inferior ones should be practised even among the seedling progeny of identified prepotent palms.

The concept of prepotency has been well researched and exploited in coconut as evidenced by the abundance of literature on the topic. Identification of prepotent palms offers immense scope for creating uniformity in a hetergeneous system where individuals are highly heterozygous due to the outbreeding nature of the crop. The identification of prepotent palms and their utilization have become established as the most viable means of ensuring a regular supply of elite planting material in coconut.

2.4.3. Arecanut

Bavappa and Ramachander (1967a) reported that phenotypically identical areca palms did not possess identical potentiality with regard to transmitting the genetic ability to produce more to the progeny. Mother palms having high, medium and low mean progeny yields were studied for the percentage frequency of yields of each family. The low yielders were found to produce a large proportion of low yielding progenies, but the yield trend of progenies from the medium and high yielding groups was more or less similar. It was not possible to locate mother palms of high yield coupled with a high frequency of high yielding progenies. They expressed the view that even though prepotent palms are present in arecanut, it is doubtful whether sufficiently large number of such palms could be identified so as to make available enough seed material for direct use. Along with the distribution of open pollinated nuts from the mother palms, it was suggested to take up large scale crossing of phenotypically high yielders with pollen collected from the prepotent palms as the only way of utilising the limited number of prepotent palms available. Another suggestion was to find out whether the high yielding first generation progenies of the prepotent mother palms are similar transmitters as their mothers. If this could be established, even with a limited number of prepotent mother palms, in the course of 5-10 years, sufficiently large sized plantations could be raised for the supply of good planting material. Prepotent palms were also suggested for use in isolated seed gardens.

In view of the significant positive genotypic correlation of collar girth and number of leaves (Bavappa and Ramachander, 1967b) and negative correlation of seedling height at the time of transplanting with subsequent yield (Bavappa and Ramachander, 1967a), Bavappa (1970) suggested selection of seedlings having maximum number of leaves and minimum height.

2.4.4. Cashew

Gopikumar et al. (1979) reported that certain cashew types transmitted characters strongly to their progenies while others did not. Susamma et al. (1984) conducted seedling progeny analysis of two different cashew types, Kottarakkara-1 and Kottarakkara-27 from thirty mother trees of each of the two types. The recovery of vigorous seedlings were more in the medium yielding group followed by the high yielding group. There was significant difference between the two types with respect to recovery of vigorous seedlings but the types were comparable with respect to recovery of prepotent trees. The results revealed that all high yielders are not prepotent and individual trees differ in their genetic superiority to transmit desirable characters to the progeny.

2.5. Inbreeding depression

The reduction in viability, vigour, fertility and other types of deterioration that accompanies inbreeding is referred to as inbreeding depression (Allard, 1960). The important effects of continued self fertilization in a naturally cross breeding species as evidenced by the classic works of East (1908) and Shull (1909) in maize can be summarised as follows:

(1) A large number of lethal and sub vital types appear in the early generations of selfing.

(2) The material rapidly separates into distinct lines which become increasingly uniform for differences in various morphological and functional characterstics.

(3) Many of the lines decrease in vigour and fecundity until they cannot be maintained even under the most favourable cultural conditions.

(4) The lines that survive show a general decline in size and vigour.

Rubber, coconut and arecanut are three outbreeding species where natural self pollination occurs to a limited extent. Literature on the effects of inbreeding in these tree crops is scanty. Reports on the phenomenon in eucalyptus and pine, two forest tree crops where planting material is generated through seed orchards, are worth scrutiny.

2.5.1. Rubber

Sharp (1940) reported that the growth of self pollinated seedlings obtained from some Pilmoor clones was so poor that the trees would be worthless commercially. Selfed seedlings showed inferior girth (only one third of that of the seedling crosses using the same parent with other clones) and yield.

Wycherley (1971) observed that most clones set more seed when cross pollinated than when selfed although a few are equally fertile whether crossed or selfed. Gilbert et al. (1973) compared the mean girth and yields of the families discussed by Sharp (1951) and Ross and Brookson (1966) with the values calculated from the G.C.A. of the parents. It was noted that outcrosses of non-related parents compared more favourably with expected values than did crosses of half or full sib parents. Moreover, the marked inferiority of the crosses between full sibs compared with the outcrosses suggested some inbreeding depression.

Tan and Subramaniam (1976) have also shown that selfed families are inferior to outcrossed families in nursery vigour and yield. It was inferred that inbreeding is common in Hevea but the degree of inbreeding may be variable in different clones. To be on the safe side, it was suggested to avoid mating of closely related parents for the improvement of yield and vigour.

Simmonds (1986) has drawn further inferences from the data of Tan and Subramaniam (1976). It was observed that vigour (estimated as girth) of nursery seedlings after culling out runts, was much the same for selfs and crosses. But survival in crossed families was 93 per cent as against 53 per cent in selfed families. When a correction is made for culling rates, the selfs would have had only a little over half the girth of the crosses. Even though the surviving selfs were not much inferior in girth, they yielded only about 46 per cent as that of the crosses confirming inbreeding depression for yield. While elucidating the effect of selfing on yield of a polycross population, Simmonds (1986) suggested the use of open pollinated seed from monoclone blocks to study selfs derived from specific clones. He has outlined an experiment that could throw light on a polycross population structure. The frequency of runts and culling rates could be taken as a rough direct measure of inbreeding.

Simmonds (1986) has further indicated that selfing in rubber is discriminated against at the embryo level. Jayasekera (1987) from a comparison of self and cross pollination reported that fluorescence microscopic studies showed no difference in pollen tube growth in pistils between selfed and crossed flowers with respect to percentage of penetrated ovules.

A selfing rate of about 22 per cent was calculated by Simmonds (1989) based on the following observations: The clone PB 5/51 is heterozygous for a recessive yellow gene as evidenced by 25 per cent yellows in a selfed progeny, while crosses with other clones yielded no yellows. Open pollinated PB 5/51 seed from seed gardens gave about 4-7 per cent yellows. The range of selfing was thus worked out to be 16-28 per cent. It was also established that rubber is an outbreeder and shows inbreeding depression on selfing due to the segregation of homozygous recessive genes. The deleterious effects in terms of pollination success (0-1.2 per cent under selfing against 1-7.6 per cent under crossing), runts discarded (42.8-57.1 per cent in selfs against 3.3-17.0 per cent in crosses), weighted girth of seedlings (3.5±0.35 cm for selfs against 5.5±0.24 cm for crosses) and weighted test tap yield per seedling 2.1±0.67 g for selfs against 6.3±0.46 g for crosses) were presented by Simmonds (1989) based on the data generated by Tan and Subramaniam (1976). It was inferred that inbreeding reduces fertility, vigour and yield and increases the runt frequency.

Based on adult progeny data of Gilbert _et al_. (1973), Simmonds (1989) reported that for full sib families, the observed values were less than the expected values calculated from G.C.A. estimates for girth (-2.8) and yield (-4.9), while for families derived from unselected parents, observed values were greater than expected for girth (+1.4) and yield (+2.4). It is impossible to get accurate estimates of the effect of selfing because family means are biased upwards by infertility, inviability and the inevitable discard of runt seedlings.

All these observations point to the expression of inbreeding depression at various stages of plant development in rubber.

2.5.2. Coconut

Satyabalan and Lakshmanachar (1960) found that variability in the progeny was not significantly reduced by self pollination when compared with open pollination, but vigour was markedly reduced in seedlings.

Liyanage (1969) studied the effect of inbreeding on some characters in coconut. Eight high yielding palms of known breeding value were subjected to self pollination and open pollination in successive inflorescences. Observation of the endosperm and embryo weight showed palms with a high breeding value to suffer less loss of weight of the endosperm and embryo on selfing when compared to open pollination. Palms of low breeding value showed a marked decrease in the weight of endosperm and embryo on selfing. The correlation between loss in endosperm weight due to selfing and the breeding value of the palm was high (r = 0.6935). On the basis of these observations, Liyanage (1972) suggested studying the inbreeding depression in endosperm and embryo weight of nuts as a quick method of identifying good genotypes.

Nambiar et al. (1970) from a study on the cytological behaviour of inbred and open pollinated progenies of some coconut cultivars reported that microsporogenesis was regular and comparable in both groups of the Laccadive variety indicating no inbreeding depression. A comparatively higher frequency of chromosome aberrations and pollen sterility were observed in the inbred progenies of Phillippines and Andamans varieties and in both the inbred and open pollinated progenies of Cochin China and New Guinea. Studies on the course of microsporogenesis in the progeny of a self pollinated New Guinea palm which produced defective nuts revealed aberrant meiosis. The sterility in this palm was attributed to inbreeding (Pillai and Kumar, 1972). Satyabalan and Kumar (1981) observed that mean annual yield and cumulative yield were more in progenies obtained from hybridization than those obtained by selfing Chowghat Dwarf Orange. Hence introduction of fresh variability into the Dwarf was suggested to be better than manipulating the available variability.

2.5.3. Arecanut

The extent of overlapping of the male and female phases was suggested to provide an indication of the extent of possible selfing in the crop, though not as a direct index of selfing (Bavappa and Ramachander, 1967b). Murthy and Bavappa (1960) observed that in 16 per cent of the palms there is overlapping of the male and female phases. Bhat *et al*. (1962) reported that overlapping of male and female phases was found to occur in 16 out of 18 spadices.

2.5.4. Forest trees

Elridge and Griffin (19830 compared four selfed families, four open pollinated families and one outcrossed family of eucalyptus. Within thirteen years, the selfed families were suppressed and many trees had died out. The results support the contention that the mixed breeding system of this species is maintained by selection against inbred trees through self thinning of the stand. Potts *et al*. (1986) reported low success of self pollination and close intraspecific crosses of eucalyptus. Seedlings from open pollination of *Eucalyptus gunnii* were intermediate in vigour and survival between self and wide intraspecific crosses. This effect was a result of inbreeding depression in the 10-30 per cent of open pollinated seed arising from self fertilization. Inbreeding depression was also evident in close crosses. There was significantly higher mortality in seedlings from selfings as compared to the wide intraspecific crosses. Furthermore there was strong evidence for inbreeding depression in the height and vigour of surviving seedlings.

Adams and Joly (1979) studied the degree of allozyme variability among clones of pine and also the proportion of orchard progeny resulting from self fertilization. A very low proportion of selfs (1.2 per cent) was found in most of the clones studied. It was found that because selfing generally causes a large proportion of aborted seed, clones with unusually high selfing rates are probably low seed producers and would likely be rogued out of seed orchards. Wilcox (1982) compared self pollinated progenies of twenty five pine (Pinus radiata) trees with their artificially cross pollinated progenies. The selfed progenies had less diameter, more crooked stem, less desirable branching habit and poor needle retention. A very weak correlation was obtained between the relative performance of selfs and their corresponding crosses.

2.6. Seed gardens

A seed orchard as defined by Zobel et. al. (1985) is "a plantation of genetically superior trees isolated to reduce pollination from genetically inferior ones and intensively managed to produce regular and abundant crops of sound and easily harvested seed". Special planting designs are used while planting the grafts in the orchard so that no two grafts coming from a given clone are allowed to be neighbours and further more all possible combinations for natural cross pollination are provided among the clones and inbreeding is reduced to the minimum.

Seed orchard method of producing genetically improved seeds for use in raising plantations is widely practised in coconut (Pillai and Nayar, 1979), rubber (Ferwerda, 1969; Marattukalam et al., 1980; Kavitha, 1990) and forest tree species (Kedharnath, 1986).

In rubber, the number of clones planted in a polyclonal seed garden usually ranges from five to ten. The polyclonal gardens established in 1963-1967 in Kanyakumari district (Marattukalam et al., 1980) have been laid out with clones selected according to the following criteria:

(1) High yield, vigour and disease resistance.

(2) Synchronous flowering to provide adequate chances for cross pollination.

(3) Comparatively high seed bearing capacity (not less than 150 seeds per tree).

(4) Capacity to produce good seedling families.

Evidently and as opined by Simmonds (1985) seed gardens in rubber have generally been constructed on intuitive rather than genetic principles, that is, simply by assembling the best available clones of the time avoiding related clones as far as possible.

The earlier seed gardens were planted with one or more primary clones among which Tjir 1 was popular. Trials in Malaysia (Burkill, 1959) indicated that Tjir 1 monoclonal seedlings were among the most vigorous. However, it later became evident that selfed progenies were generally less vigorous than those resulting from crossing between selected clones. Malaysian trials showed that seedlings from the Prang Besar isolated polyclone gardens yielded better than monoclonal seedlings of a number of high yielding secondary clones (Anon., 1973b). The degree to which selfing reduced vigour and yield was found to vary somewhat with the clone.

In polyclonal seed gardens, natural pollination results in some seed being derived from crossing between clones and some from self pollination since there is no evidence of self incompatibility in the species. Reciprocal cross experiments have shown that it does not matter which of a pair of clones is the female parent and which provides the pollen (Wycherley, 1971).

Simmonds (1986) while elaborating on the theoretical aspects of polycross populations of rubber seedlings has stated that knowledge of seed garden genetics in the crop is deficient. Suggestions for relevant experiments were made and it was pointed out that isozyme genes would offer a powerful method of analysing the genetical dynamics of seed gardens and their products. A number of field layouts for polycross gardens have been suggested with a view to maximise outcrossing, minimise inbreeding and to equalise crossing between all possible pairs of clones in the array.

Tan (1987) examined the scope of selection from polycross progenies. He emphasised that such progenies will provide material in addition to that from controlled pollination, for subsequent screening and selection. Problems associated with low fruit set do not arise and the relatively large polycross population that can be raised allows for a more effective selection for multiple characters. A similar view with respect to exercising selection in polycross populations was expressed by Simmonds (1989). He further stated that more, rather than fewer parents should enter a seed garden to keep inbreeding down. He has outlined the genetic principles underlying the selection of clones for seed gardens. Components of seed gardens should be proven high yielding clones and their selection should be based on G.C.A. estimates derived from the performance of their seedling progenies in replicated trials conducted by the breeders.

Naijian and Jingxiang (1990) suggested an improved recurrent selection programme for rubber with combining ability test, random mating in isolated seed gardens and application of selection index in the nursery as the key techniques. This new system, as opined by the authors, will be able to accumulate all the optimum genes for increasing dry rubber production.

MATERIALS AND METHODS

MATERIALS AND METHODS

3.1. Location

The study consisted of three experiments, viz.

1. Estimation of genetic divergence among forty clones of rubber.
2. Assessment of prepotency in twenty selected clones.
3. Estimation of inbreeding depression in the first inbred generation of eighteen selected clones.

The experiment on genetic divergence was undertaken during 1988 to 1990 at the Central Experiment Station of the Rubber Research Institute of India, situated at Chethackal in Pathanamthitta district of Kerala State. Seedling progeny analyses for the studies on prepotency and inbreeding depression were conducted during 1988 to 1990 and 1990 to 1991 respectively at the Rubber Research Institute of India Experiment Station, Kottayam.

3.2. Materials

3.2.1. Genetic divergence

Forty clones from the germplasm collection maintained by the Botany Division of the Rubber Research Institute of India at the Central Experiment Station, Chethackal were utilized for the study. The trees were in the third year of tapping at the time of commencement of the experiment. An account of these clones is presented in table 1 and the variation in their leaf morphology is presented in figure 1.

3.2.2. Prepotency

Material used for the study consisted of open pollinated seedling progeny at the age of one year and two years, generated from twenty clones with promising early yields selected from among those included in the study on genetic divergence (Table 1).

3.2.3. Inbreeding depression

Material for the study comprised one year old inbred and open pollinated seedling progeny from eighteen clones assessed for prepotency (Table 1).

3.3. Methods

3.3.1. Experimental methods

3.3.1.1. Estimation of genetic divergence

The germplasm garden selected for the study was planted in 1977 as a small scale evaluation trial of some clones of both indigenous and exotic origin, adopting a randomised block design with three replications and five trees per plot. The spacing was

Table 1. Clones studied for genetic divergence, prepotency and inbreeding depression.

Sl.No.	Clone	Place of origin	Parentage
1.	AVROS 255	Algemene Verenging Rubber Planters Oostkust, Sumatra, Indonesia.	Primary clone
2.	AVROS 352	-do-	-do-
3.	AVT 73@+	A.V. Thomas and Company, India.	-do-
4.	BD 5@+	Bodjong Datar, Java, Indonesia.	-do-
5.	BD 10	-do-	-do-
6.	Ch 2@+	Chemara, Malaysia	-do-
7.	Ch 4	-do-	-do-
8.	Ch 26@+	-do-	Inbred from clone BR 2
9.	Ch 29	-do-	-do-
10.	Ch 32@+	-do-	-do-
11.	Ch 153@	-do-	Tjir 1 x Ch 5
12.	Gl 1@+	Glenshiel, Malaysia	Primary clone
13.	GT 1*	Godang Tapen, Indonesia	-do-
14.	HC 28	Hilcroft, Sri Lanka	-do-
15.	HC 55	-do-	-do-
16.	LCB 1320@+	s'Lands Caoutchouc Bedrijven, Java, Indonesia.	-do-
17.	Lun N	Lunderston, Malaysia	-do-
18.	Mil 3/2	Millakande, Sri Lanka	-do-

(Contd....)

Table 1 (contd....)

Sl.No.	Clone	Place of origin	Parentage
19.	PB 6/50	Prang Besar, Malaysia	PB 24 x PB 28
20.	PB 5/51[@+]	-do-	PB 56 x PB 24
21.	PB 5/60	-do-	-do-
22.	PB 5/63	-do-	-do-
23.	PB 5/76[@+]	-do-	-do-
24.	PB 5/139	-do-	-do-
25.	PB 28/59	-do-	Primary clone
26.	PB 28/83[@+]	-do-	-do-
27.	PB 86[@+]	-do-	-do-
28.	PB 206[@+]	-do-	-do-
29.	PB 213	-do-	PB 56 x PB 86
30.	PB 215[@+]	-do-	Not known
31.	PB 217[@+]	-do-	PB 5/51 x PB 6/9
32.	PB 230[@+]	-do-	Not known
33.	PB 235[@+]	-do-	PB 5/51 x PB 5/78
34.	PB 242[@+]	-do-	PB 5/51 x PB 32/36
35.	PB 252[@+]	-do-	PB 86 x PB 32/36
37.	PR 107	Profestation voor Rubber-name, Indonesia.	Primary clone
37.	RRII 105[@+]	Rubber Research Institute of India, Kottayam, India.	Tjir 1 x Gl 1
38.	RSY 23	Ranny Shaliacary Yendayar, India.	Primary clone

(Contd....2)

Table 1 (contd....)

Sl.No.	Clone	Place of origin	Parentage
39.	Tjir 16	Tjirandji, Indonesia	Primary clone
40.	Waring 4	Waringiana, Sri Lanka	-do-

* Male sterile clones.

@ clones assessed for prepotency.

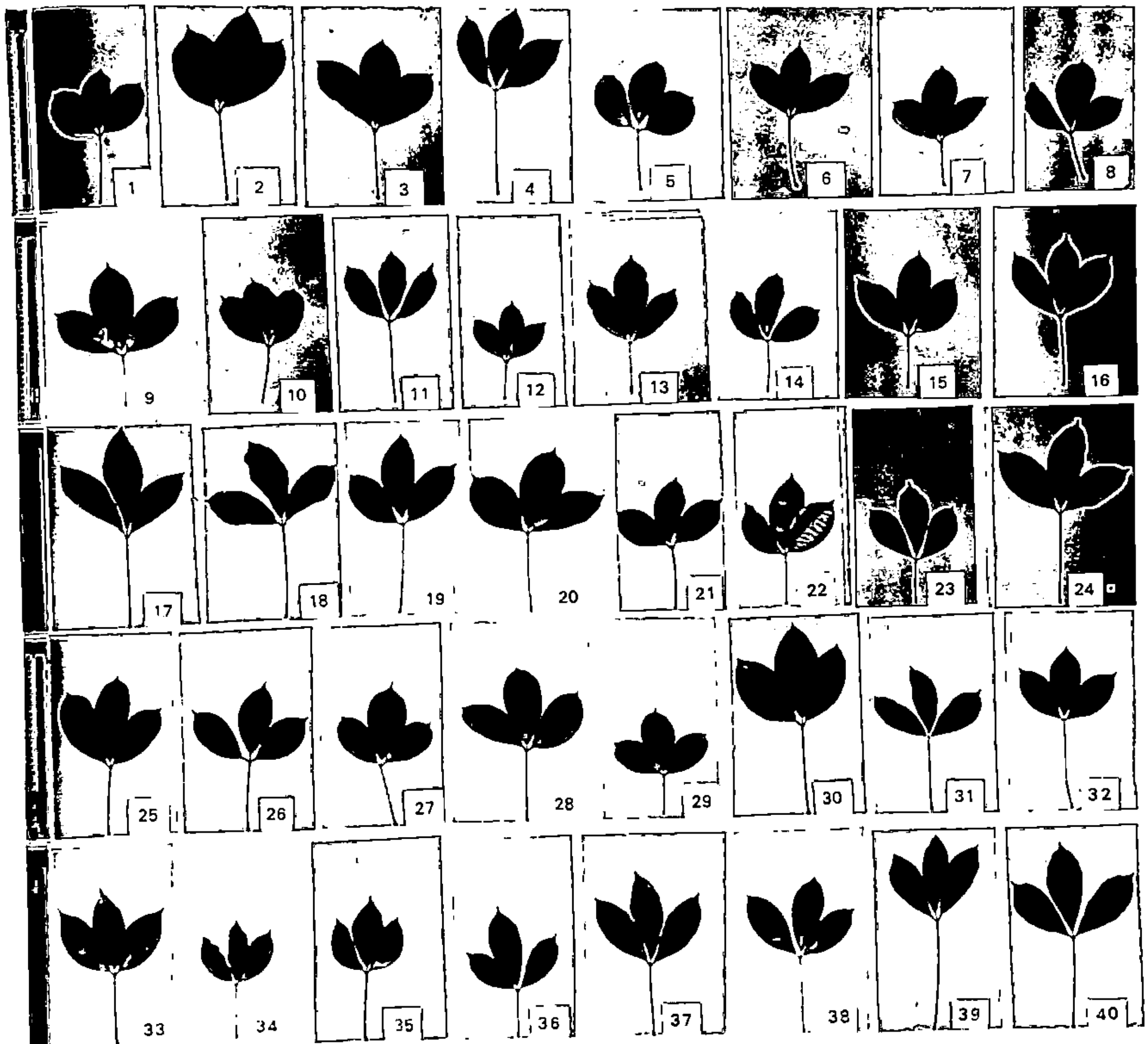
\+ Clones assessed for inbreeding depression.

Source: Paardekooper (1965), Chandrasekharan (1971), Ang (1982), Saraswathy Amma *et al.*, (1988; 1989).

Figure 1. Variation in leaf morphology among clones.

Number	Clone	Number	Clone
1.	AVROS 255	21.	PB 5/60
2.	AVROS 352	22.	PB 5/63
3.	AVT 73	23.	PB 5/76
4.	BD 5	24.	PB 5/139
5.	BD 10	25.	PB 28/59
6.	Ch 2	26.	PB 28/83
7.	Ch 4	27.	PB 86
8.	Ch 26	28.	PB 206
9.	Ch 29	29.	PB 213
10.	Ch 32	30.	PB 215
11.	Ch 153	31.	PB 217
12.	GT 1	32.	PB 230
13.	Gl 1	33.	PB 235
14.	HC 28	34.	PB 242
15.	HC 55	35.	PB 252
16.	LCB 1320	36.	PR 107
17.	Lun N	37.	RRII 105
18.	Mil 3/2	38.	RSY 23
19.	PB 6/50	39.	Tjir 16
20.	PB 5/51	40.	Waring 4

Figure 1



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5.5 x 5.5 m. All cultural operations were carried out uniformly as recommended by the Rubber Board. The trees were opened for tapping following the half spiral alternate daily system in 1986.

Prior to commencement of the experiment, trees for observation were selected on the basis of the record of yield and vigour during the first and second years of tapping. Two trees from each plot with yield and girth representative of the mean values for the respective plots were chosen and were numbered serially. A total of 240 trees (40 x 3 x 2) were subjected to observations and the following characters were recorded:-

(i) Girth

Girth of the trunk at a height of 150 cm from the bud union was measured at the commencement of the third, fourth and fifth years of tapping (1988, 1989 and 1990).

(ii) Girth increment rate under tapping

Increase in girth from the third to the fifth year of tapping was determined, from which the mean girth increment per year was worked out.

(iii) Length of tapping panel

The length of the tapping cut was measured during the fourth year of tapping.

(iv) Virgin bark thickness

Thickness of the virgin bark on the untapped portion of the trunk at the opposite side of the tapping panel was measured using a Schleiper's guage at a height of 130 cm from the bud union, during the fourth year of tapping.

(v) Renewed bark thickness

Thickness of renewed bark was measured in the fourth year of tapping from the top portion of the tapping panel bearing bark of three years regenerated growth.

(vi) Height at forking

The height from ground level to the point of first forking was measured.

(vii) Latex flow rate

Initial rate of latex flow was recorded in the fourth year of tapping once a month over a period of 12 months from January 1989 to December 1989. The volume of latex obtained in the first five minutes after tapping was measured and the flow rate per minute was determined.

Three values were computed from the observations thus recorded viz.,

1. mean over the 12 months (i.e. for the fourth year of tapping)
2. mean value for the period from February to May when the trees are under stress due to refoliation and summer
3. mean value for the peak yield period i.e. September to December

(viii) Volume of latex

The total volume of latex obtained from each tree per tapping was recorded once a month from January 1989 to December 1989. The mean values for the fourth year of tapping, the stress period and the peak yield period were computed.

(ix) Plugging index

Plugging index was computed for each month from January 1989 to December 1989 employing the formula proposed by Milford *et al*. (1969):

$$P.I. = \frac{\text{mean initial fow rate (ml/min)}}{\text{total volume yield (ml)}} \times 100$$

The mean values for the fourth year of tapping, the stress period and the peak yield period were computed.

(x) Dry rubber content

The percentage dry rubber content of latex (D.R.C.) obtained from each tree was determined at monthly intervals from January to December 1989. Latex samples of known volume (20 ml) from each tree were coagulated with one per cent acetic acid and the coagulum was oven dried at 55°C for one week. The dried samples were then weighed using an Anamed M-50 top pan balance and the D.R.C. was determined as per cent rubber content on a dry weight by volume basis (Sethuraj, 1981).

The mean values for the fourth year of tapping, the stress period and the peak yield period were computed.

(xi) Dry rubber yield

Dry rubber yield per tree per tapping was recorded on two tapping days per month from January to December 1989.

The first recording was done by cup coagulation whereby the latex was coagulated in the collection cup using 1 per cent acetic acid. The coagula were then partially dried under shade for a week followed by drying in the smoke house for about one month. The dried lumps were weighed using a pan balance. As the lumps retain moisture even after prolonged drying, a deduction of 10 per cent was made from the recorded weight to compensate for the residual moisture (Markose, 1984).

The second recording was computed as the product of the volume of latex per tree per tapping and the percentage dry rubber content of the respective tree. The mean of the two recordings was then worked out for each tree.

The mean values for the stress period and the peak yield period were separately computed. The yield depression in summer was also recorded as percentage of the annual mean.

(xii) Chlorophyll content

Chlorophyll content was estimated following Arnon (1949). Samples of fresh leaf from individual trees were collected, washed, blotted, weighed and then homogenised in 80 per cent acetone. The extract was centrifuged and the supernatent was taken out. The residue was re-extracted with additional volume of 80 per cent acetone until it no longer contained traces of green colour. All the supernatents were pooled and made up to 25 ml with 80 per cent acetone. The absorbance of this acetone extract was measured at 645 nm and 663 nm on a spectrophotometer using 80 per cent acetone as blank. Total chlorophyll, chlorophyll-a and chlorophyll-b were estimated using the following equations:

$$\text{Total chlorophyll} = (20.2 \times \text{OD at } 645 \text{ nm}) + (8.02 \times \text{OD at } 663 \text{ nm}) \times \frac{25}{1000}$$

$$\text{Chlorophyll-a} = (12.7 \times \text{OD at 663 nm}) - (2.69 \times \text{OD at 645 nm}) \times \frac{25}{1000}$$

$$\text{Chlorophyll-b} = (22.9 \times \text{OD at 645 nm}) - (4.68 \times \text{OD at 663 nm}) \times \frac{25}{1000}$$

The chlorophyll content was expressed as mg per g fresh weight. The chlorophyll a:b ratio was also computed.

(xiii) Wintering

Observations were recorded at weekly intervals during December-March, 1988-1989 and 1989-1990 to study the pattern of wintering and refoliation.

(a) Leaf fall:-

A visual grading of the extent of leaf fall and the period of maximum leaf fall were recorded.

(b) Refoliation:-

The period of completion of refoliation was recorded.

(xiv) Flowering attributes

(a) Period of flowering:-

The period of 50 per cent flowering was recorded by weekly observations during December-March, 1988-1989 and 1989-1990 The period when 50 per cent or more of the panicles on a tree had opened male flowers was taken as the period of 50 per cent flowering of individual trees.

(b) Spread of flowering:-

The number of days from 50 per cent to 100 per cent flowering for each tree was recorded as the flowering spread.

(c) Sex ratio:-

The number of female and male flowers per panicle and the number of panicles per flowering twig were recorded. The female:male ratio was computed from three flowering twigs selected at random from two trees per clone.

(xv) Incidence of diseases

The incidence of powdery mildew, abnormal leaf fall, pink disease and tapping panel dryness were recorded based on a visual assessment made during two years.

3.3.1.2. Prepotency

3.3.1.2.1. Selection of clones

The clones included in the study on genetic divergence were examined with respect to yield records for the first two years of tapping. Twenty clones with a promising early yield trend were selected for the assessment of prepotency through seedling progeny analysis.

3.3.1.2.2. Fruit collection and seed germination

Fruits resultant of open pollination were collected at the yellow pod stage from the selected clones in July, 1988. In order to obtain seeds representative of a polycross, fruits were harvested from branches in proximity with those of other clones situated in the adjacent plots and collection was done from all the three replications of each clone. The fruits of each clone were bulked and seeds were taken out from 50 fruits, amounting to 150 seeds per clone. The seeds were sown in sand beds for germination. The following observations were made:

(i) Seed weight

Weight per seed was recorded from thirty seeds selected at random from each clone. A Sartorius electronic balance was used.

(ii) Days for germination

Seeds were sown in beds made of river sand on the day following harvest. The number of days taken from sowing to germination of 50 per cent or more of the seeds of each clone was recorded.

(iii) Germination percentage

The number of seeds germinated upto 25 days after sowing expressed as percentage of the number sown for each clone was recorded.

3.3.1.2.3. Seedling progeny analysis

Sprouted seeds of the twenty clones were planted in nursery beds at a spacing of 60 x 60 cm. The seeds were planted at the stage of emergence of the radicle. A randomised block design with four replications and 21 plants per plot was employed. Planting within a plot was done in three rows of seven plants each.

Employing a stratified sampling procedure, five plants per row were selected based on visual observation of early vigour. Data on the following characters were collected from fifteen seedlings per plot.

(i) Plant height

Height from soil level to the topmost flush of leaves at the age of one year and at two years.

(ii) Girth

Girth at a height of 10 cm from ground level at the age of one year and two years. Girth increment between the first and second year of growth was also computed.

(iii) Bark thickness

Bark thickness was measured from 2 x 2 cm pieces of bark samples collected at a height of 15 cm from ground level at the age of one year and two years.

(iv) Number of leaf flushes

The number of leaf flushes produced during the first year of growth and those retained at the age of one year and two years.

(v) Number of leaves

The number of leaves per plant at the age of one year.

(vi) Number of latex vessel rows

Bark samples were collected at the age of two years and fixed and preserved in 90:5:5 Formalin Aceto Alcohol. Radial longitudinal sections of the bark were taken and stained in Sudan IV. Number of latex vessel rows was recorded from observation of three sections from each bark sample under a light microscope.

(vii) Rubber yield

Rubber yield obtained on test tapping the seedlings was recorded at the first and second year. At the age of one year, the test incision method of determining juvenile yield (Annamma *et al*., 1989) was employed. Using a special knife with two slanting blades fixed 10 cm apart, incisions were made on two sides of the stem (Fig. 2). The latex oozing out from the four incisions thus made was collected in pre-weighed strips of blotting paper

Figure 2. Test incision on one year old seedling.

Figure 3. Latex from incisions dripping into blotting paper.

Figure 4. Two year old seedlings under test tapping.

Figure 2

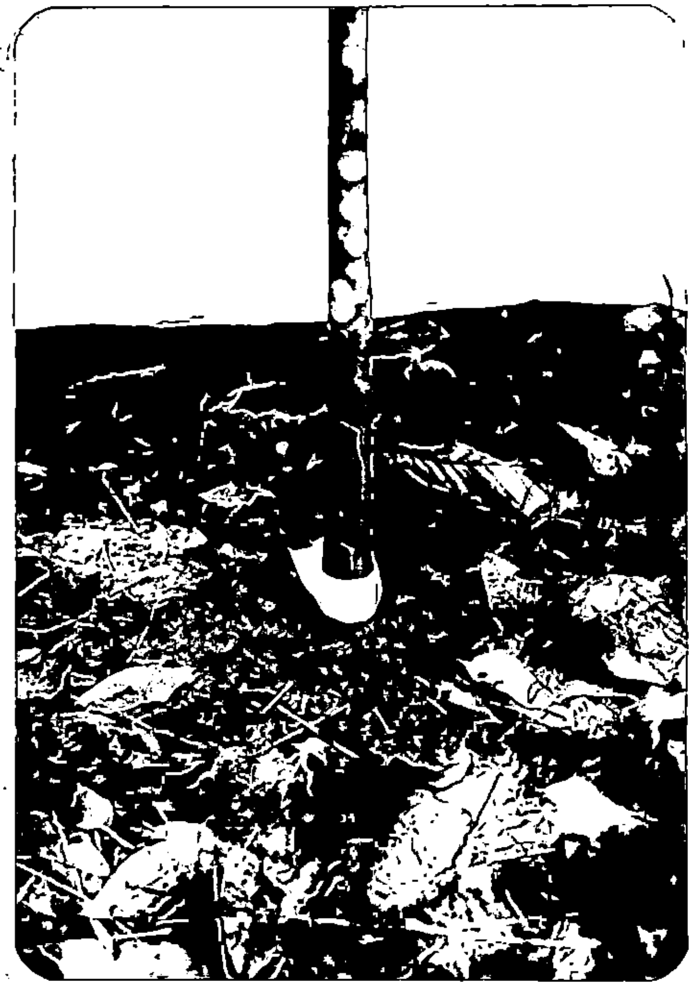


Figure 3

Figure 4

fixed to the base of the stem using metal clips (Fig. 3). The blotting paper strips along with the latex were weighed after oven drying at 55°C for two days and the dry weight was determined.

At the age of two years, test tapping (Fig. 4) was done at a height of 15 cm from the plant base employing the modified HMM method (Tan and Subramaniam, 1976). A half spiral system of tapping was followed on alternate days for a period of 20 days. Latex obtained from ten test tappings was collected, oven dried and weighed for recording yield on test tapping

3.3.1.3. Inbreeding depression

Eighteen out of the 20 clones assessed for prepotency were subjected to the study of inbreeding depression in the first inbred generation.

Inbred seeds of the clones were generated through artificial selfing and by seed collection from the centre of large monoclonal stands exceeding 5 ha. Open pollinated seeds of these clones were collected from the peripheral rows of each clonal stand. The seeds were sown on germination beds and sprouted ones planted in the nursery at a spacing of 30 x 30 cm. The inbred and outbred seedlings of each clone were planted in adjacent plots.

Data on the following aspects were recorded.

(i) Fruit set

Selfing through hand pollination was attempted on about 500 female flowers of each clone. The same number of female flowers were also tagged and left unprotected to enable open pollination. Fruit set was recorded as percentage of the number of female flowers pollinated.

(ii) Days for germination

The number of days taken from sowing to germination of 50 per cent or more of the seeds of each clone.

(iii) Germination percentage

The number of seeds germinated was recorded as percentage of the number sown.

(iv) Plant height

Height of seedlings one year after sowing of the sprouted seeds.

(v) Girth

Stem girth at a height of 10 cm from ground level at the age of one year.

(vi) Number of leaf flushes

The number of leaf flushes retained at the age of one year.

(vii) Number of leaves

The total number of leaves present at the at the age of one year.

(viii) Rubber yield

Juvenile yield at the age of one year employing the test incision method.

(ix) Morphological abnormalities

The occurrence of abnormalities like chlorosis of leaves and stunted growth in the seedlings.

Observations (iv) to (viii) were recorded from all surviving seedlings of inbred and outbred origin.

3.3.2. Statistical techniques

3.3.2.1. Genetic Divergence

3.3.2.1.1. Analysis of variance and covariance

Analyses of variance and covariance were carried out following standard statistical techniques in order to:

(i) test whether there are significant differences among clones with respect to the various traits,

(ii) estimate the components of variance and covariance, and

(iii) compute the correlation coefficients.

Phenotypic variation for a character is the sum of the genotypic and environmental variations and was determined by the method given by Kempthorne (1957) as

$$V(P) = V(G) + V(E) + 2\ Cov\ (G,E),$$

where, $V(P) = \sigma^2_{p(x)}$ = Variance due to phenotype

$V(G) = \sigma^2_{g(x)}$ = Variance due to genotype

$V(E) = \sigma^2_{e(x)}$ = Variance due to environment, and

$Cov(G,E)$ = Covariance between genotype and environment.

When the genotype and the environment are independent, Cov(G,E) is equal to zero so that,

$$V(P) = V(G) + V(E) \quad \text{or}$$

$$\sigma^2_{p(x)} = \sigma^2_{g(x)} + \sigma^2_{e(x)}$$

The extent of covariance between x and y due to the genotype and environment was estimated as suggested by Kempthorne (1957) as:

$$Cov(Px\ y) = Cov(Gx\ y) + Cov(Ex\ y) \quad \text{or}$$

$$\sigma_{p(x\ y)} = \sigma_{g(x\ y)} + \sigma_{e(x\ y)},$$

where $\sigma_{p(x\ y)}$ = Phenotypic covariance between x and y

$\sigma_{g(x\ y)}$ = Genotypic covariance between x and y

$\sigma_{e(x\ y)}$ = Environmental covariance between x and y.

In the experiment designed in a randomised complete block design with 'v' treatments and 'r' replications, the estimates of $\sigma^2_{p(x)}$, $\sigma^2_{p(y)}$, $\sigma^2_{g(x)}$, $\sigma^2_{g(y)}$, $\sigma^2_{e(x)}$, $\sigma^2_{e(y)}$, $\sigma_{p(x\ y)}$, $\sigma_{g(x\ y)}$ and $\sigma_{e(x\ y)}$ were obtained from the analysis of variance-covariance (Table 2).

Table 2. Analysis of variance/covariance.

Source	d.f.	$M.S._{xx}$	Expectation of $M.S._{xx}$	$M.S.P._{(xy)}$	Expectation of $M.S.P._{(xy)}$	$M.S._{yy}$	Expectation of $M.S._{yy}$
Block	(r-1)	B_{xx}		B_{xy}		B_{yy}	
Treatment	(v-1)	V_{xx}	$\sigma^2_{e(x)} + r\,\sigma^2_{g(x)}$	V_{xy}	$\sigma_{e(xy)} = r\,\sigma_{g(xy)}$	V_{yy}	$\sigma^2_{e(y)} + r\,\sigma^2_{g(y)}$
Error	(r-1)(v-1)	E_{xx}	$\sigma^2_{e(x)}$	E_{xy}	$\sigma_{e(xy)}$	E_{yy}	$\sigma^2_{e(y)}$
Total	(rv-1)	T_{xx}	$\sigma^2_{p(x)}$	T_{xy}	$\sigma_{p(xy)}$	T_{yy}	$\sigma^2_{p(y)}$

Hence we have the following estimates

$$\hat{\sigma}^2_{g(x)} = \frac{1}{r}(V_{xx} - E_{xx}) \qquad \hat{\sigma}^2_{e(x)} = E_{xx}$$

$$\hat{\sigma}^2_{g(y)} = \frac{1}{r}(V_{yy} - E_{yy}) \qquad \hat{\sigma}^2_{e(y)} = E_{yy}$$

$$\hat{\sigma}_{g(xy)} = \frac{1}{r}(V_{xy} - E_{xy}) \qquad \hat{\sigma}^2_{e(xy)} = E_{xy}$$

3.3.2.1.2. Coefficient of variation

The coefficients of variation were estimated as:

Phenotypic coefficient of variation (P.C.V.)

$$\text{for character } x = \frac{\sigma p(x)}{\bar{X}} \times 100 \quad \text{and}$$

Genotypic coefficient of variation (G.C.V.)

$$\text{for character } x = \frac{\sigma g(x)}{\bar{X}} \times 100,$$

where $\sigma_{p(x)}$ and $\sigma_{g(x)}$ are the phenotypic and genotypic standard deviations respectively and $\bar{X}$ is the mean of the character x.

3.3.2.1.3. Heritability (H^2)

Heritability in the broad sense is the fraction of the total variance which is heritable and was estimated as percentage, following Jain (1982) as:

$$H^2 = \frac{\sigma g^2}{\sigma p^2} \times 100$$

3.3.2.1.4. Genetic advance under selection (G.A.)

Genetic advance was estimated as:

$$G.A. = \frac{K\ H^2\ \sigma_{p(x)}}{\bar{X}},$$

where $\bar{X}$ is the mean of the character x and K is the selection differential which is 2.06 at 5 per cent intensity of selection in large samples (Allard, 1960).

3.3.2.1.5. Correlations

The phenotypic correlation coefficient between x and y was estimated as:

$$r_{p(x\ y)} = \frac{\sigma_{p(x\ y)}}{\sigma_{p(x)} \times \sigma_{p(y)}}$$

where, $\sigma_{p(x\ y)}$ is the phenotypic covariance between x and y and $\sigma_{p(x)}$ and $\sigma_{p(y)}$ are the standard deviations of x and y respectively.

The significance of the phenotypic correlation coefficients was tested with reference to the critical value of 'r' at n-2 degrees of freedom where 'n' is the number of pairs of observations (Snedecor and Cochran, 1968).

The genotypic correlation coefficient was estimated as

$$r_{g(xy)} = \frac{\sigma_{g(xy)}}{\sigma_{g(x)} \times \sigma_{g(y)}}$$

where, $\sigma_{g(xy)}$ is the genotypic covariance between x and y and $\sigma_{g(x)}$ and $\sigma_{g(y)}$ are the standard deviations of x and y respectively.

The standard error of r_g was calculated as:

$$SE\ r_{g(xy)} = \frac{1}{(f+1)} \left[\frac{1}{2}(1-r^2_{g(xy)})^2 - \frac{1}{2}(1-r^2_{g(xy)}) \right.$$

$$\frac{1}{D} - \frac{r_{p(xy)}\ r_{g(xy)}}{C} + 4\left(\frac{r_{g(xy)}}{D} - \frac{r_{p(xy)}}{C}\right)^2 +$$

$$\left. \frac{2(1-r^2_{g(xy)})^2\ (1-r^2_{p(xy)})}{C^2} \right]^{\frac{1}{2}},$$

where $\frac{1}{D} = \frac{1}{2}\left(\frac{1}{H^2_x} + \frac{1}{H^2_y}\right),$

$C = \sqrt{H^2_x\ H^2_y},$

f = degrees of freedom for error,

H^2_x = Heritability of character x and

H^2_y = Heritability of character y.

The environmental correlation coefficient was estimated as:

$$r_{e(xy)} = \frac{\sigma_{e(xy)}}{\sigma_{e(x)} \times \sigma_{e(y)}}$$

where, $\sigma_{e(xy)}$ is the environmental covariance between x and y and $\sigma_{e(x)}$ and $\sigma_{e(y)}$ are the standard deviations of x and y respectively (Narain et al., 1979).

3.3.2.1.6. Path analysis

The system of simultaneous equations which give solutions for path coefficients are:

$$r_{x_i x} = r_{x_i x_1} P_1 + r_{x_i x_2} P_2 + \text{------} + P_i + \text{------} \; r_{x_i x_k} P_k$$

where i = 1,2, ..., k, $r_{x_i y}$ is the correlation of the i^{th} independent variable (x_i) with the dependent variable (y), P_i is the direct effect of x_i on y and $r_{x_i x_k} P_k$ is the indirect effect of x_i via x_k on y.

The residual "R" was calculated from the following relation (Singh and Choudhary, 1979) as,

$$R^2 = (1 - \sum_{i=1}^{k} r_{x_i y} P_i)$$

3.3.2.1.7. D^2 analysis

A measure for group distance based on multiple characters was given by Mahalanobis (1928). With $x_1, x_2, x_3,$ ------, x_p as the multiple measurements available on each population and $d_1, d_2,$ ------ d_p as $(\bar{x}_1^1 - \bar{x}_1^2)$, $(\bar{x}_2^1 - \bar{x}_2^2)$, ------ $(\bar{x}_p^1 - \bar{x}_p^2)$ respectively being the difference in the means of two populations, Mahalanobis' D_2 statistic is estimated as follows:

$$D^2 = b_1d_1 + b_2d_2 + \text{--------} \; b_pd_p \qquad \ldots\ldots (1)$$

Here $\bar{x}^1_i$ is the mean value of the i^{th} character in the first population and $\bar{x}^2_i$ is the mean value of the i^{th} character in the second population. The b_i values are estimated such that the ratio of the variance between populations to the variance within populations is maximised. In terms of variances and covariances, the D^2 value is obtained as follows:

$$pD^2 = \sum_i \sum_j W^{ij} (\bar{x}_i^1 - \bar{x}_i^2) \; (\bar{x}_j^1 - \bar{x}_j^2) \ldots\ldots (2)$$

where, W^{ij} is the inverse of the estimated variance-covariance matrix.

The estimation of D^2 values by the formula given in equation (2) is very complicated when the number of characters studied is large. In the present experiment, twenty two characters were utilised. The computation was therefore simplified by transforming the characters to render them independent and expressing them in terms of their respective standard errors. The computation of D^2 values was thus reduced to simple summation of the differences in mean values of the various characters of the two populations i.e., $\sum d_i^2$. Therefore the correlated variables were first transformed to uncorrelated ones and the D^2 values were worked out. Transformation was done using the pivotal condensation method.

When Y_1, Y_2 ------ Y_p were the transformed variates, the mean deviation for each combination, i.e., $\bar{Y}_i^1 - \bar{Y}_i^2$ with i = 1,2, ------ p was computed and the D^2 was calculated as the sum of the squares of these deviations, i.e., $\sum (\bar{Y}^1{}_i - \bar{Y}^2{}_i)^2$.

Contribution of individual characters towards divergence:

In all the combinations (780 in the present experiment), each character was ranked on the basis of d_i values. Rank 1 was given to the highest mean difference and rank 'p' to the lowest mean difference where p is the total number of characters (22 in this case). Finally a table was prepared showing the percentage contribution of each character towards divergence in terms of the number of times each character appeared first in ranking. In the case of characters which did not appear first in ranking, their relative contribution towards divergence was determined in terms of their rank totals.

Grouping of the clones into clusters:

The Tocher's method was followed. The first step was to arrange the clones in the order of their relative distances from each other. The two clones having the smallest distance from each other were considered first, to which a third clone having the smallest mean D^2 value from the first two clones was added. Then the nearest fourth clone was added and so on. At a certain stage when it was found that there was a disrupt increase in the mean D^2

of the cluster on adding a particular clone, that clone was excluded from that cluster. Formation of the second cluster was then initiated with another pair of clones which had the next higher D^2 value to that of the first pair in the first cluster and when the mean D^2 values exceeded the critical value, a third cluster was initiated. The process was continued in this manner until all the 40 clones were included in one or the other cluster.

The mean intra cluster distances were computed by using the formula, $\sum D_i^2/N$, where $\sum D_i^2$ is the sum of distances between all possible combinations (N) of the clones included in a cluster. The mean inter cluster distances were worked out by using the distances between all possible combinations of the clusters obtained. For this purpose, the sum of distances between all possible combinations of the clones in a pair of clusters was taken. The sum of D^2 values divided by the product of the number of clones in each cluster gave the inter cluster distance between the particular pair of clusters. The mean inter and intra cluster distances were then tabulated, based on which a cluster diagram was drawn to scale using the D $(= \sqrt{D^2})$ values.

3.3.2.1.8. Factor analysis

The larger clusters were subjected to Factor analysis to identify the factors of divergence.

The basic factor analysis model written in matrix notation is as,

$$Z = \underset{\sim}{A}\,\underline{F} + \underline{e}$$

where, Z is the p x 1 vector of standardised variables,

$\underset{\sim}{A}$ is the p x k matrix of factor coefficients,

$\underline{F}$ is the k x 1 vector of (k p) common factors, and

$\underline{e}$ is the p x 1 vector of specific (unique) factors.

The environment correlation matrix was utilized in the present study. Principal factor analysis (PFA) was applied to identify the factors contributing to genetic divergence.

i) Estimation of communality

The squared multiple correlation (SMC) of each variable with all other variables of the set is the best possible systematic estimate of communality (Guttman, 1956).

The SMC of variable Z_i is given by:

$$\text{SMC } R^2_{i1,2 \text{ ---- } (i-1),\ (i+1) \text{ ---- } p} = 1 - \frac{1}{r^{ii}}$$

where r^{ii} is the diagonal element of $\underset{\sim}{R}^{-1}$ corresponding to the variable Z_i and $\underset{\sim}{R}$ is the environment correlation matrix.

ii) Principal factor analysis (PFA)

From the classical factor analysis model, the relevant portion of the determination of the common factor coefficients may be:

$$Z = \underset{\sim}{A}\ \underline{F}$$

or $$Z_1 = a_{11}F_1 + a_{12}F_2 + \text{------}\ a_{1k}F_k$$

$$\text{-------------------------}$$

$$\text{-------------------------}$$

$$Z_p = a_{p1}F_1 + a_{p2}F_2 + \text{------}\ a_{pk}F_k$$

The sum of squares of factor coefficients give the communality of a particular variable while a_{im}^2 indicates the contribution of the factor F_m to the communality of Z_i. The principal factor method involves the selection of the first factor coefficients a_{i1} so as to make the sum of the contribution of that factor to the total communality a maximum.

i.e., $$V_1 = a_{11}^2 + \text{------}\ a_{p1}^2$$

is maximum.

The criterion regarding the number of common factors to retain in the factor model is equal to the number of principal components whose eigen values are greater than one.

Jacobi method was used to find out the eigen values and vectors of the matrix A.

The vectors of factor loadings matrix were determined. The sum of the squares of factor loadings of the variable gives the corresponding communality i.e., the squared factor coefficients were considered as the percentage variance components of the common factor. The iteration process was continued with the new estimates of communalities until a specified degree of convergence occurred. The controlling equation to ensure that no vital information is lost is:

$$R_i^* = AA'.$$

iii) Factor rotation

After extraction, the matrix of factor loadings was subjected to varimax orthogonal rotation. The normal varimax solution is invariant under changes in the composition of the variables.

3.3.2.2. Prepotency (Seedling progeny analysis)

i) Analysis of variance

Data on seven juvenile traits at the age of one year viz. plant height, girth, number of leaf flushes produced, number of flushes retained, number of leaves, bark thickness and yield of rubber on test incision were subjected to the analysis of variance as per standard statistical techniques. Data on seven traits at the age of two years viz. plant height, girth, girth increment between the first and second year of growth, bark thickness, number of latex vessel rows, number of leaf flushes and rubber yield on test tapping were also subjected to the analysis of variance.

Genetic parameters such as genotypic and phenotypic co-efficients of variation, heritability in the broad sense and genetic advance were computed from these data.

ii) Variation within progenies

Each of the 20 progenies at the age of two years was subjected to analysis for the estimation of phenotypic coefficient of variation for rubber yield on test tapping, girth, number of latex vessel rows and number of leaf flushes.

iii) Correlations

Phenotypic correlations among the traits at the age of one year and two years were computed and tested against the critical value of 'r' for n - 2 = 78 degrees of freedom following Snedecor and Cochran (1968).

iv) Performance Index

If X_{i1}, X_{i2} ----- X_{ik} are the means of k characters in the i^{th} progeny and W_1, W_2 ------ $W_k = \frac{1}{\text{Variance } X_1}$ ---------, $\frac{1}{\text{Variance } X_k}$, the quantities of information in the data with respect to these characters, the performance index of the i^{th} progeny is estimated as,

$$P_i = W_1 X_{i1} + W_2 X_{i2} \text{ ------- } W_k X_{ik}.$$

The performance index for each of the 20 progenies at the age of one year was computed based on six traits viz. plant height (X_1), girth (X_2), number of leaf flushes retained (X_3), number of leaves (X_4), bark thickness (X_5) and yield of rubber on test incision (X_6).

For the computation of performance index at the age of two years, four traits viz. yield on test tapping, girth, number of latex vessel rows and number of leaf flushes were utilized. The progenies were then ranked in each of the two years on the basis of their performance indices.

v) Index Score

In order to determine the percentage recovery of superior seedlings within each progeny at the age of two years, an index score method (Singh and Choudhary, 1979) was adopted.

The range of variability for each of the four traits viz. yield on test tapping, girth, number of latex vessel rows and number of leaf flushes was classified into three groups using the criterion $\bar{X} \pm 2SE$ as detailed in table 3.

Table 3. Index scores for the various classes.

Clss	Class interval	Index score
1	Below Mean - 2SE	1
2	Between Mean - 2SE & Mean + 2SE	2
3	Above Mean + 2SE	3

Individual seedlings with values in the range of any of the three classes were assigned the respective scores. The scores for the four traits for each seedling were then totalled. The total index score values for individual seedlings thus ranged from 4 to 12. Seedlings with an index score greater than 8 indicating a moderate to high performance for the combination of traits were considered superior. The percentage recovery of superior seedlings within each plot was then determined. Data on the percentage recovery of superior seedlings were subjected to the analysis of variance.

vi) Correlations among prepotency criteria

Phenotypic correlations among 13 attributes were estimated and their significance tested against the critical value of 'r' at n - 2 = 18 degrees of freedom. The attributes were the prepotency criteria viz., performance indices for the first and second years of growth, the percentage recovery of superior seedlings in the second year, the juvenile traits like rubber yield in the first and second year of growth, girth in the first and second year, girth increment between the first and second year of growth, bark thickness in the first year, number of latex vessel rows in the second year and the three seed attributes viz., weight, germination percentage and the number of days for germination.

The statistical computations pertaining to the genetic divergence and prepotency studies were carried out on a VERSA IWS system in the Department of Agricultural Statistics, College of Agriculture, Vellayani.

3.3.2.3. Inbreeding Depression

Comparison of fruit set under selfing and under open pollination was made utilizing the Chi-square test of independence (Snedecor and Cochran, 1968). Germination percentages of selfed and open pollination seeds were also estimated.

Data on plant height, girth, number of leaf flushes, number of leaves and rubber yield on test incision were analysed and inbreeding depression estimated.

The extent of inbreeding depression for each trait at the juvenile stage in the seedling progeny was estimated as:

$$I.D. = \frac{\bar{X}\ OP - \bar{X}S}{\bar{X}\ OP} \times 100,$$

where $\bar{X}OP$ = mean value for the trait in the open pollinated progeny

and $\bar{X}S$ = mean value for the trait in the selfed progeny.

A 't' test was employed as the test of significance for inbreeding depression.

$$t_{n_1 + n_2 - 2} = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{n_1 s_1^2 + n_2 s_2^2}{n_1 + n_2 - 2} \left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

where $\bar{X}_1$ = $\bar{X}OP$

$\bar{X}_2$ = $\bar{X}S$

n_1 = number of observations in the open pollinated progeny

n_2 = number of observations in the selfed progeny

s_1^2 = variance for the trait in the open pollinated progeny

s_2^2 = variance for the trait in the selfed progeny

Morphological abnormalities in the progeny of each clone were recorded and their frequencies were estimated.

RESULTS

RESULTS

Forty clones of Indian, Indonesian, Malaysian and Sri Lankan origin were evaluated for genetic divergence. Of these, twenty promising yielders from genetically divergent clusters were assessed for prepotency through seedling progeny analysis. Eighteen out of the twenty clones were studied for the extent of inbreeding depression in the first generation of selfing. The results of the three experiments are presented in the forthcoming pages.

4.1. Genetic divergence

Forty clones were studied for yield and yield components, morphological and structural attributes, chlorophyll content, wintering and flowering behaviour and incidence of diseases. The data were subjected to the analysis of variance and covariance for the estimation of genetic parameters. The cause and effect relationships among yield and its components were determined through path analysis. Clones with synchronous wintering and flowering were identified. Genetic divergence was estimated through the Mahalanobis' D^2 statistic based on twenty two variables. The factors of divergence were identified through principal factor analysis.

4.1.1. Genetic variability

The results of the analysis of variance among forty clones at the fourth year of tapping are presented in table 4. The clones exhibited significant variation for all the characters except chlorophyll a:b ratio.

4.1.1.1. Dry rubber yield

The annual mean dry rubber yield for the fourth year of tapping, the mean dry rubber yield for the stress period from February to May and for the peak period from September to December and yield depression under stress were observed to show highly significant clonal variation (Table 4). The mean yield of clones is presented in table 5 and variability in figure 5.

The annual mean dry rubber yield ranged from 22.37 g $tree^{-1}$ $tapping^{-1}$ (Ch 29) to 77.01 g $tree^{-1}$ $tapping^{-1}$ (PB 235) with a general mean of 46.22 g $tree^{-1}$ $tapping^{-1}$. Clones PB 235 and PB 217 gave very high yields of more than 70 g $tree^{-1}$ $tapping^{-1}$ and were on par with eight other clones viz. RRII 105, PB 252, Ch 26, PB 5/76, PB 28/83 and PB 242 which yielded more than 60 g $tree^{-1}$ $tapping^{-1}$ and clones PB 230 and LCB 1320 with about 58 g $tree^{-1}$ $tapping^{-1}$. Eleven clones, PB 5/51, PB 215, GT 1, PB 5/63, Ch 153, PB 86, PB 206, Ch 2, Gl 1, PB 6/50 and AVT 73 were the medium yielders. The rest of the clones were low yielders and were on par with the lowest yielder Ch 29.

During the stress period, PB 217 gave the highest yield of

Table 4. Analysis of variance among clones.

Sl. No.	Characters	Mean squares			F (Clones)
		Replications	Clones	Error	
1.	Dry rubber yield (annual)	1067.41	603.20	162.61	3.71**
2.	Dry rubber yield (stress)	926.36	437.08	131.55	3.32**
3.	Dry rubber yield (peak)	1504.08	904.19	244.55	3.70**
4.	Yield depression under stress	1279.14	223.42	100.90	2.21**
5.	Volume of latex (annual)	10521.25	4177.78	1529.48	2.73**
6.	Volume of latex (stress)	7891.97	3318.29	1120.94	2.96**
7.	Volume of latex (peak)	15468.50	6292.89	2590.48	2.43**
8.	Dry rubber content (annual)	0.66	30.35	4.15	7.32**
9.	Dry rubber content (stress)	11.47	36.08	8.70	4.15**
10.	Dry rubber conent (peak)	91.60	32.51	8.04	4.04**
11.	Latex flow rate (annual)	8.81	4.29	1.06	4.06**
12.	Latex flow rate (stress)	4.10	3.64	1.16	3.14**
13.	Latex flow rate (peak)	18.69	5.55	1.36	4.09**
14.	Plugging index (annual)	4.18	2.61	0.81	3.22**
15.	Plugging index (stress)	16.37	9.98	3.07	3.25**
16.	Plugging index (peak)	0.38	0.73	0.37	1.98**
17.	Girth	130.56	173.17	44.00	3.94**
18.	Girth increment rate under tapping	0.85	2.37	0.98	2.41**
19.	Length of tapping panel	273.86	50.75	24.00	2.11**
20.	Height at forking	0.13	0.76	0.48	1.59*
21.	Virgin bark thickness	11.69	2.44	0.82	2.96**
22.	Renewed bark thickness	0.94	1.46	0.54	2.70**
23.	Total chlorophyll	34.73	0.83	0.45	1.84*
24.	Chlorophyll a	25.45	0.32	0.20	1.57*
25.	Chlorophyll b	3.37	0.21	0.13	1.66*
26.	Chlorophyll a:b ratio	9.98	0.30	0.26	1.15

* Significant at P = 0.05

**Significant at P = 0.01

Table 5. Yield of clones at the fourth year of tapping.

Sl. No.	Clone	Dry rubber yield (g tree^{-1} tapping^{-1})			Yield depression under stress** (%)	Volume of latex (ml tree^{-1} tapping^{-1})		
		Annual**	Stress**	Peak**		Annual**	Stress**	Peak**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.	Waring 4	27.06	18.15	35.53	32.4	93.72	50.75	130.79
2.	AVROS 352	33.98	24.89	52.81	27.6	137.26	75.61	194.17
3.	Ch 4	27.16	17.74	41.98	35.1	88.59	43.18	144.38
4.	PB 213	39.95	27.13	49.55	34.2	136.59	76.55	180.63
5.	BD 10	27.00	18.12	41.92	33.6	85.00	43.32	135.09
6.	PB 215	54.67	39.57	81.23	29.9	158.52	95.38	239.79
7.	PR 107	36.60	25.40	46.06	30.7	112.90	65.19	155.34
8.	Mil 3/2	39.40	31.67	47.61	19.1	136.21	92.09	187.42
9.	Gl 1	46.03	33.20	62.65	27.8	144.93	70.11	213.96
10.	PB 252	67.13	54.05	81.98	19.5	209.88	141.33	266.88
11.	PB 28/83	63.36	53.01	79.49	18.1	172.58	109.78	247.29
12.	Ch 32	31.76	24.65	40.09	25.2	102.25	52.84	147.25
13.	Lun N	36.54	28.69	41.97	22.4	117.64	76.67	149.17
14.	Tjir 16	28.51	14.45	40.86	49.4	105.69	45.85	158.84
15.	PB 230	57.77	36.28	78.72	37.3	173.82	87.63	246.25
16.	PB 28/59	35.20	24.02	43.18	39.2	117.97	90.08	134.38
17.	HC 55	31.58	24.67	41.92	23.3	98.73	53.42	160.42
18.	LCB 1320	57.68	37.28	80.16	35.7	171.68	96.13	242.42
19.	PB 206	47.01	32.92	62.21	30.0	150.85	78.79	216.04
20.	PB 242	62.94	48.37	75.35	22.1	187.53	116.13	242.50
21.	PB 86	48.16	39.53	58.45	17.6	160.43	129.50	190.63
22.	GT 1	54.14	34.16	68.38	37.4	175.47	110.25	225.84
23.	Ch 153	52.95	38.27	62.41	30.2	159.06	100.23	203.96
24.	Ch 29	22.37	12.32	34.12	48.8	77.33	37.50	121.00

Table 5 contd.....

Table 5 contd..

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
25.	AVT 73	43.26	37.56	45.29	13.8	145.68	119.46	167.15
26.	PB 5/139	40.16	28.00	56.21	37.0	116.72	75.79	159.38
27.	PB 6/50	45.46	31.19	60.58	31.4	155.51	84.58	198.55
28.	Ch 26	66.64	47.10	84.96	28.7	199.26	120.79	273.83
29.	RRII 105	68.20	52.79	95.60	23.4	198.16	125.90	279.79
30.	PB 5/51	56.05	35.90	80.09	35.5	151.60	83.63	208.96
31.	PB 5/60	38.21	24.90	49.73	34.9	114.06	52.13	154.38
32.	PB 5/76	63.65	42.65	86.93	34.3	175.20	98.69	257.92
33.	RSY 23	40.58	30.14	57.55	25.1	121.24	69.90	190.96
34.	Ch 2	46.87	25.25	73.88	45.6	148.01	48.71	242.29
35.	BD 5	29.94	17.47	47.17	42.2	85.88	31.90	145.46
36.	HC 28	41.95	32.20	50.22	18.4	125.54	73.92	160.09
37.	PB 217	71.19	60.82	84.39	16.9	207.34	163.42	265.63
38.	PB 5/63	53.51	37.53	72.84	29.0	163.49	98.67	220.00
39.	AVROS 255	37.10	24.53	55.05	39.3	121.49	55.44	192.71
40.	PB 235	77.01	58.11	85.76	25.0	212.39	166.63	241.65
General Mean		46.22	33.12	60.87	30.11	142.90	85.20	197.33
CD (0.05)		20.740	18.654	25.434	16.34	63.611	54.455	82.78

** Clonal variation significant at P = 0.01

Figure 5. Dry rubber yield in clones.

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

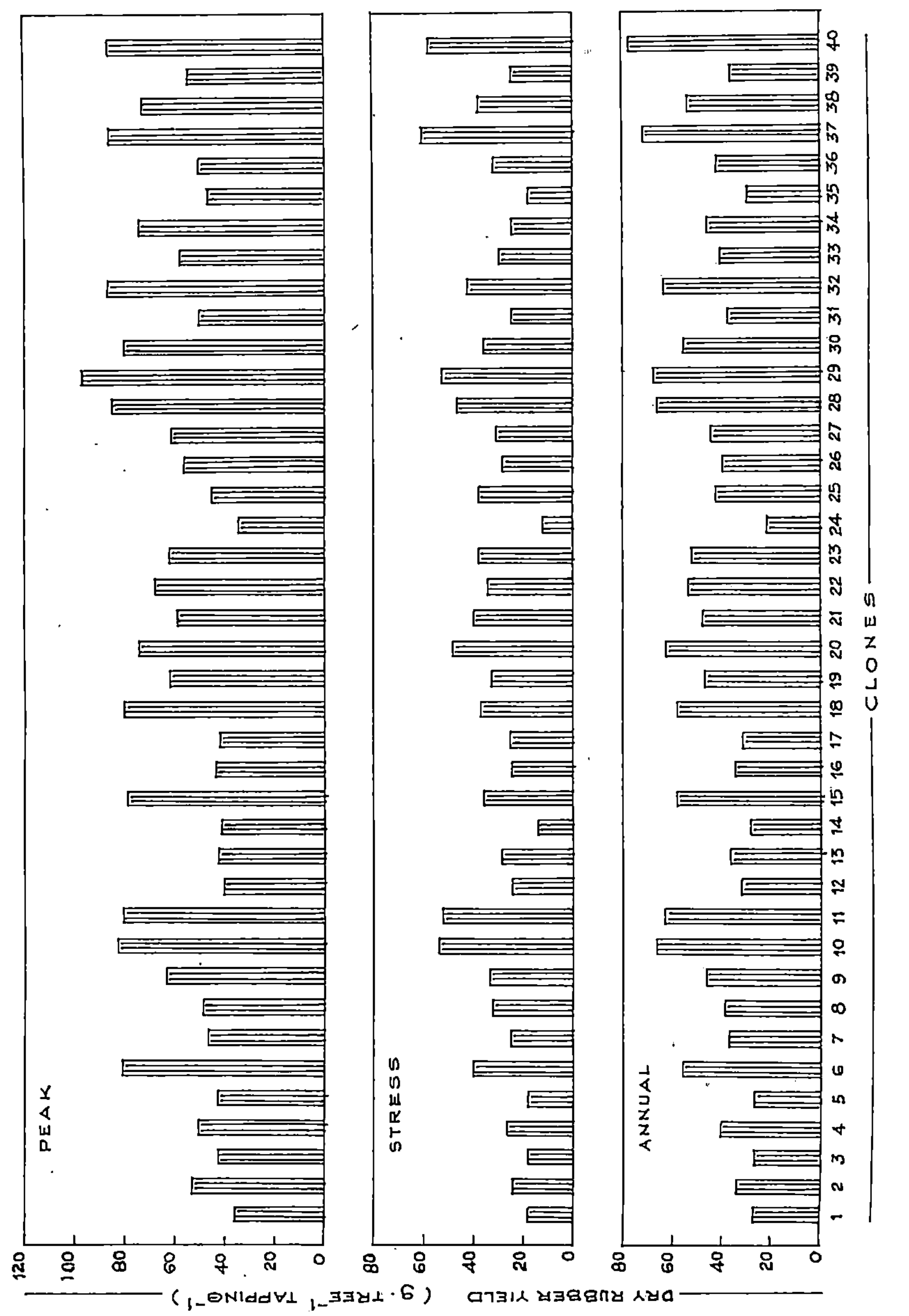


FIG.5. DRY RUBBER YIELD IN CLONES.

60.82 g tree^{-1} tapping^{-1} and Ch 29 was the lowest yielder (12.32 g tree^{-1} tapping^{-1}). The forty clones in general recorded a yield of 33.12 g tree^{-1} tapping^{-1}. Seven clones viz., PB 235, PB 252, PB 28/83 and RRII 105 with more than 50 g tree^{-1} tapping^{-1} and PB 242, Ch 26 and PB 5/76 with more than 40 g tree^{-1} tapping^{-1} were on par with PB 217.

The clones in general recorded a mean yield of 60.87 g tree^{-1} tapping^{-1} during the peak period. RRII 105 with 95.60 g tree^{-1} tapping^{-1} was the highest yielder while Ch 29 gave the lowest yield of 34.12 g tree^{-1} tapping^{-1}. Thirteen clones were on par with RRII 105 viz., PB 5/76, PB 235, Ch 26, PB 217, PB 252, PB 215, LCB 1320 and PB 5/51 with more than 80 g tree^{-1} tapping^{-1} and PB 28/83, PB 230, PB 242, Ch 2 and PB 5/63 with more than 70 g tree^{-1} tapping^{-1}.

The percentage yield depression under stress ranged from 13.84 for AVT 73 to 49.4 for Tjir 16 with a general mean of 30.11. Eighteen clones were on par with AVT 73 viz. PB 217, PB 86, PB 28/83, HC 28, Mil 3/2 and PB 252 with less than 20 per cent yield depression and PB 242, Lun N, HC 55, RRII 105, PB 235, RSY 23, Ch 32, AVROS 352, Gl 1, Ch 26, PB 5/63 and PB 215 with less than 30 per cent yield depression (Table 5).

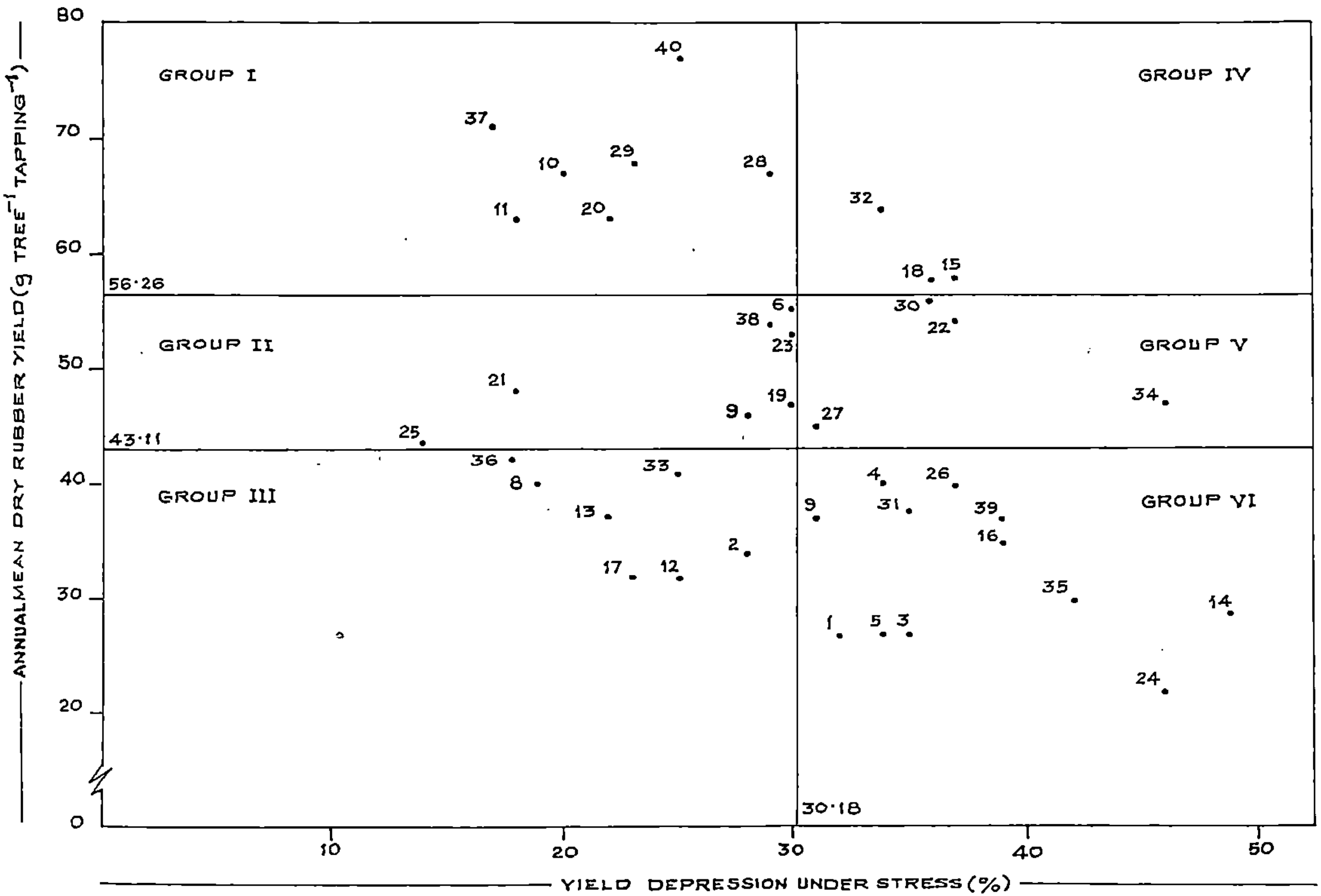
Figure 6 shows the annual mean yield plotted against the extent of yield depression under stress for the forty clones. Seven

Figure 6. Dry rubber yield against yield depression under stress in clones.

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

Group I - High yield and low depression; Group II - Medium yield and low depression; Group III - Low yield and low depression; Group IV - High yield and high depression; Group V - Medium yield and high depression; Group VI - Low yield and high depression.

FIG.6. DRY RUBBER YIELD AGAINST YIELD DEPRESSION UNDER STRESS IN CLONES.



and PB 252 were classified under group I representing high yield in combination with a low yield depression under stress. Seven clones with medium yield and low yield depression under stress were grouped under the second category. They were PB 215, PB 5/63, Ch 153, PB 86, PB 206, Gl 1 and AVT 73. Group III which denoted clones with low yield and low yield depression under stress included seven clones, viz., HC 28, RSY 23, Mil 3/2, Lun N AVROS 352, Ch 32 and HC 55. Group IV comprised three clones PB 5/76, LCB 1320 and PB 230 with high yield and high yield depression under stress. Group V comprised four medium yielders with high yield depression viz. PB 5/51, GT 1, Ch 2 and PB 6/50. Twelve clones viz. PB 213, PR 107, PB 5/139, PB 5/60, AVROS 255, PB 28/59, BD 5, Tjir 16, Ch 29, Waring 4, BD 10 and Ch 4 with low yield and low yield depression under stress came under group VI.

4.1.1.2. Volume of latex

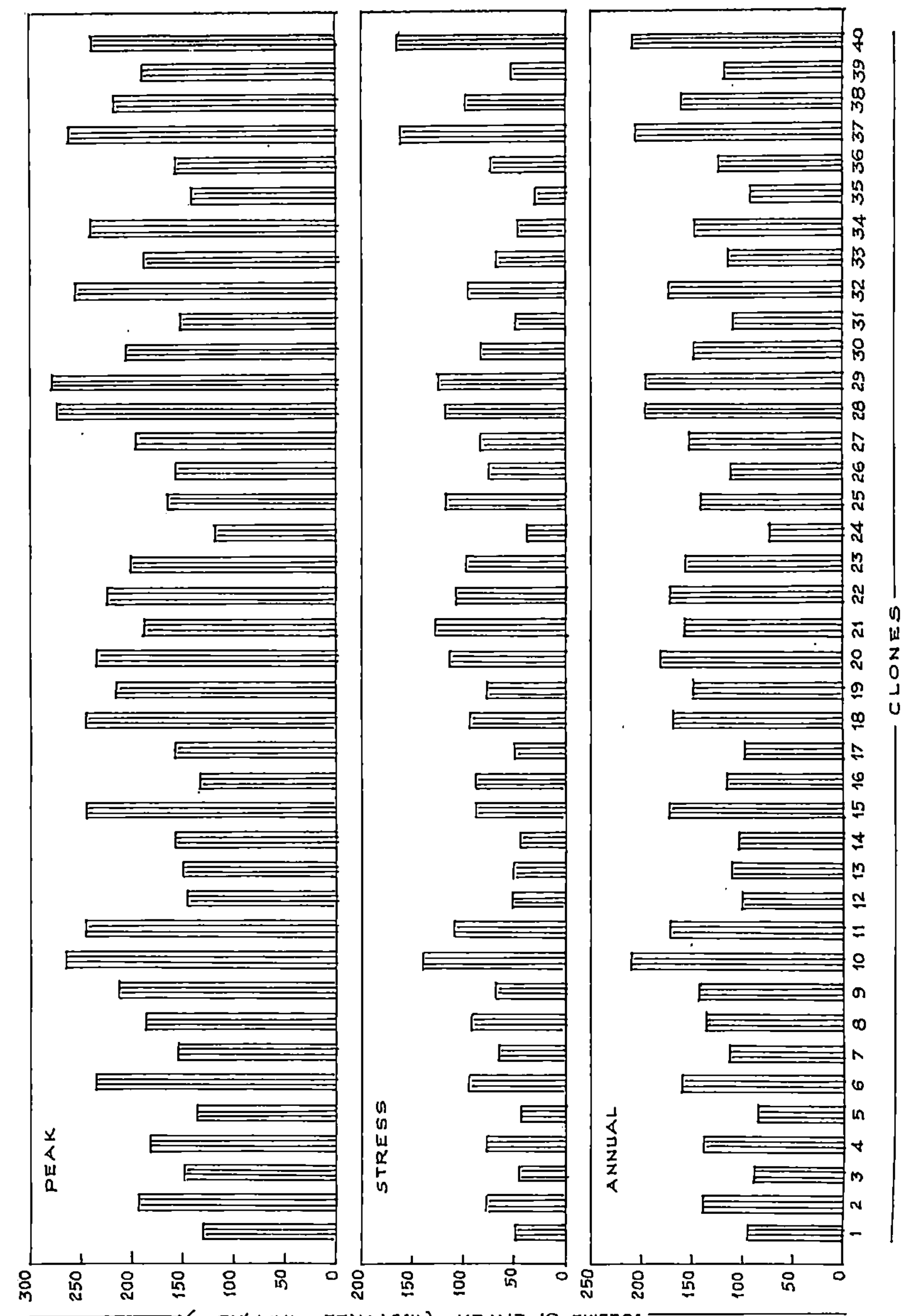
Yield of latex recorded as mean over the fourth year of tapping, for the stress period and for the peak yield period exhibited highly significant clonal variation (Tables 4 and 5). Figure 7 represents the variability for volume of latex among clones.

Annual mean yield of latex over the forty clones was 142.90 ml tree^{-1} tapping^{-1} ranging from 77.33 ml tree^{-1} tapping

Figure 7. Volume of latex in clones.

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

FIG. 7. VOLUME OF LATEX IN CLONES.



for Ch 29 to 212.39 ml tree^{-1} tapping^{-1} for PB 235. Seventeen clones were on par with PB 235 of which PB 252 and PB 217 yielded more than 200 ml tree^{-1} tapping^{-1}, Ch 26 and RRII 105 gave more than 190 ml tree^{-1} tapping^{-1}, GT 1, PB 5/76, PB 230, PB 28/83 and LCB 1320 yielded more than 170 ml tree^{-1} tapping^{-1}, PB 5/63 and PB 86, yielded more than 160 ml tree^{-1} tapping^{-1} and five clones viz. Ch 153, PB 215, PB 6/50, PB 5/51 and PB 206 yielded more than 150 ml tree^{-1} tapping^{-1}.

The clones recorded a general mean yield of 85.20 ml of latex tree^{-1} tapping^{-1} under stress and values for individual clones ranged from 31.90 ml tree^{-1} tapping^{-1} (BD 5) to 166.63 ml tree^{-1} tapping^{-1} (PB 235). Eight clones were superior and on par for yield of latex viz. PB 235, PB 217, PB 252, PB 86, RRII 105, Ch 26, AVT 73 and PB 242 which yielded more than 115 ml tree^{-1} tapping^{-1}.

During the peak yield period, RRII 105 gave the highest yield of latex (279.79 ml tree^{-1} tapping^{-1}) followed by eighteen clones which were on par with it. Of these, four clones viz. Ch 26, PB 252, PB 217 and PB 5/76 yielded more than 250 ml tree^{-1} tapping^{-1}, six clones viz. PB 28/83, PB 230, PB 242, LCB 1320, Ch 2 and PB 235 gave more than 240 ml tree^{-1} tapping^{-1} and eight clones viz. PB 215, GT 1, PB 5/63, PB 206, Gl 1, PB 5/51, Ch 153 and PB 6/50 yielded about 200 ml tree^{-1} tapping^{-1} and above. The general mean value was 197.33 ml tree^{-1} tapping^{-1}.

4.1.1.3. Dry rubber content

Clonal differences with respect to dry rubber content (D.R.C.) expressed as mean over the fourth year of tapping, the stress period and the peak yield period were highly significant (Table 4). Variability for the trait is represented in figure 8 and table 6.

Annual mean D.R.C. among the forty clones ranged from 28.13 per cent for Waring 4 to 40.88 per cent for PB 28/83 which was superior and on par with ten other clones viz. PB 5/76, PB 5/51, LCB 1320, BD 10, PB 235, RSY 23, HC 55, PB 215, RRII 105 and Ch 153 exhibiting D.R.C. values greater than 37 per cent. Six clones, PB 28/59, PB 86, Ch 29, Tjir 16, AVT 73 and Waring 4 had a low dry rubber content. The forty clones in general recorded a D.R.C. of 34.77 per cent.

During the stress period, D.R.C. values ranged from 29.93 per cent (Waring 4) to 43.47 per cent (PB 28/83) with a general mean of 36.81 per cent. Thirteen clones were superior and on par with PB 28/83 viz. PB 5/51, PB 5/76, Ch 2, BD 10, LCB 1320, HC 55 and PB 215 having D.R.C. values higher than 40 per cent and PR 107, RRII 105, BD 5, RSY 23, Ch 32 and Ch 153 with D.R.C. values higher than 38.79 per cent.

Dry rubber content during the peak yield period was high in respect of twelve clones viz. PB 5/51, PB 5/76 and PB 28/83

Figure 8. Dry rubber content in clones.

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

FIG.8. DRY RUBBER CONTENT IN CLONES.

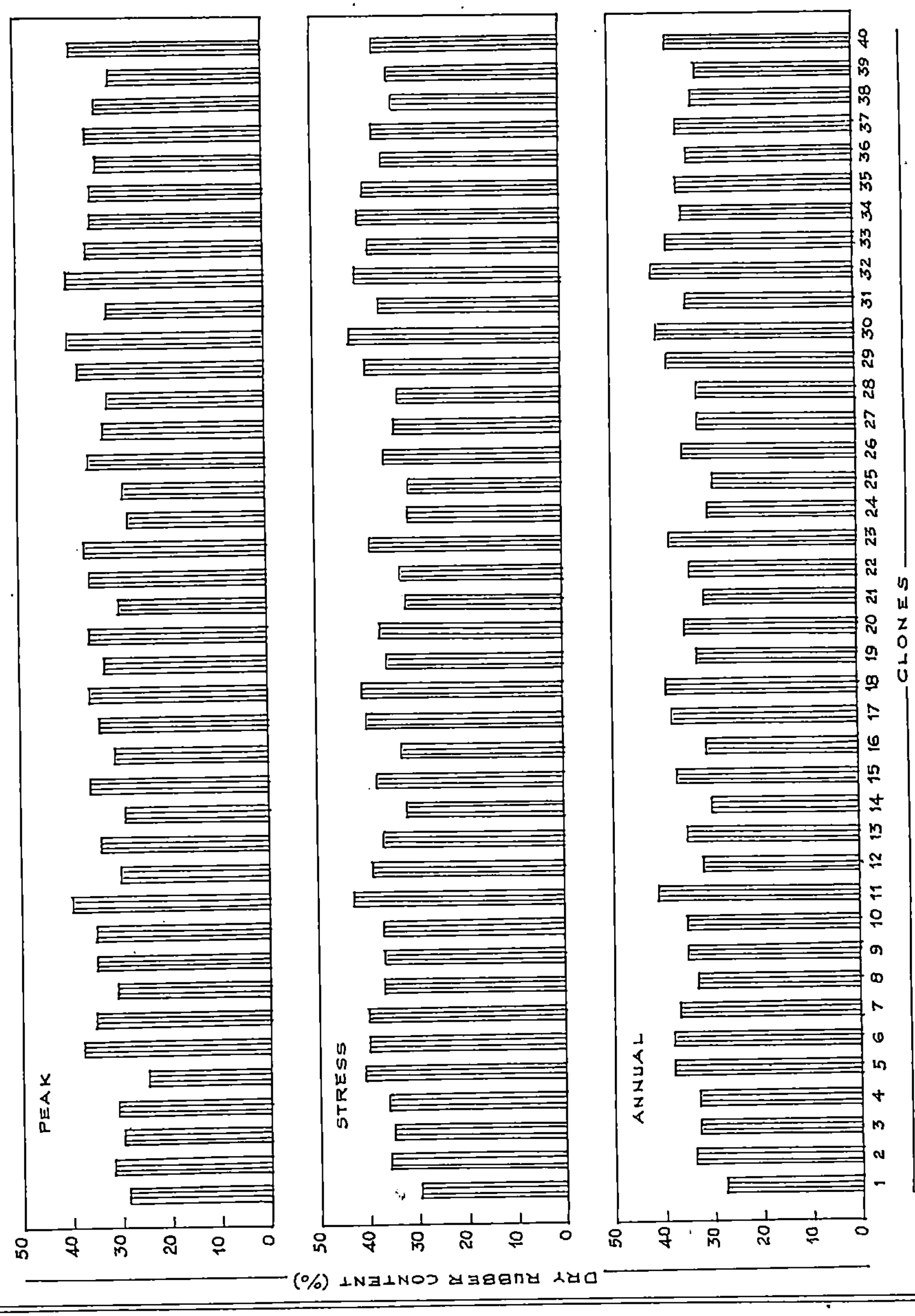


Table 6. Dry rubber content, latex flow rate and plugging index in clones.

Sl. No.	Clone	Dry rubber content (%)			Latex flow rate (ml min^{-1})			Plugging index		
		Annual **	Stress**	Peak**	Annual**	Stress**	Peak**	Annual**	Stress**	Peak**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1.	Waring 4	28.13	29.93	28.53	2.63	2.41	3.03	4.30	7.24	2.45
2.	AVROS 352	33.56	35.84	31.50	3.85	3.54	4.07	4.35	6.22	2.60
3.	Ch 4	32.62	35.27	30.38	3.34	3.12	3.85	5.41	7.73	3.76
4.	PB 213	33.31	35.56	31.11	4.35	3.69	5.07	4.31	6.27	3.11
5.	BD 10	38.36	40.57	25.07	3.10	2.58	3.84	5.39	8.00	3.48
6.	PB 215	37.66	40.04	37.83	5.74	4.97	6.49	5.07	6.89	3.24
7.	PR 107	37.08	39.84	34.75	4.38	3.49	5.06	4.82	6.59	3.60
8.	Mil 3/2	33.01	37.10	30.84	3.76	3.25	4.58	2.90	4.08	2.51
9.	Gl 1	35.25	36.97	35.12	5.11	4.75	5.67	4.82	8.12	2.68
10.	PB 252	34.52	37.14	34.52	6.51	5.62	7.18	3.45	4.39	2.77
11.	PB 28/83	40.88	43.47	40.03	5.02	4.63	5.56	3.24	4.30	2.28
12.	Ch 32	32.26	38.96	30.33	3.07	2.36	3.56	3.92	5.66	2.55
13.	Lun N	34.57	36.78	34.07	3.81	3.54	4.40	4.45	5.97	3.60
14.	Tjir 16	30.13	31.59	28.66	3.50	3.26	3.82	5.24	9.32	2.70
15.	PB 230	36.87	37.87	36.29	5.55	4.30	6.46	4.42	6.16	3.33
16.	PB 28/59	31.34	32.55	30.64	2.87	2.76	2.93	3.01	4.19	2.32

(Contd....)

Table 6 contd...

(1) (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
17. HC 55	37.80	40.21	34.40	3.12	2.82	3.32	4.99	7.68	2.54
18. LCB 1320	38.76	40.56	36.19	5.23	4.25	6.12	3.90	5.59	2.68
19. PB 206	33.30	35.65	32.69	4.52	3.80	5.15	3.82	5.72	2.56
20. PB 242	35.19	36.61	35.92	6.18	5.41	6.60	3.69	4.93	2.75
21. PB 86	30.50	31.55	29.75	5.60	5.43	6.29	3.85	4.55	3.55
22. GT 1	33.92	32.66	35.54	4.09	3.99	4.42	3.19	4.93	2.12
23. Ch 153	37.63	38.79	36.72	5.43	4.87	5.67	5.52	8.82	3.46
24. Ch 29	30.16	30.74	28.38	2.72	2.16	3.35	4.64	6.39	3.39
25. AVT 73	29.40	31.29	29.40	4.08	3.63	4.13	3.67	4.63	2.63
26. PB 5/139	35.28	35.66	35.52	3.75	3.24	4.27	4.54	6.96	2.94
27. PB 6/50	32.17	33.82	33.13	4.70	4.32	4.96	3.65	5.41	2.42
28. Ch 26	31.89	32.56	32.43	5.83	5.20	6.18	3.34	4.54	2.26
29. RRII 105	37.63	39.81	37.99	6.73	5.67	7.62	4.25	5.68	2.87
30. PB 5/51	39.96	42.64	40.35	5.34	4.65	6.13	4.55	6.33	3.34
31. PB 5/60	33.78	36.71	32.32	4.38	3.80	4.69	5.26	8.39	3.33
32. PB 5/76	40.82	41.64	40.20	6.33	5.72	7.14	4.73	6.60	2.94
33. RSY 23	37.91	39.31	36.00	5.53	4.15	7.44	5.55	7.01	4.16
34. Ch 2	34.99	41.21	34.84	5.42	3.72	6.82	6.21	11.16	3.05
35. BD 5	36.39	39.79	35.25	4.01	3.14	4.83	7.29	11.71	3.70
36. HC 28	33.86	35.86	33.84	4.56	4.28	4.58	4.65	6.17	3.30

(Contd...)

Table 6 contd.....

(1) (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
37. PB 217	36.48	38.18	36.29	7.31	6.36	8.31	4.05	4.60	3.31
38. PB 5/63	32.65	34.01	33.56	4.56	3.95	5.00	3.27	4.15	2.59
39. AVROS 255	32.40	35.33	31.19	3.90	2.91	4.73	4.13	6.11	2.61
40. PB 235	38.21	38.30	39.36	6.15	6.37	5.89	3.15	4.13	2.60
General mean	34.77	36.81	34.02	4.65	4.05	5.23	4.37	6.33	2.95
CD (0.05)	3.312	4.797	4.613	1.673	1.753	1.895	1.463	2.849	0.989

** Clonal variation significant at P = 0.01.

with more than 40 per cent and PB 235, RRII 105, PB 215, Ch 153, PB 217, PB 230, LCB 1320, RSY 23 and PB 242 with values higher than 35.75 per cent. The lowest D.R.C. was recorded by Ch 29 (28.38 per cent) and the general mean was 34.02 per cent.

4.1.1.4. Latex flow rate

Highly significant clonal variation was observed for the initial rate of latex flow during the stress period, the peak yield period and the fourth year of tapping (Table 4). Table 6 also gives the performance of the forty clones.

The annual mean latex flow rate ranged from 2.63 ml $minute^{-1}$ for Waring 4 to 7.31 ml $minute^{-1}$ for PB 217 with a general mean of 4.65 ml $minute^{-1}$. Eight clones viz. PB 217 with a flow rate of 7.31 ml $minute^{-1}$, RRII 105, PB 252, PB 5/76, PB 242 and PB 235 with a flow rate exceeding 6.0 ml $minute^{-1}$ and Ch 26 and PB 215 with a flow rate exceeding 5.7 ml $minute^{-1}$ were superior and on par.

Mean flow rate under stress for the clones in general was 4.05 ml $minute^{-1}$ and ranged from 2.16 ml $minute^{-1}$ (Ch 29) to 6.37 ml $minute^{-1}$ (PB 235). Twelve clones were on par with PB 235 viz. PB 217 (6.36 ml $minute^{-1}$), PB 5/76, RRII 105, PB 252, PB 86, PB 242, Ch 26 (greater than 5.2 ml $minute^{-1}$) and PB 215, Ch 153, Gl 1, PB 5/51 and PB 28/83 (greater than 4.63 ml $minute^{-1}$).

The general mean rate of latex flow during the peak yield period was 5.23 ml minute^{-1} and ranged from 2.93 ml minute^{-1} (PB 28/59) to 8.31 ml minute^{-1} (PB 217). Eight clones were superior and on par with PB 217 viz. RRII 105, RSY 23, PB 252 and PB 5/76 with a flow rate exceeding 7 ml minute^{-1} and Ch 2, PB 242, PB 215 and PB 230 with a flow rate exceeding 6.4 ml minute^{-1}.

4.1.1.5. Plugging index

Clonal variation for plugging index over the fourth year of tapping, for the stress period and for the peak yield period was highly significant (Table 4). Figure 9 represents the variability and the performance of the forty clones is presented in table 6.

Plugging index during the fourth year of tapping of the clones in general was 4.37 and ranged from 2.90 (Mil 3/2) to 7.29 (BD 5). Twenty clones were superior and on par with Mil 3/2. All the clones with high annual mean yield had a low plugging index, except PB 5/76. Other low plugging clones included medium and low yielders.

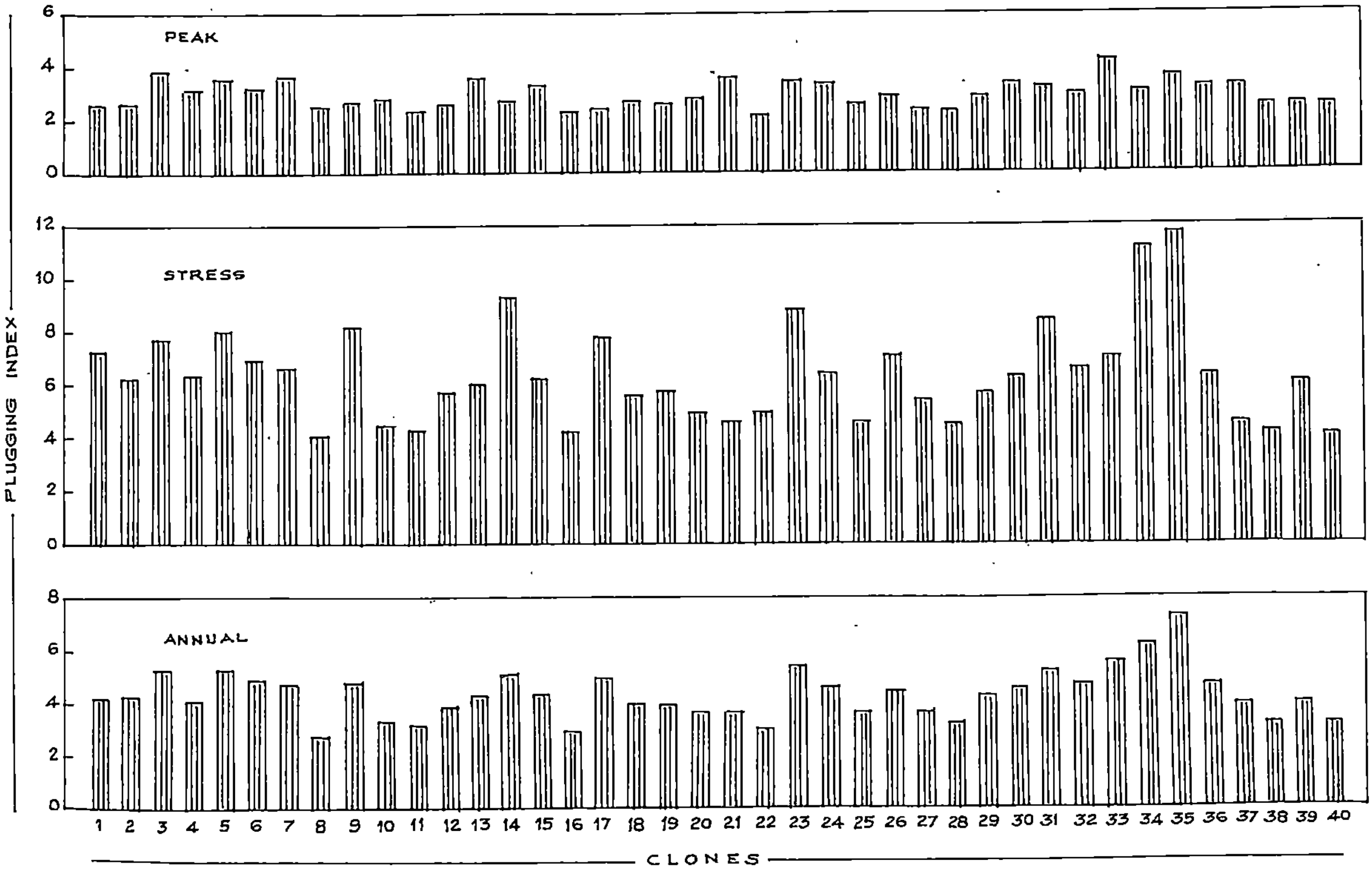
The general mean value for plugging index during the stress period was 6.33 ranging from 4.08 (Mil 3/2) to 11.71 (BD 5). Twenty seven clones recorded values which were superior and on par with Mil 3/2.

Plugging index during the peak yield period was 2.95 for the clones in general and ranged from 2.12 (GT 1) to 4.16 (RSY 23). Twenty four clones recorded low values which were on par with GT 1.

Figure 9. Plugging index in clones.

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

FIG. 9. PLUGGING INDEX IN CLONES.



4.1.1.6. Girth

The vigour of clones in terms of girth is presented in table 7 and figure 10. Highly significant differences among clones were evident (Table 4). The clones in general recorded a mean girth of 72.89 cm during the fourth year of tapping. Girth ranged from 60.08 cm (Ch 2) to 96.33 cm (PB 235). Clones PB 215 (86.92 cm) and AVT 73 (86.42 cm) were superior and on par with PB 235.

4.1.1.7. Girth increment rate under tapping

The variability in mean rate of girth increment under tapping is represented along with the girth of clones in figure 10 and table 7. Highly significant clonal variation was observed (Table 4) with the clones in general showing a mean girth increment rate of 3.78 cm $year^{-1}$. The clone AVT 73 recorded the maximum girth increment rate of 5.96 cm $year^{-1}$ and was on par with nine clones viz. RSY 23, PB 235,. PB 28/59, HC 28, Ch 2, PB 215, PB 217, PB 6/50 and PB 230. Ch 32 showed the lowest rate of girth increment (2.34 cm $year^{-1}$).

4.1.1.8. Length of tapping panel

Highly significant clonal differences were observed for length of the tapping panel (Table 4) and the range of variability for the trait was 36.75 cm (PB 5/139) to 56.92 cm (PB 235) with a general mean of 42.47 cm (Table 7). Clones PB 217 (50.17 cm)

Table 7. Morphological and structural attributes in clones.

Sl. No.	Clone	Girth** (cm)	Girth increment** (cm year^{-1})	Tapping panel length** (cm)	Forking height* (m)	Bark thickness (mm) Virgin**	Bark thickness (mm) Renewed**
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.	Waring 4	65.08	2.92	40.75	3.8	6.08	5.50
2.	AVROS 352	75.50	4.08	42.00	3.3	8.00	7.67
3.	Ch 4	68.00	2.63	39.25	3.8	7.67	6.33
4.	PB 213	66.92	2.92	39.67	2.7	7.50	7.00
5.	BD' 10	72.25	3.79	38.50	3.4	7.00	6.83
6.	PB 215	86.92	4.67	46.08	3.5	8.58	8.00
7.	PR 107	63.83	3.38	37.58	3.6	7.33	6.67
8.	Mil 3/2	74.83	3.88	40.83	3.4	6.75	7.00
9.	Gl 1	72.08	4.21	43.58	2.8	8.58	8.00
10.	PB 252	80.25	3.92	47.92	4.8	9.33	8.50
11.	PB 28/83	62.92	3.42	43.58	3.3	8.33	7.33
12.	Ch 32	60.08	2.34	37.42	2.9	5.75	6.33
13.	Lun N	65.75	2.46	41.17	3.2	7.67	6.67
14.	Tjir 16	65.67	2.71	40.50	2.9	7.50	8.00
15.	PB 230	75.67	4.42	42.33	3.6	7.08	7.00
16.	PB 28/59	72.00	4.83	40.33	3.2	7.00	7.67
17.	HC 55	67.17	2.71	37.33	3.0	6.50	6.67

(Contd.....)

Table 7. Contd.....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
18.	LCB 1320	80.83	4.30	46.00	4.3	7.75	7.50
19.	PB 206	64.75	2.59	39.68	2.7	5.75	6.33
20.	PB 242	78.92	3.71	47.00	4.5	9.25	8.67
21.	PB 86	73.25	4.04	43.08	3.4	6.58	6.33
22.	GT 1	77.25	4.09	46.08	3.3	7.42	7.00
23.	Ch 153	75.58	4.30	43.25	3.4	7.75	7.83
24.	Ch 29	67.67	3.33	39.83	3.6	6.17	6.33
25.	AVT 73	86.42	5.96	48.08	3.3	7.00	7.50
26.	PB 5/139	65.50	3.25	36.75	2.8	6.92	6.83
27.	PB 6/50	79.67	4.50	47.83	3.2	7.50	7.17
28.	Ch 26	74.25	3.79	37.08	2.8	7.58	7.50
29.	RRII 105	68.75	3.04	42.67	2.9	7.58	7.50
30.	PB 5/51	71.75	4.34	45.25	4.1	8.33	6.33
31.	PB 5/60	68.33	2.75	39.25	3.4	6.17	6.17
32.	PB 5/76	73.25	4.00	42.58	2.6	7.17	7.17
33.	RSY 23	78.25	5.58	39.58	3.3	7.08	7.50
34.	Ch 2	75.08	4.75	42.92	3.5	7.67	7.00
35.	BD 5	65.33	3.38	41.08	3.0	6.08	7.83

(Contd.....)

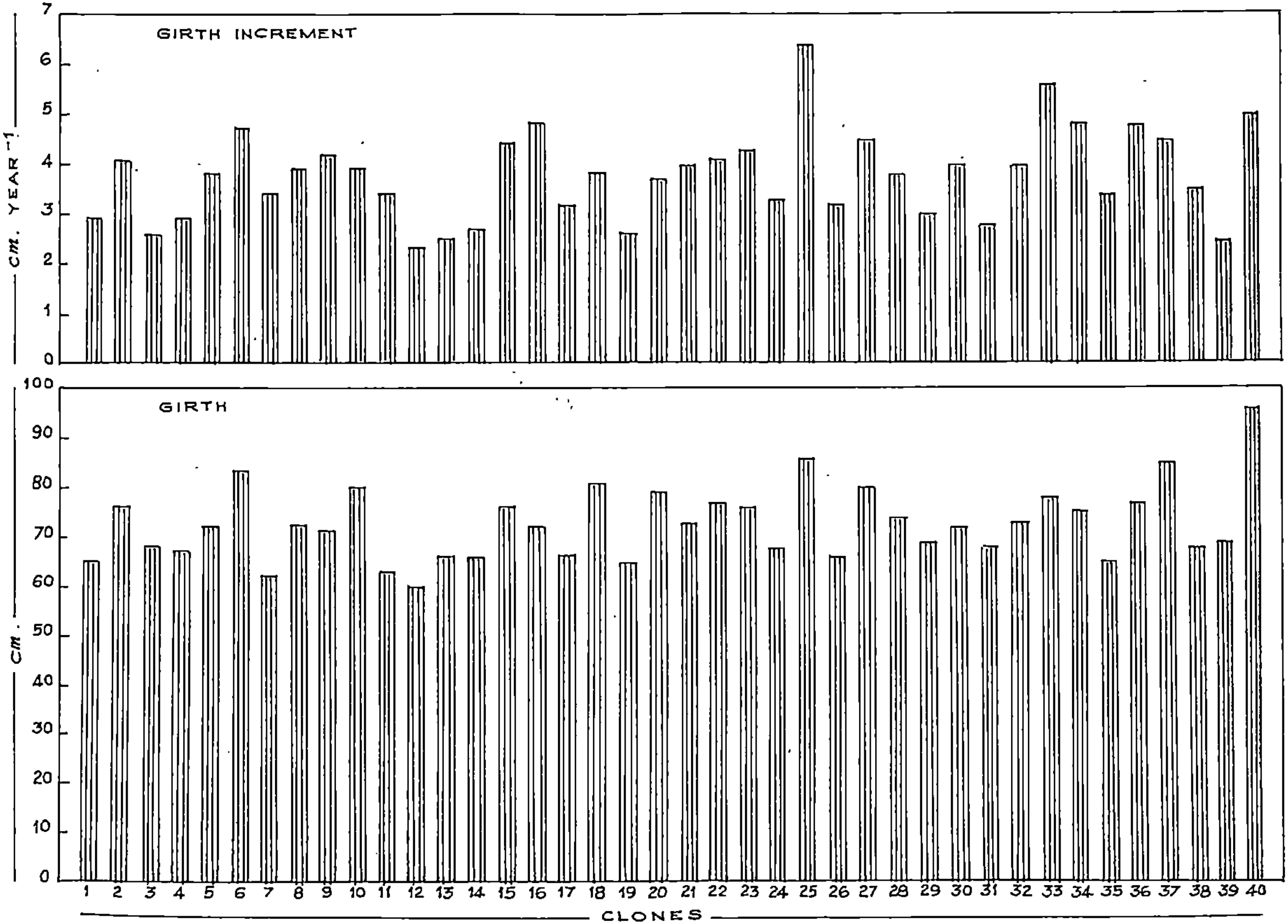
Table 7 contd.....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
36.	HC 28	76.50	4.79	43.08	2.8	7.42	6.67
37.	PB 217	85.08	4.50	50.17	3.6	7.25	6.67
38.	PB 5/63	68.33	3.54	42.25	3.2	8.00	7.00
39.	AVROS 255	69.50	2.46	39.75	4.1	6.50	6.17
40.	PB 235	96.33	4.96	56.92	3.8	9.17	7.83
General mean		72.89	3.78	42.47	3.36	7.37	7.10
C.D (0.05)		10.789	1.613	7.968	1.122	1.477	1.195

* Clonal variation significant at P = 0.05

** Clonal variation significant at P = 0.01

FIG.10. GIRTH AND GIRTH INCREMENT IN CLONES.



and AVT 73 (48.08 cm) were superior and on par with PB 235.

4.1.1.9. Height at forking

The clones differed significantly with respect to height at first forking (Table 7) and the range of variability was 2.57 m (PB 5/76) to 4.79 m (PB 252) with the clones in general having produced the first fork at a height of 3.36 m.

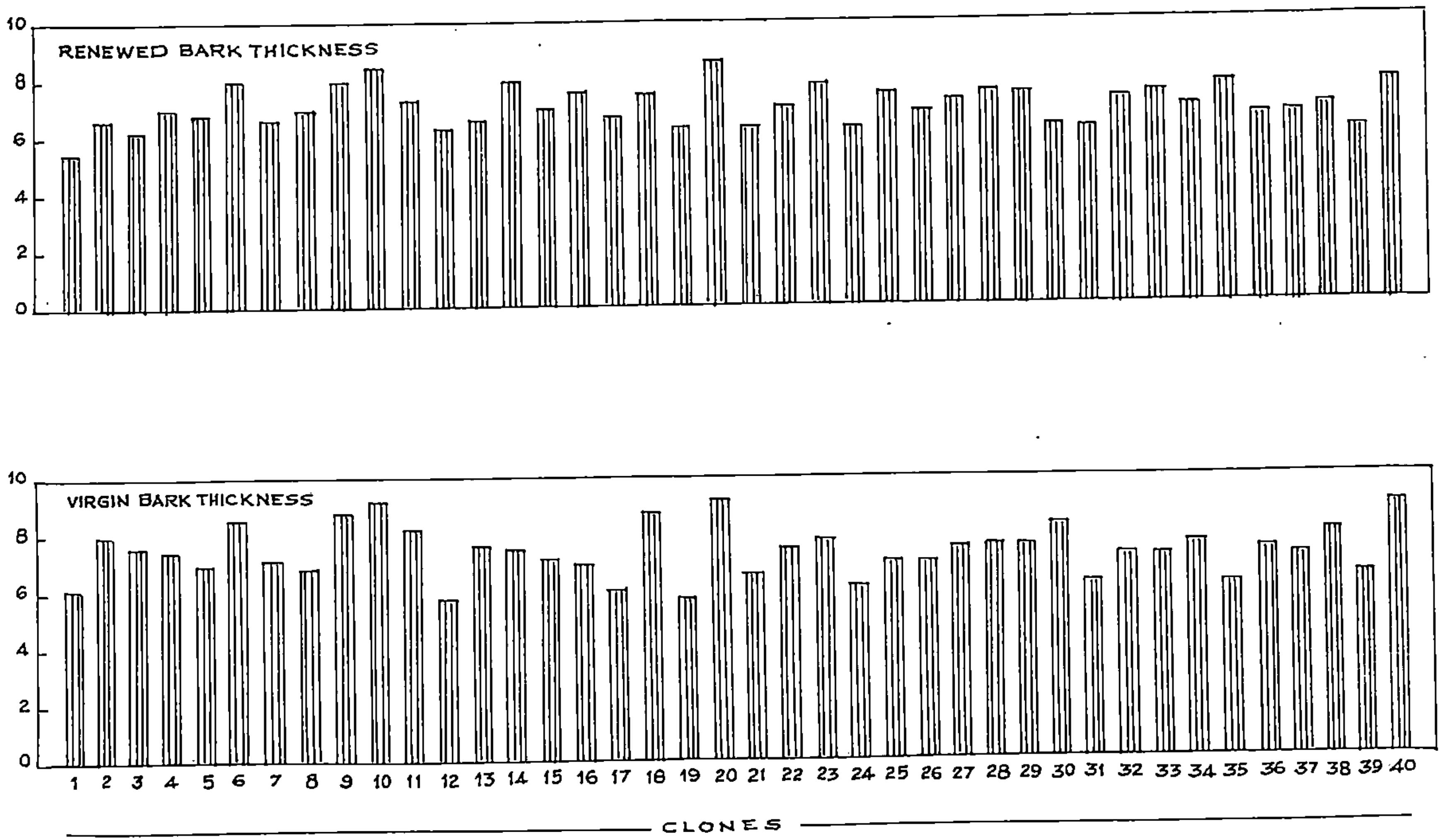
4.1.1.10. Virgin bark thickness

Variability for virgin bark thickness was highly significant (Table 4) and is presented in table 7 and figure 11. Virgin bark thickness ranged from 5.75 mm in clone PB 206 to 9.33 mm in PB 252. The clones in general exhibited a thickness of 7.37 mm for the virgin bark. Eight clones viz. PB 242 and PB 235 with values greater than 9 mm and PB 215, Gl 1, PB 28/83, PB 5/51, AVROS 352 and PB 5/63 with values greater than 8 mm were on par with PB 252. Seventeen clones had thin bark and were on par with PB 206.

4.1.1.11. Renewed bark thickness

Highly significant clonal variation was observed for thickness of four years, renewed bark (Table 4). The general mean value for the trait was 7.1 mm with a range of 5.5 mm (Waring 4) to 8.67 mm (PB 242). Fourteen clones showed values greater than 7.5 mm and were on par with PB 242. The variability for the trait is represented in figure 11 and table 7.

FIG.11. BARK THICKNESS IN CLONES.



4.1.1.12. Chlorophyll content

There was significant clonal variation for total chlorophyll, chlorophyll-a and chlorophyll-b, but not for the chlorophyll a:b ratio (Table 4).

Total chlorophyll content ranged from 2.12 mg per g fresh weight of leaf (PB 86) to 4.63 mg per g fresh weight (Gl 1) as shown in table 8. Seven clones were on par with Gl 1 viz. Lun N, RRII 105, PB 5/139, PB 28/59, BD 10, PB 215 and Ch 26 with a total chlorophyll content greater than 3.5 mg per g fresh weight. The general mean value was 3.27 mg.

Content of chlorophyll-a ranged from 1.13 mg per g fresh weight of leaf (PB 86) to 2.59 mg per g fresh weight (Lun N) with a general mean of 1.75 mg per g fresh weight as shown in table 8.

Chlorophyll-b showed a range of 0.99 mg per g fresh weight of leaf (PB 86) to 2.06 mg per g fresh weight and a general mean of 1.52 mg per g fresh weight of leaf.

The general mean value with respect to chlorophyll a:b ratio was 1.24 and individual values ranged from 0.88 in clone PB 235 to 2.07 in clone Ch 32.

4.1.2. Genetic parameters

The mean, standard error, range and estimates of the genetic

Table 8. Leaf chlorophyll content in clones.

Sl. No.	Clones	Total chlorophyll* (mg/g fresh wt of leaf)	Chlorophyll a* (mg/g fresh wt of leaf)	Chlorophyll b* (mg/g fresh wt of leaf)	Chlorophyll a:b ratio
(1)	(2)	(3)	(4)	(5)	(6)
1.	Waring 4	3.27	1.67	1.60	0.97
2.	AVROS 352	3.42	2.10	1.33	1.63
3.	Ch 4	3.34	1.86	1.48	1.24
4.	PB 213	2.36	1.27	1.10	1.25
5.	BD 10	3.86	1.89	1.96	0.90
6.	PB 215	3.68	2.31	1.37	1.77
7.	PR 107	3.14	1.61	1.53	1.05
8.	Mil 3/2	3.31	1.79	1.52	1.41
9.	Gl 1	4.63	2.56	2.06	1.31
10.	PB 252	3.29	1.64	1.65	0.97
11.	PB 28/83	3.47	1.66	1.81	0.89
12.	Ch 32	2.85	1.74	1.12	2.07
13.	Lun N	4.56	2.59	1.98	1.34
14.	Tjir 16	3.27	1.76	1.51	1.23
15.	PB 230	3.35	1.84	1.52	1.28
16.	PB 28/59	3.91	2.03	1.88	1.02
17.	HC 55	3.44	1.84	1.60	1.18
18.	LCB 1320	3.29	1.76	1.53	1.12
19.	PB 206	3.45	1.64	1.81	0.94
20.	PB 242	2.87	1.45	1.42	1.00
21.	PB 86	2.12	1.13	0.99	1.12
22.	GT 1	2.81	1.51	1.30	1.23
23.	Ch 153	3.15	1.84	1.31	1.44
24.	Ch 29	3.09	1.59	1.50	0.99

Figure 11. Bark thickness in clones

Number	Clone	Number	Clone
1.	Waring 4	21.	PB 86
2.	AVROS 352	22.	GT 1
3.	Ch 4	23.	Ch 153
4.	PB 213	24.	Ch 29
5.	BD 10	25.	AVT 73
6.	PB 215	26.	PB 5/139
7.	PR 107	27.	PB 6/50
8.	Mil 3/2	28.	Ch 26
9.	Gl 1	29.	RRII 105
10.	PB 252	30.	PB 5/51
11.	PB 28/83	31.	PB 5/60
12.	Ch 32	32.	PB 5/76
13.	Lun N	33.	RSY 23
14.	Tjir 16	34.	Ch 2
15.	PB 230	35.	BD 5
16.	PB 28/59	36.	HC 28
17.	HC 55	37.	PB 217
18.	LCB 1320	38.	PB 5/63
19.	PB 206	39.	AVROS 255
20.	PB 242	40.	PB 235

Table 8 contd...

(1)	(2)	(3)	(4)	(5)	(6)
25.	AVT 73	2.87	1.63	1.23	2.06
26.	PB 5/139	3.94	2.29	1.65	1.56
27.	PB 6/50	3.33	1.77	1.55	1.44
28.	Ch 26	3.57	1.84	1.73	1.03
29.	RRII 105	4.13	2.21	1.92	1.23
30.	PB 5/51	3.13	1.64	1.49	1.13
31.	PB 5/60	3.41	1.71	1.71	0.99
32.	PB 5/76	2.95	1.60	1.35	1.30
33.	RSY 23	3.35	1.61	1.74	0.92
34.	Ch 2	3.40	2.14	1.26	2.07
35.	BD 5	2.50	1.35	1.15	1.17
36.	HC 28	2.90	1.47	1.43	1.04
37.	PB 217	2.84	1.59	1.26	1.30
38	PB 5/63	2.82	1.47	1.35	1.19
39.	AVROS 255	2.40	1.20	1.20	0.95
40.	PB 235	3.34	1.59	1.75	0.88
General mean		3.27	1.75	1.52	1.24
C.D. (0.05)		1.094	0.736	0.577	0.832

* Clonal variation significant at P = 0.05.

parameters such as genotypic and phenotypic coefficients of variation (G.C.V. and P.C.V.), heritability and genetic advance at 5 per cent intensity of selection as percentage of mean are presented in table 9. The histogram representing the genetic parameters is presented in figure 12.

Estimates of genotypic coefficient of variation ranged from 7.0 to 31.8 for the various traits studied. G.C.V. was highest for volume of latex under stress (31.8) followed by dry rubber yield under stress (30.5), annual mean dry rubber yield (26.2), dry rubber yield during the peak period (24.4) and plugging index under stress (24.0). The high genotypic coefficients of variation recorded for these characters indicate existence of substantial genetic variability. Length of tapping panel and renewed bark thickness exhibited very low G.C.V. (7.0 and 7.8 respectively) followed by dry rubber content under stress (8.2), D.R.C. during the peak period (8.4), annual mean D.R.C. (8.5) and girth (9.0) indicating low genetic variability for these traits. Annual mean latex flow rate, latex flow rate under stress and during the peak period and dry rubber yield under stress recorded moderate genotypic coefficients of variation.

The phenotypic coefficients of variation ranged from 10.3 for annual mean dry rubber content to 50.5 for volume of latex under stress. P.C.V. estimates for dry rubber yield under stress

Table 9. Estimates of genetic parameters in clones.

Sl. No.	Characters	Mean	S.E.	Range	Coefficient of variation		Herit-ability (%)	Genetic advance (%)
					Geno-typic	Pheno-typic		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.	Dry rubber yield (annual) (g tree^{-1} tapping^{-1}	46.2	7.36	22.4-77.0	26.2	38.1	47.5	37.2
2.	Dry rubber yield (stress) (g tree^{-1} tapping^{-1})	33.1	6.62	12.3-60.8	30.5	46.1	43.6	41.5
3.	Dry rubber yield (peak) (g tree^{-1} tapping^{-1})	60.9	9.03	34.1-95.6	24.4	35.4	47.3	34.5
4.	Yield depression under stress (%)	30.1	5.80	13.8-49.4	21.2	39.5	28.8	23.5
5.	Volume of latex (annual) (ml tree^{-1} tapping^{-1})	142.9	22.58	77.3-212.4	20.8	34.4	36.6	25.9
6.	Volume of latex (stress) (ml tree^{-1} tapping^{-1})	85.2	19.33	31.9-166.6	31.8	50.5	39.5	41.1
7.	Volume of latex (peak) (ml tree^{-1} tapping^{-1})	197.3	29.39	121.0-279.8	17.8	31.3	32.3	20.8
8.	Dry rubber content (annual (%)	34.8	1.18	28.1-40.9	8.5	10.3	67.8	14.4
9.	Dry rubber content (stress) (%)	36.8	1.70	29.9-43.5	8.2	11.5	51.2	12.1
10.	Dry rubber content (peak) (%)	34.0	1.64	28.4-40.4	8.4	11.8	50.3	12.3

(Contd.....2)

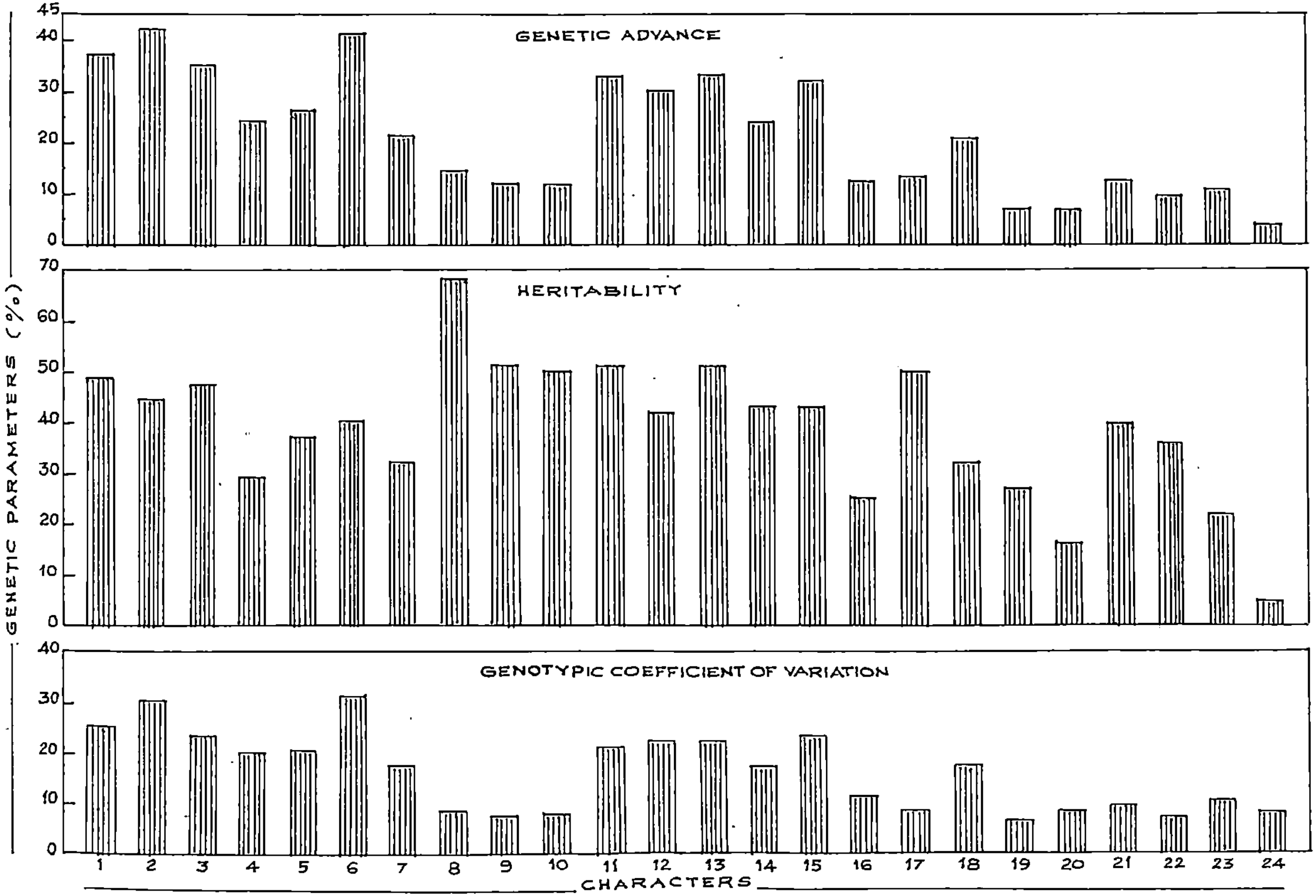
Table 9 contd....

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
11.	Latex flow rate (annual) ((ml minute^{-1})	4.7	0.59	2.6-7.3	22.3	31.4	50.5	32.7
12.	Latex flow rate (stress) (ml minute^{-1})	4.1	0.62	2.2-6.4	22.5	34.8	41.6	29.8
13.	Latex flow rate (peak) (ml minute^{-1})	5.2	0.67	2.9-8.3	22.6	31.7	50.6	33.2
14.	Plugging index (annual)	4.4	0.52	2.9-7.3	17.7	27.2	42.6	23.8
15.	Plugging index (stress)	6.3	0.01	4.1-11.7	24.0	36.6	42.9	32.3
16.	Plugging index (peak)	3.0	0.35	2.1-4.2	11.8	23.8	24.7	12.1
17.	Girth (cm)	72.9	3.83	60.1-96.3	9.0	12.8	49.5	13.0
18.	Girth increment rate (cm year^{-1})	3.8	0.57	2.3-6.0	18.0	31.8	31.9	20.9
19.	Length of tapping panel (cm)	42.5	2.83	36.8-56.9	7.0	13.5	27.1	7.5
20.	Height at forking (m)	3.4	0.40	2.6-4.8	9.1	22.5	16.4	7.6
21.	Virgin bark thickness (mm)	7.4	0.52	5.8-9.3	10.0	15.8	39.5	12.9
22.	Renewed bark thickness (mm)	7.1	0.42	5.5-8.7	7.8	13.0	36.1	9.6
23.	Total chlorophyll (mg per g fresh weight)	3.3	0.39	2.1-4.6	10.9	23.3	21.9	10.5
24.	Chlorophyll a (mg per g fresh wt.)	1.8	0.26	1.1-2.6	11.3	28.2	16.0	9.3
25.	Chlorophyll b (mg per g fresh wt.)	1.5	0.20	1.0-2.1	11.0	25.7	18.0	9.5
26.	Chlorophyll a: b ratio	1.2	0.30	0.9-2.1	9.2	42.3	4.9	4.2

Figure 12. Estimates of genetic parameters in clones

Number	Character	Number	Character
1.	Dry rubber yield (annual)	13.	Latex flow rate (peak)
2.	Dry rubber yield (stress)	14.	Plugging index (annual)
3.	Dry rubber yield (peak)	15.	Plugging index (stress)
4.	Yield depression (stress)	16.	Plugging index (peak)
5.	Volume of latex (annual)	17.	Girth
6.	Volume of latex (stress)	18.	Girth increment rate
7.	Volume of latex (peak)	19.	Length of tapping panel
8.	Dry rubber content (annual)	20.	Height at forking
9.	Dry rubber content (stress)	21.	Virgin bark thickness
10.	Dry rubber content (peak)	22.	Renewed bark thickness
11.	Latex flow rate (annual)	23.	Total chlorophyll
12.	Latex flow rate (stress)	24.	Chlorophyll a:b ratio

FIG.12. ESTIMATES OF GENETIC PARAMETERS IN CLONES.



(46.1), chlorophyll a:b ratio (42.3) and yield depression under stress (39.5) were relatively high. Dry rubber yield over the three periods, girth, length of tapping panel, virgin bark thickness and renewed bark thickness showed low variability as evidenced by the low P.C.V. values.

Heritability estimates ranged from 4.9 for chlorophyll a:b ratio to 67.8 for annual mean dry rubber content. Relatively high heritability (greater than 40) was recorded by D.R.C. under stress (51.2), latex flow rate during the peak period (50.6), annual mean latex flow rate (50.5) and D.R.C. during the peak period (50.3). High heritability was also observed for girth (49.5), annual mean dry rubber yield (47.5), peak dry rubber yield (47.3), dry rubber yield under stress (43.6), plugging index under stress (42.9), annual mean plugging index (42.6), latex flow rate under stress (41.6). Moderate estimates of heritability ranging from 21 to 40 were recorded by volume of latex during the three periods, yield depression under stress and bark thickness (virgin and renewed). Chlorophyll a:b ratio, chlorophyll-a content, height at forking and chlorophyll-b content recorded comparatively low heritabilities ie. less than 20 (4.9, 16.0, 16.4 and 18.0 respectively), indicating the large influence of the environment in the expression of these characters.

The genetic advance under selection was highest for dry rubber yield under stress (41.5). High estimates of expected genetic advance (greater than 28) were obtained for dry rubber yield during the three periods (37.2, 41.5 and 34.5), latex flow rate during the three periods (32.7, 29.8 and 53.2), volume of latex under stress (41.1) and plugging index under stress (32.3). Genetic advance was low (less than 16) for chlorophyll a:b ratio (4.2), length of the tapping panel (7.5), height at forking (7.6), content of chlorophyll-a (9.3) and chlorophyll-b (9.5), renewed bark thickness (9.6), plugging index during the peak yield period (12.1), D.R.C. during the three periods (14.4, 12.1 and 12.3), girth (13.0) and virgin bark thickness (12.9).

Moderate to high heritability coupled with high genetic advance was recorded for characters like dry rubber yield over the three periods, rate of latex flow over the three periods, volume of latex during the three periods, rate of girth increment under tapping, annual mean plugging index and plugging index under stress. Genetic variability, essential for selection to be effective was low for dry rubber content but high estimates of heritability and low genetic advance under selection was observed for this trait during the three periods. Girth, virgin bark thickness and renewed bark thickness also recorded moderate to high heritability estimates coupled with low genetic advance. Total chlorophyll, chlorophyll-a, chlorophyll-b and the chlorophyll a:b ratio showed low genetic variability, heritability and genetic advance.

4.1.3. Wintering attributes

4.1.3.1. Leaf fall

The period of maximum leaf fall for more than 50 per cent trees in each clone recorded as the mean over two years is presented in table 10. The period for individual clones ranged from the first to the fourth week of January. The clones were classified as early (January 1st week), intermediate (January 2nd and 3rd weeks) and late (January 4th week) wintering types.

Two clones, AVROS 352 and BD 5 recorded early leaf fall and nineteen clones each fell under the intermediate and late leaf fall categories. Six clones viz. Waring 4, BD 10, Ch 29, PB 6/50, Ch 26 and PB 235 exhibited partial wintering (part of the leaves were retained even after completion of leaf fall and onset of refoliation.

4.1.3.2. Refoliation

The period of 100 per cent refoliation of more than 50 per cent trees in each clone recorded as the mean over two years is also presented in table 10. The period in individual clones ranged from the first to the last week of February. The clones were classified as early (February 1st week), intermediate (February 2nd and 3rd weeks) and late (February 4th week) types. Four clones, AVROS 352, Gl 1, Lun N and AVT 73 were observed to complete

Table 10. Wintering attributes in clones.

Sl. No.	Clones	Maximum leaf fall period		Period of 100% refoliation	
1.	Waring 4	January	2nd week* (I)	February	2nd week (I)
2.	AVROS 352	-do-	1st week (E)	-do-	1st week (E)
3.	Ch 4	-do-	2nd week (I)	-do-	2nd week (I)
4.	PB 213	-do-	4th week (L)	-do-	4th week (L)
5.	BD 10	-do-	4th week* (L)	-do-	4th week (L)
6.	PB 215	-do-	3rd week (I)	-do-	3rd week (I)
7.	PR 107	-do-	4th week (L)	-do-	4th week (L)
8.	Mil 3/2	-do-	4th week (L)	-do	4th week (L)
9.	Gl 1	-do-	2nd week (I)	-do-	1st week (E)
10.	PB 252	-do-	3rd week (I)	-do-	2nd week (I)
11.	PB 28/83	-do-	3rd week (I)	-do-	2nd week (I)
12.	Ch 32	-do-	3rd week (I)	-do-	2nd week (I)
13.	Lun N	-do-	3rd week (I)	-do-	1st week (E)
14.	Tjir 16	-do-	3rd week (I)	-do-	4th week (L)
15.	PB 230	-do-	4th week (L)	-do-	4th week (L)
16.	PB 28/59	-do-	4th week (L)	-do-	4th week (L)
17.	HC 55	-do-	3rd week (I)	-do	3rd week (I)
18.	LCB 1320	-do-	4th week (L)	-do-	2nd week (I)
19.	PB 206	-do-	4th week (L)	-d-	4th week (L)
20.	PB 242	-do-	3rd week (I)	-do-	2nd week (I)
21.	PB 86	-do-	4th week (L)	-do-	4th week (L)
22.	GT 1	-do-	4th week (L)	-do-	4th week (L)
23.	Ch 153	-do-	3rd week (I)	-do-	2nd week (I)
24.	Ch 29	-do-	3rd week* (I)	-do-	2nd week (I)
25.	AVT 73	-do-	3rd week (I)	-do-	1st week (E)
26.	PB 5/139	-do-	4th week (L)	do-	4th week (L)

(contd...2)

Table 10 contd.....

Sl. No.	Clones	Maximum leaf fall period		Period of 100% refoliation	
27.	PB 6/50	-do-	4th week* (L)	-do-	2nd week (I)
28.	Ch 26	-do-	4th week* (L)	-do-	4th week (L)
29.	RRII 105	-do-	3rd week (I)	-do-	2nd week (I)
30.	PB 5/51	-do-	3rd week (I)	-do-	3rd week (I)
31.	PB 5/60	-do-	4th week (L)	-do-	4th week (L)
32.	PB 5/76	-do-	4th week (L)	-do-	4th week (L)
33.	RSY 23	-do-	4th week (L)	-do-	4th week (L)
34.	Ch 2	-do-	4th week (L)	-do-	4th week (L)
35.	BD 5	-do-	1st week (E)	-do-	2nd week (I)
36.	HC 28	-do-	4th week (L)	-do-	4th week (L)
37.	PB 217	-do-	3rd week (I)	-do-	2nd week (I)
38.	PB 5/63	-do-	4th week (L)	-do-	4th week (L)
39.	AVROS 255	-do-	2nd week (I)	-do-	3rd week (I)
40.	PB 235	-do-	3rd week* (I)	-do-	2nd week (I)

Letters in parenthesis : E = Early

I - Intermediate

L = Late

* Partial wintering

refoliation early. Eighteen clones each were of the intermediate and late types.

Most of the clones exhibited a uniform interval between leaf fall and refoliation. Clones Gl 1, Lun N, AVT 73, LCB 1320 and PB 6/50 showed a relatively short interval and clones Tjir 16 and BD 5 showed a relatively long interval between leaf fall and refoliation.

4.1.4. Flowering attributes

Table 11 presents the flowering attributes such as period of 50 per cent flowering, flowering spread, number of panicles per flowering twig, number of male flowers per panicle, number of female flowers per panicle and the ratio of the number of female flowers to the numbers of male flowers per panicle (sex ratio).

4.1.4.1. Period of flowering

The period of flowering in more than 50 per cent of the trees in each clone recorded as the mean over two years is also provided in table 11. The period in individual clones ranged from the second week of February to the first week of March. The forty clones were classified as early (February 2nd week), intermediate (February 3rd and 4th weeks) and late (March 1st week) flowering types as indicated in the table.

Seven clones, Ch 4, Gl 1, PB 252, Lun N, AVT 73, RRII 105

Table 11. Flowering attributes in clones.

Sl. No.	Clones	Period of 50% flowering		Flowering spread (days)	No. of panicles per flowering twig	No. of male flowers per panicle	No. of female flowers per panicle	Sex ratio
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
1.	Waring 4	February	4th week (I)	6	9	70	5	0.076
2.	AVROS 352	-do-	4th week (I)	6	12	87	4	0.046
3.	Ch 4	-do-	2nd week (E)	11	15	206	8	0.037
4.	PB 213	-do-	4th week (I)	12	10	139	5	0.036
5.	BD 10	March	1st week (L)	8	15	199	6	0.030
6.	PB 215	February	3rd week (I)	18	8	67	4	0.060
7.	PR 107	-do-	4th week (I)	10	7	92	2	0.023
8.	Mil 3/2	March	1st week (L)	9	9	96	4	0.047
9.	Gl 1	February	2nd week (E)	9	16	136	5	0.036
10.	PB 252	-do-	2nd week (E)	14	14	193	5	0.026
11.	PB 28/83	-do-	4th week (I)	12	17	101	2	0.024
12.	Ch 32	-do-	4th week (I)	11	10	160	3	0.020
13.	Lun N	-do-	2nd week (E)	15	19	307	6	0.018
14.	Tjir 16	-do-	4th week (I)	14	7	129	2	0.018
15.	PB 230	-do-	4th week (I)	12	16	205	5	0.023
16.	PB 28/59	-do-	4th week (I)	12	9	56	2	0.040
17.	HC 55	-do-	4th week (I)	11	10	119	5	0.044
18.	LCB 1320	-do-	4th week (I)	12	11	96	4	0.040
19.	PB 206	-do-	4th week (I)	12	12	188	3	0.017
20.	PB 242	-do-	3rd week (I)	13	11	109	3	0.025
21.	PB 86	-do-	3rd week (I)	12	11	55	6	0.117
22.	GT 1	March	1st week (L)	6	11	119	12	0.103

(Contd......2/-)

Table 11 contd...

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
23.	Ch 153	February 4th week (I)	7	9	50	2	0.040
24.	Ch 29	-do- 4th week (I)	14	7	105	3	0.028
25.	AVT 73	-do- 2nd week (E)	12	8	170	6	0.033
26.	PB 5/139	-do- 4th week (I)	12	8	144	4	0.030
27.	PB 6/50	-do- 4th week (I)	7	10	205	7	0.034
28.	Ch 26	-do- 3rd week (I)	9	9	215	6	0.026
29.	RRII 105	-do- 2nd week (E)	13	10	143	6	0.057
30.	PB 5/51	February 4th week (I)	10	15	153	4	0.028
31.	PB 5/60	-do- 4th week (I)	8	9	113	3	0.027
32.	PB 5/76	-do- 4th week (I)	12	12	157	9	0.060
33.	RSY 23	March 1st week (L).	6	5	84	6	0.067
34.	Ch 2	February 4th week (I)	13	16	377	6	0.017
35.	BD 5	-do- 4th week (I)	14	8	126	12	0.094
36.	HC 28	-do- 4th week (I)	8	12	143	3	0.021
37.	PB 217	-do- 4th week (I)	12	14	107	3	0.028
38.	PB 5/63	-do- 4th week (I)	12	7	48	1	0.034
39.	AVROS 255	-do- 2nd week (E)	14	5	116	3	0.025
40.	PB 235	-do- 4th week (I)	17	5	91	2	0.022
General Mean			11.13	10.7	136.9	4.68	0.039

Letters in parenthesis : E = Early flowering

I = Intermediate flowering

L = Late flowering

and AVROS 255 were of the early flowering type and came into 50 per cent flowering by the second week of February. Twenty nine clones were of the intermediate flowering type of which 50 per cent flowering occurred in the third week of February for four clones and in the fourth week of February for twenty five clones. Four clones viz. BD 10, Mil/32, GT 1 and RSY 23 were of the late flowering type and came into 50 per cent flowering by the first week of March.

4.1.4.2. Spread of flowering

Flowering spread as determined from the day of 50 per cent to 100 per cent flowering in individual trees and recorded as the mean for six trees per clone over two years is presented in table 11.

The forty clones in general showed a mean flowering spread of 11 days with a range from 6 to 18 days. PB 215 and PB 235 recorded a comparatively longer flowering spread of 18 and 17 days respectively, followed by Lun N (15 days), and PB 250, Tjir 16, Ch 29, BD 5 and AVROS 255 (14 days each). The shortest flowering spread of 6 days was recorded by four clones viz. Waring 4, AVROS 352, GT 1 and RSY 23.

4.1.4.3. Number of panicles per flowering twig

The clones in general produced a mean number of 11 panicles per flowering twig. The number ranged from 5 panicles (RSY 23, AVROS 255, PB 2350 to 19 panicles (Lun N). Clones PB 28/83, Gl 1, PB 230, Ch 2, Ch 4 and PB 5/51 recorded more than 15 panicles per flowering twig.

4.1.4.4. Number of male flowers per panicle

The number of male flowers per panicle ranged from 50 (Ch 153) to 377 (Ch 2) with the clones in general having recorded a mean number of 137. Clones Lun N, Ch 26, Ch 4, PB 230 and PB 6/50 recorded more than 200 male flowers per panicle.

4.1.4.5. Number of female flowers per panicle

The clones in general produced a mean number of 5 female flowers per panicle. The highest number of 12 flowers was recorded in clones GT 1 and BD 5 followed by PB 5/76 (9 flowers) and Ch 4 (8 flowers). The lowest number of one female flower per panicle was recorded in PB 5/63.

4.1.4.6. Sex ratio

The ratio of the number of female flowers to the number of male flowers per panicle was 0.039 for the forty clones in general with PB 86 showing the highest ratio of 0.117 followed in GT 1 (0.103), BD 5 (0.094), Waring 4 (0.076), RSY 23 (0.067), PB 215 (0.060) and RRII 105 (0.057). The lowest ratio of 0.017 was recorded in Ch 2 and PB 206.

4.1.5. Incidence of diseases

The percentages of incidence of diseases like powdery mildew, abnormal leaf fall, pink disease and tapping panel dryness recorded from the clones during 1989 and 1990 are presented in table 12.

Infection by Oidium heveae led to 26 per cent of leaves being affected by powdery mildew in the clones in general. Clone Tjir 16 with 65 per cent leaves affected was the most susceptible while the lowest incidence of 3.3 per cent affected leaves was recorded by Ch 26 and Lun N. Clones Ch 26, Lun N, AVROS 352, RSY 23 and BD 5 recorded less than 10 per cent affected leaves.

The incidence of abnormal leaf fall due to Phytophthora palmivora was highest in BD 5 with 30 per cent leaf fall and the lowest in PB 230 which showed only 1 per cent leaf fall. Clones PB 230, Gl 1, AVROS 352, BD 10, PB 28/59, GT 1, AVT 73, RRII 105 and PB 5/60 recorded less than 5 per cent leaf fall. The clones in general showed 10 per cent leaf fall due to the disease.

The incidence of pink disease caused by Corticium salmonicolor ranged from 0.0 per cent (PB 5/63, Waring 4, AVROS 352, PB 215, PR 107, Mil 3/2, PB 252, PB 28/83, Ch 32, PB 230, PB 206, AVT 73 and PB 5/60) to 36.4 per cent (Ch 2 and Ch 26). The clones in general recorded 3.62 per cent affected trees.

Clones PB 28/83 and PB 235 were found to be highly susceptible

Table 12. Incidence of diseases in clones.

Sl. No.	Clones	Powdery mildew (% infected leaves)	Abnormal leaf fall (% leaf fall)	Pink disease (% affected trees)	Tapping panel dryness (% affected trees)
(1)	(2)	(3)	(4)	(5)	(6)
1.	Waring 4	18.3	7.3	0.0	0.0
2.	AVROS 352	5.0	3.0	0.0	0.0
3.	Ch 4	11.7	7.8	7.1	0.0
4.	PB 213	30.0	6.7	7.7	0.0
5.	BD 10	45.0	5.0	7.7	15.4
6.	PB 215	13.3	12.7	0.0	7.7
7.	PR 107	20.0	7.3	0.0	7.1
8.	Mil 3/2	33.3	7.0	0.0	14.3
9.	Gl 1	35.0	2.0	7.7	7.1
10.	PB 252	30.0	12.3	0.0	0.0
11.	PB 28/83	41.7	16.3	0.0	23.1
12.	Ch 32	18.3	18.5	0.0	0.0
13.	Lun N	3.3	8.3	14.3	0.0
14.	Tjir 16	65.0	13.0	27.3	0.0
15.	PB 230	18.3	1.0	0.0	15.4
16.	PB 28/59	28.3	5.0	15.4	0.0
17.	HC 55	20.0	19.3	7.7	0.0
18.	LCB 1320	18.3	10.7	16.7	0.0
19.	PB 206	33.3	10.7	0.0	0.0
20.	PB 242	31.7	15.7	8.3	8.3
21.	PB 86	13.3	7.5	7.1	0.0
22.	GT 1	41.7	2.7	15.4	7.1
23.	Ch 153	40.0	6.7	15.4	0.0
24.	Ch 29	16.7	8.3	8.3	20.0

(Contd.....2/-)

Table 12 contd....

(1)	(2)	(3)	(4)	(5)	(6)
25.	AVT 73	31.7	4.0	0.0	15.4
26.	PB 5/139	38.3	7.0	18.2	14.3
27	PB 6/50	36.7	10.0	15.4	0.0
28.	Ch 26	3.3	5.7	36.4	21.4
29.	RRII 105	26.7	5.0	7.7	8.3
30.	PB 5/51	40.0	19.7	25.0	15.4
31.	PB 5/60	21.7	2.7	0.0	0.0
32.	PB 5/76	35.0	7.5	21.4	0.0
33	RSY 23	10.0	15.0	7.1	0.0
34.	Ch 2	15.0	7.3	36.4	0.0
35.	BD 5	10.0	30.0	15.4	15.4
36.	HC 28	20.0	23.3	9.1	0.0
37.	PB 217	30.0	9.3	15.4	15.4
38.	PB 5/63	31.7	10.0	0.0	0.0
39	AVROS 255	10.0	14.0	20.0	0.0
40.	PB 235	48.3	12.3	7.7	23.1
General Mean		25.99	9.95	3.62	6.36

to tapping panel dryness with 23.1 per cent of the trees being affected. Clones AVROS 255, PB 5/63, HC 28, Ch 2, RSY 23, PB 5/60, PB 5/76, PB 6/50, Ch 153, PB 86, PB 206, LCB 1320, HC 55, PB 28/59, Tjir 16, Lun N, Ch 32, PB 252, PB 213, Ch 4, AVROS 352 and Waring 4 did not show incidence of tapping panel dryness. In general 6.36 per cent of the trees studied were affected by the disorder.

4.1.6. Correlations

The genotypic correlation coefficients along with the respective estimates of standard error for dry rubber yield, the physiological components of yield, morphological and structural attributes are presented in table 13. The coefficients ranged from 0.02 to 1.00 and their S.E. estimates ranged from 0.010 to 0.578. The phenotypic correlation coefficients are presented in table 14. The coefficients ranged from 0.01 to 0.96.

4.1.6.1. Correlation of dry rubber yield with the physiological components of yield.

At the genotypic level correlations of annual mean dry rubber yield with dry rubber yield during the stress and peak periods, annual mean yield of latex, latex yield during the stress and peak periods, annual mean dry rubber content, D.R.C. during the stress and peak periods, annual mean latex flow rate and latex flow rate during the stress and peak periods were positive while the relationships with yield depression under stress, annual mean plugging

Table 13. Genotypic correlations of rubber yield with physiological, morphological and structural attributes in clones at the fourth year of tapping.

	Dry rubber yield (annual)	Dry rubber yield (stress)	Dry rubber yield (peak)	Yield depression (stress)	Volume of latex (annual)	Volume of latex (stress)	Volume of latex (peak)	D.R.C. (annual)	D.R.C. (stress)	D.R.C. (peak)	Latex flow rate (annual)	Latex flow rate (stress)	Latex flow rate (peak)	Plugging index (annual)	Plugging index (stress)	Plugging index (peak)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	Renewed bark thickness
Dry rubber yield (annual)	--	0.96	0.95	-0.41	0.98	0.88	0.94	0.50	0.36	0.82	0.92	0.96	0.81	-0.36	-0.45	-0.19	0.54	0.39	0.67	0.69	0.43
Dry rubber yield (stress)	0.008	--	0.86	-0.63	0.94	0.94	0.86	0.44	0.31	0.73	0.88	0.93	0.76	-0.46	-0.59	-0.20	0.53	0.37	0.66	0.65	0.44
Dry rubber yield (peak)	0.010	0.047	--	-0.21	0.93	0.70	1.00	0.60	0.52	0.88	0.93	0.90	0.86	-0.18	-0.25	-0.09	0.46	0.32	0.54	0.70	0.40
Yield depression (stress)	0.320	0.203	0.391	--	-0.42	-0.63	-0.26	-0.09	-0.09	-0.16	-0.39	-0.46	-0.33	0.44	0.62	0.07	-0.32	-0.33	-0.31	-0.26	-0.16
Volume of latex (annual)	0.012	0.017	0.032	0.356	--	0.91	0.93	0.33	0.19	0.69	0.91	0.94	0.78	-0.46	-0.53	-0.28	0.59	0.44	0.66	0.71	0.49
Volume of latex (stress)	0.038	0.017	0.122	0.221	0.029	--	0.68	0.20	0.03	0.50	0.74	0.85	0.58	-0.65	-0.75	-0.31	0.66	0.54	0.74	0.59	0.46
Volume of latex (peak)	0.031	0.058	0.046	0.456	0.019	0.156	--	0.52	0.45	0.82	0.96	0.89	0.90	-0.18	-0.24	-0.12	0.45	0.33	0.43	0.69	0.47
D.R.C. (annual)	0.180	0.208	0.151	0.342	0.260	0.279	0.228	--	0.97	1.00	0.52	0.48	0.55	0.31	0.18	0.32	0.13	0.17	0.19	0.40	0.26
D.R.C. (stress)	0.262	0.285	0.228	0.395	0.339	0.342	0.306	0.048	--	0.97	0.46	0.36	0.55	0.45	0.32	0.42	0.02	0.07	0.09	0.30	0.18
D.R.C. (peak)	0.512	0.178	0.140	0.391	0.227	0.263	0.239	0.065	0.159	--	0.79	0.80	0.76	0.13	0.02	0.15	0.32	0.38	0.55	0.60	0.40
Latex flow rate (annual)	0.029	0.041	0.038	0.321	0.050	0.102	0.090	0.167	0.231	0.157	--	0.96	0.97	-0.05	-0.18	0.17	0.54	0.43	0.52	0.64	0.45
Latex flow rate (stress)	0.046	0.035	0.059	0.314	0.054	0.058	0.084	0.204	0.294	0.196	0.009	--	0.87	-0.18	-0.32	-0.09	0.59	0.44	0.65	0.73	0.49
Latex flow rate (peak)	0.063	0.089	0.044	0.351	0.090	0.176	0.081	0.156	0.207	0.154	0.007	0.045	--	0.10	-0.05	0.33	0.44	0.36	0.36	0.50	0.35
Plugging index (annual)	0.265	0.239	0.323	0.314	0.258	0.167	0.392	0.266	0.280	0.330	0.332	0.343	0.337	--	0.97	0.76	-0.16	-0.03	-0.28	-0.20	0.09
Plugging index (stress)	0.237	0.188	0.304	0.225	0.234	0.128	0.368	0.282	0.300	0.332	0.312	0.305	0.330	0.025	--	0.58	-0.28	-0.17	-0.32	-0.27	0.08
Plugging index (peak)	0.438	0.440	0.444	0.578	0.445	0.436	0.536	0.338	0.392	0.427	0.429	0.488	0.398	0.180	0.339	--	0.07	0.12	-0.15	-0.13	-0.22
Girth	0.181	0.192	0.216	0.348	0.184	0.147	0.263	0.257	0.306	0.264	0.178	0.171	0.216	0.320	0.291	0.455	--	1.00	0.94	0.54	0.55
Girth increment rate	0.310	0.330	0.332	0.460	0.340	0.299	0.410	0.313	0.378	0.330	0.284	0.313	0.303	0.419	0.397	0.548	0.228	--	0.84	0.55	0.51
Tapping panel length	0.173	0.182	0.248	0.472	0.196	0.152	0.364	0.335	0.409	0.316	0.235	0.185	0.317	0.392	0.377	0.578	0.151	0.347	--	0.68	0.47
Virgin bark thickness	0.174	0.194	0.190	0.416	0.288	0.231	0.236	0.232	0.305	0.212	0.191	0.179	0.235	0.350	0.341	0.487	0.210	0.351	0.223	--	0.84
Renewed bark thickness	0.272	0.288	0.271	0.468	0.012	0.308	0.317	0.278	0.343	0.297	0.256	0.272	0.290	0.408	0.403	0.498	0.244	0.325	0.356	0.196	--

Values above the diagonal are genotypic correlation coefficients.
Values below the diagonal are S.E. of genotypic correlation coefficients.

Table 14. Phenotypic correlation coefficients of rubber yield with phyisological, morphological and structural attributes in clones at the fourth year of tapping.

	Dry rubber yield (annual)	Dry rubber yield (stres)	Dry rubber yield (peak)	Yield depression (stress)	volume of latex (annual	Volume of latex (stress)	Volume of latex (peak)	D.R.C (annual)	D.R.C. (stress)	D.R.C. (peak)	Latex flow rate (annual)	Latex flow rate (stress)	Latex flow rate (peak)	Plugging index (annual)	Plugging index (stress)	Plugging index (peak)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	Renewed bark thickness	Forking height	Total chlorophyll	Chlorphyll a: b ratio
Dry rubber yield (annual)	1.00	0.95**	0.94**	-0.38**	0.96**	0.86**	0.91**	0.46**	0.28**	0.54**	0.87**	0.87**	0.79**	-0.49**	-0.49**	-0.26**	0.59**	0.38**	0.67**	0.53**	0.42**	0.15	-0.02	0.02
Dry rubber yield (stress)		1.00	0.83**	-0.62**	0.93**	0.92**	0.83**	0.41**	0.26**	0.48**	0.84**	0.88**	0.74**	-0.53**	-0.57**	-0.23**	0.59**	0.37**	0.67**	0.52**	0.38**	0.14	-0.02	0.03
Dry rubber yield (peak)			1.00	-0.19*	0.89**	0.72**	0.94**	0.52**	0.34**	0.60**	0.86**	0.81**	0.83**	-0.34**	-0.36**	-0.23**	0.51**	0.36**	0.57**	0.49**	0.42**	0.13	0.01	0.01
Yield depression (stress)				1.00	-0.41**	-0.59**	-0.27**	-0.11	-0.11	-0.13	-0.35**	-0.45**	-0.25**	0.45**	0.56**	0.08	-0.30**	-0.18*	-0.34**	-0.22*	-0.08	-0.04	-0.01	-0.14
Volume of latex (annual)					1.00	0.89**	0.93**	0.32**	0.16	0.40**	0.84**	0.85**	0.75**	-0.57**	-0.54**	-0.34**	0.62**	0.37**	0.69**	0.53**	0.44**	0.18*	-0.04	0.05
Volume of latex (stress)						1.00	0.74**	0.21*	0.01	0.31**	0.73**	0.82**	0.62**	-0.62**	-0.66**	-0.24**	0.64**	0.38**	0.70**	0.47**	0.35**	0.17	-0.08	-0.002
Volume of latex (peak)							1.00	0.41**	0.28**	0.45**	0.82**	0.79**	0.80**	-0.42**	-0.40**	-0.35**	0.51**	0.29**	0.58**	0.48**	0.44**	0.15	-0.03	-0.05
D.R.C. (annual)								1.00	0.85**	0.84**	0.48**	0.41**	0.52**	0.14	0.04	0.21*	0.22**	0.20*	0.23*	0.36**	0.27**	0.08	0.13	0.03
D.R.C. (stress)									1.00	0.61**	0.32**	0.20*	0.38**	0.21*	0.16	0.17	0.03	0.07	0.07	0.22*	0.15	0.08	0.08	0.14
D.R.C. (peak)										1.00	0.51**	0.46**	0.51**	0.03	-0.03	0.10	0.29**	0.24**	0.31**	0.44**	0.28**	0.04	0.20*	-0.09
Latex flow rate (annual)											1.00	0.94**	0.96**	-0.17	-0.27**	0.07	0.57**	0.41**	0.64**	0.49**	0.44**	0.13	-0.03	-0.01
Latex flow rate (stress)												1.00	0.83**	-0.30**	-0.36**	-0.05	0.61**	0.40**	0.70**	0.54**	0.43**	0.10	0.01	0.06
Latex flow rate (peak)													1.00	-0.07	-0.19*	-0.17	0.47**	0.41**	0.53**	0.42**	0.38**	0.15	-0.05	-0.01
Plugging index (annual)														1.00	0.92**	0.64**	-0.32**	-0.15	-0.36**	-0.23**	-0.14	-0.13	0.04	-0.01
Plugging index (stress)															1.00	0.36**	-0.34**	-0.19*	-0.37**	-0.21*	-0.12	-0.14	0.08	0.003
Plugging index (peak)																1.00	-0.13	0.04	-0.17	-0.08	-0.10	0.02	-0.06	-0.08
Girth																	1.00	0.62**	0.74**	0.50**	0.40**	0.25**	-0.05	0.04
Girth increment rate																		1.00	0.42**	0.24**	0.36**	-0.06	-0.01	0.18*
Tapping panel length																			1.00	0.56**	0.39**	0.25**	0.03	0.01
Virgin bark thickness																				1.00	0.55**	0.31**	0.19*	-0.11
Renewed bark thickness																					1.00	0.04	0.10	0.01
Forking height																						1.00	-0.13	-0.14
Total chlorophyll																							1.00	-0.05
Chlorophyll a:b ratio																								1.00

* Significant at P = 0.05

** Significant at P = 0.01.

index and plugging indices during the stress and peak periods were negative. High positive genotypic correlations with a low S.E. were observed for annual mean dry rubber yield with dry rubber yield during the stress and peak periods, volume of latex during the three periods, latex flow rate during the three periods and D.R.C. during the peak yield period. A moderately high negative correlation of low S.E. was recorded between annual mean dry rubber yield and yield depression under stress.

Genotypic correlation between dry rubber yield during the stress and peak periods was high. Yield during the stress and peak periods recorded positive correlations with volume of latex during the three periods, D.R.C. during the three periods and latex flow rate during the three periods. However the correlations with yield depression under stress and plugging index during the three periods were negative at the genotypic level. Peak dry rubber yield showed a very high genotypic correlation (r = 1.00) with peak volume of latex. The positive genotypic correlations of dry rubber yield duirng the stress and peak periods with volume of latex during the three periods, D.R.C. during the peak yield period and latex flow rate during the three periods had low estimates of S.E. The genotypic correlation of dry rubber yield during the peak period with annual mean D.R.C. was high with low S.E. The negative relationships of dry rubber yield under stress with yield depression under stress and plugging index under stress were also supported by low S.E. estimates.

At the phenotypic level, annual mean dry rubber yield exhibited highly significant positive correlation with yield during the stress and peak periods, volume of latex during the three periods, D.R.C. during the three periods and latex flow rate during the three periods. Phenotypic correlations of annual mean dry rubber yield with volume of latex and latex flow rate during the three periods were particularly high ($r > 0.50$). Annual mean dry rubber yield exhibited highly significant negative correlation with yield depression under stress and plugging indices during the three periods.

Dry rubber yield during the stress and peak periods were highly correlated at the phenotypic level. Yield during these two periods showed highly significant positive phenotypic correlations with volume of latex, D.R.C. and latex flow rate during the three periods. There was a highly significant negative correlation between dry rubber yield during the stress and peak periods and plugging indices during the three periods. Yield depression under stress showed a highly significant negative correlation with dry rubber yield under stress while its negative relationship with peak dry rubber yield was significant only at $P = 0.05$.

4.1.6.2. Correlation of dry rubber yield with morphological and structural attributes and chlorophyll content.

Annual mean dry rubber yield recorded positive genotypic correlation with girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness. The correlations were moderately high and had a low S.E. in respect of girth, tapping panel length and virgin bark thickness.

Dry rubber yield during the stress and peak periods also exhibited positive genotypic correlation with girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness. Yield under stress had moderately high genotypic correlations of low S.E. with girth, tapping panel length and virgin bark thickness while peak yield had a high genotypic correlation of low S.E. with only virgin bark thickness.

At the phenotypic level, annual mean dry rubber yield and yield during the stress and peak periods exhibited highly significant positive correlations with girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness, positive but non-significant correlation with height at forking and low and non-significant correlations with total chlorophyll and chlorophyll a:b ratio.

4.1.6.3. Interrelationships among physiological, morphological and structural attributes.

At the genotypic level, depression in dry rubber yield under stress exhibited positive correlation with plugging index during the three periods and negative correlations with the rest of the traits such as volume of latex during the three periods, D.R.C. during the three periods, latex flow rate during the three periods, girth, rate of girth increment, length of tapping panel, virgin bark thickness and renewed bark thickness. The negative correlation of yield depression under stress with volume of latex under stress and its positive correlation with plugging index under stress were high with a moderately low value of S.E. Yield depression under stress showed relatively low negative genotypic correlation with D.R.C. during the three periods and renewed bark thickness and low positive correlation with plugging index during the peak yield period.

At the phenotypic level yield depression under stress showed highly significant negative correlation with volume of latex during the three periods, latex flow rate during the three periods, girth and tapping panel length while the negative correlations were significant only at P = 0.05 with respect to virgin bark thickness and girth increment rate. Correlations of the trait with D.R.C. during the three periods were negative and non-significant. Plugging indices during the three periods were positively correlated with yield depression under stress. The correlations were highly significant with respect to annual mean plugging index and plugging index under stress while the relationship was non-significant for plugging index during the peak yield period. The correlations of yield depression under stress with renewed bark thickness, height at forking, total chlorophyll and chlorophyll a:b ratio were negative and non-significant.

Volume of latex during the three periods recorded high positive interrelationships at the genotypic level with low S.E. estimates. Dry rubber content during the three periods, latex flow rate during the three periods, girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness exhibited positive genotypic correlation with volume of latex during the three periods. With respect to annual mean volume of latex and volume of latex under stress, the correlation with D.R.C. during the peak yield period was moderately high with a moderately low S.E. estimate. Volume of latex during the peak yield period had moderately high genotypic correlation of relatively low S.E. with D.R.C. during the three periods. Latex flow rate during the three periods and volume of latex during the three periods were highly and positively correlated at the genotypic level with low S.E. estimates. Genotypic correlations of volume of latex during the three periods with plugging indices during the three periods were negative. Peak yield of latex had only a low correlation with plugging indices during the three periods while volume of latex under stress showed moderate to high negative genotypic correlation and low S.E. with plugging indices during the three periods. A moderately high association of annual mean volume of latex with annual mean plugging index and plugging index under stress was evident at the genotypic level.

Girth showed a moderately high positive genotypic correlation of low S.E. with volume of latex during the three periods. Though moderate to high positive correlation of volume of latex with girth increment was observed, it was subject to relatively high estimates of S.E. Tapping panel length was highly and positively correlated with annual mean volume of latex and volume of latex under stress. Virgin bark thickness had a high positive genotypic correlation of only moderately low S.E. with volume of latex during the three periods. Renewed bark thickness had a moderately high positive genotypic correlation of low S.E. with annual mean volume of latex.

At the phenotypic level, volume of latex during the three periods were strongly inter-related with highly significant positive correlation coefficients. Latex flow rate during the three periods, D.R.C. during the peak period, girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness exhibited highly significant positive correlations with volume of latex during the three periods while plugging index and volume of latex had highly significant negative correlations during the three periods. Dry rubber content under stress showed a low positive phenotypic correlation with volume of latex under stress and with annual mean volume of latex. The correlations of height at forking, total chlorophyll and chlorophyll a:b ratio with volume of latex were non-significant.

Dry rubber content during the three periods were highly inter-related at the genotypic level and their correlations with all the other traits were positive. Moderate to high genotypic correlations coupled with moderate to low values of S.E. were recorded between latex flow rate and D.R.C. during the three periods. Annual mean D.R.C. had a moderately high genotypic correlation with annual mean plugging index and plugging index during the peak yield period while D.R.C. under stress showed moderately high genotypic correlation with plugging indices over the three periods but the correlation estimates had high S.E. Girth, girth increment rate, tapping panel length, virgin bark thickness and renewed bark thickness had moderately high positive genotypic correlation with D.R.C. during the peak yield period while the relationship of these traits with annual mean D.R.C. and D.R.C. under stress were low except for virgin bark thickness which had a moderately high correlation with D.R.C. during the three periods.

At the phenotypic level D.R.C. during the three periods had highly significant positive correlations. Dry rubber content and latex flow rate had highly significant positive correlations except under stress where the correlation was significant only at P = 0.05. Plugging index in general, was not significantly correlated with D.R.C. though significant but low positive correlations were observed between plugging index during the peak yield period and annual mean D.R.C. and annual mean plugging index and D.R.C. under stress. A non-significant negative correlation was observed between plugging index under stress and D.R.C during the peak yield period. Girth recorded highly significant positive correlation with annual mean D.R.C. and D.R.C. during the peak yield period. Girth increment rate, tapping panel length, virgin bark thickness and renewed bark thickness recorded highly significant positive correlations with D.R.C. during the peak yield period. Virgin and renewed bark thickness had a highly significant positive correlation with annual mean D.R.C.

Rate of latex flow during the three periods exhibited high and positive genotypic interrelationships. Latex flow rate under stress and plugging index under stress were negatively correlated at the genotypic level while annual mean plugging index and plugging index under stress were negatively correlated with annual mean latex flow rate. However, the correlations were not high in magnitude. Girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness exhibited moderate to high positive genotypic correlation with latex flow rate during the three periods. However, the S.E. of genotypic correlation of girth increment and renewed bark thickness with latex flow rate during the three periods were relatively high.

At the phenotypic level, latex flow rate during the three periods showed highly significant positive interrelationships. Rate of latex flow under stress had highly significant negative correlation with annual mean plugging index and plugging index under stress. Annual mean latex flow rate also had a significant negative correlation with plugging index under stress. Girth, girth increment, tapping panel length, virgin bark thickness and renewed bark thickness exhibited highly significant positive correlation with latex flow rate during the three periods. Forking height and chlorophyll content did not show any significant correlation with latex flow rate.

Plugging indices during the three periods exhibited high positive interrelationships at the genotypic level except for plugging indices during the stress and peak periods when a relatively high S.E. was associated with the genotypic correlation coefficient. Girth, girth increment rate, tapping panel length and virgin bark thickness exhibited negative genotypic correlation with annual mean plugging index and plugging index under stress. However, the correlations were not high.

Phenotypic interrelationships among plugging indices during the three periods were positive and highly significant Girth and tapping panel length showed a highly significant negative correlation with annual mean plugging index and plugging index under stress. Virgin bark thickness recorded a highly significant negative correlation with annual mean plugging index. The rest of the correlations shown by plugging index with morphological and structural attributes were non-significant.

Interrelationships among girth, girth increment rate, length of tapping panel, virgin bark thickness and renewed bark thickness were positive and moderate to very high at the genotypic level. However the positive correlation coefficients between girth increment rate and panel length, virgin bark thickness and renewed bark thickness had a high S.E.

At the phenotypic level interrelationships among the morphological and structural attributes were positive and highly significant, the correlation being highest between girth and tapping panel length followed by girth and girth increment rate. Height at forking had significant positive phenotypic correlation with girth, tapping panel length and virgin bark thickness. The association of forking height with girth increment was negative and non-significant. Total chlorophyll and chlorophyll a:b ratio did not show significant association with any of the traits.

4.1.7. Path analysis

Dry rubber yield under stress, peak dry rubber yield, yield depression under stress, annual mean volume of latex, volume of latex under stress, volume of latex during the peak yield period, annual mean D.R.C., D.R.C. under stress, D.R.C. during the peak yield period, annual mean latex flow rate, latex flow rate under stress, latex flow rate during the peak yield period, annual mean plugging index, plugging index under stress, plugging index during the peak yield period, girth, girth increment rate, length of the tapping panel and virgin bark thickness were considered as the components of rubber yield.

The direct and indirect effects of each of the nineteen components on annual mean dry rubber yield along with their respective genotypic correlations are presented in table 15. Figure 13 represents the direct and indirect effects of the components on dry rubber yield.

Latex flow rate during the peak yield period had the maximum direct effect (0.70) on annual mean dry rubber yield. This component was observed to exert relatively high positive indirect effects through annual mean volume of latex (0.45), dry rubber yield under stress (0.40), latex flow rate under stress (0.29), peak dry rubber yield (0.12) and annual mean D.R.C. (0.12). Positive indirect effects through the other components viz. D.R.C. during the peak yield period, tapping panel length, girth and annual mean plugging index were relatively low. Latex flow rate during the peak period also exerts relatively high negative indirect effects through annual mean latex flow rate (-0.87) and volume of latex during the peak period (-0.20). It also exerts negative indirect effects through plugging indices under stress and during the peak period, D.R.C. under stress, volume of latex under stress, yield depression under stress, girth increment and virgin bark thickness though to a relatively low extent.

Table 15. Direct and indirect effects of the components of rubber yield in clones.

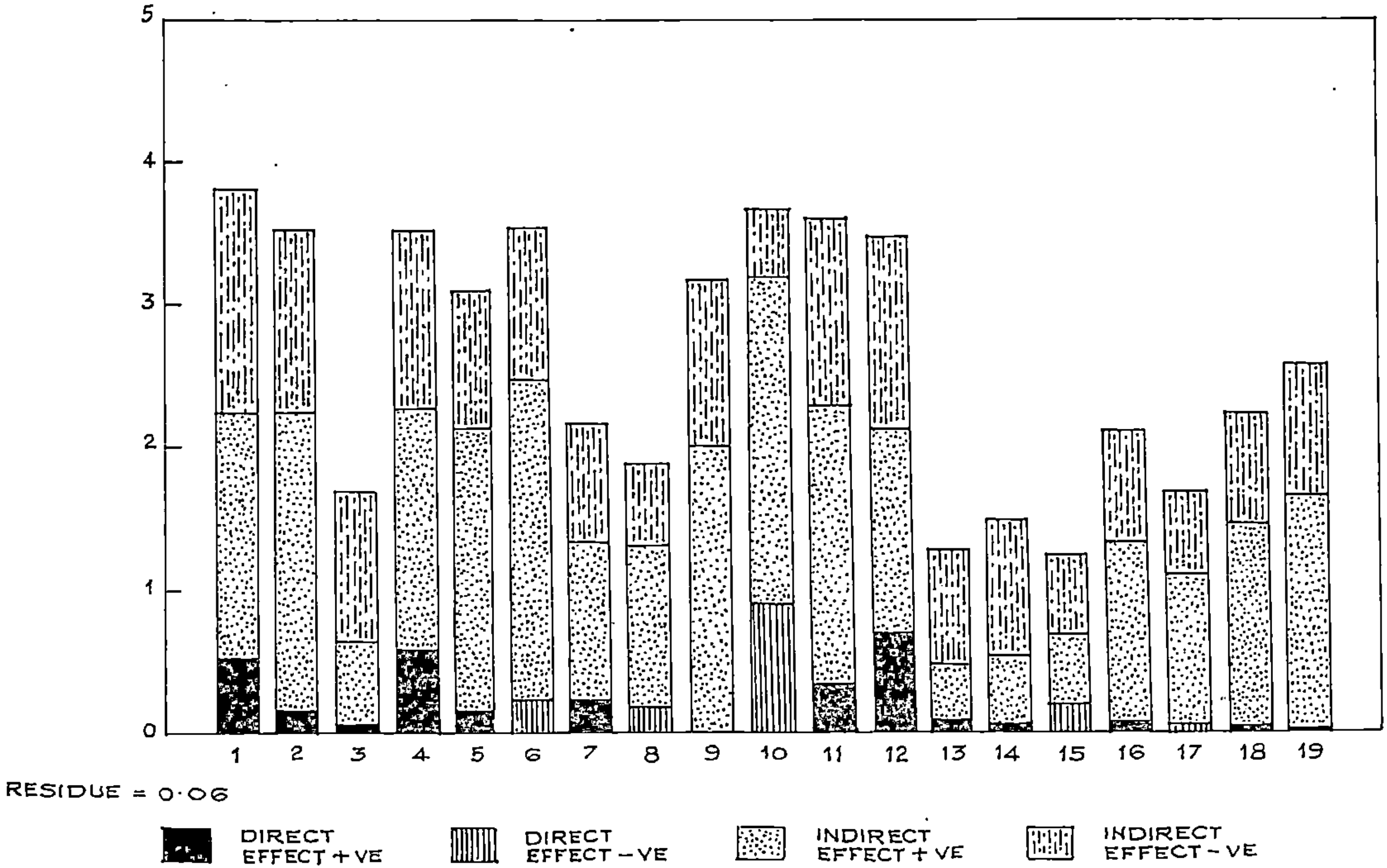
Characters	Direct effect	Indirect effects via: Dry rubber yield (stress)	Dry rubber yield (peak)	Yield depression (stress)	Volume of latex (annual)	Volume of latex (stress)	Volume of latex (peak)	D.R.C. (annual)	D.R.C. (stress)	D.R.C. (peak)	Latex flow rate (annual)	Latex flow rate (stress)	Latex flow rate (peak)	Plugging index (annual)	Plugging index (stress)	Plugging index (peak)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	Total genotypic correlation
Dry rubber yield (stress)	0.53	--	0.12	-0.03	0.54	-0.13	-0.19	0.10	-0.05	0.01	-0.79	0.32	0.53	-0.03	-0.03	0.03	0.03	-0.02	0.03	-0.01	0.96
Dry rubber yield (peak)	0.14	0.45	--	-0.01	0.53	-0.10	-0.22	0.13	-0.09	0.02	-0.83	0.31	0.60	-0.01	-0.01	-0.02	0.03	-0.02	0.02	-0.01	0.95
Yield depression (stress)	0.05	-0.33	-0.03	--	-0.24	0.09	0.06	-0.02	0.02	-0.01	0.35	-0.16	-0.23	0.03	0.03	-0.01	-0.02	0.02	-0.01	0.01	-0.41
Volume of latex (annual)	0.57	0.50	0.13	-0.02	--	-0.13	-0.20	0.07	-0.03	0.01	-0.81	0.32	0.54	-0.03	-0.03	0.05	0.04	-0.02	0.03	-0.01	0.98
Volume of latex (stres)	-0.14	0.49	0.10	-0.03	0.52	--	-0.15	0.04	-0.01	0.01	-0.66	0.29	0.41	-0.05	-0.04	0.05	0.04	-0.03	0.03	-0.01	0.88
Volume of latex (peak)	-0.22	0.45	0.14	-0.01	0.53	-0.09	--	0.11	-0.07	0.02	-0.86	0.30	0.63	-0.01	-0.01	0.02	0.03	-0.02	0.02	-0.01	0.94
D.R.C (annual)	0.22	0.23	0.08	-0.01	0.19	-0.03	-0.11	--	-0.16	0.12	-0.46	0.16	0.38	0.02	0.01	-0.06	0.01	-0.01	0.01	-0.01	0.50
D.R.C. (stress)	-0.16	0.16	0.07	-0.01	0.11	-0.01	-0.10	0.21	--	0.02	-0.42	0.12	0.38	0.03	0.02	-0.07	0.01	-0.01	0.01	-0.004	0.36
D.R.C. (peak)	0.02	0.39	0.12	-0.01	0.39	-0.07	-0.18	0.22	-0.16	--	-0.71	0.27	0.53	0.01	0.01	-0.03	0.02	-0.02	0.02	-0.01	0.82
Latex flow rate (annual)	-0.89	0.46	0.13	-0.02	0.52	-0.10	-0.21	0.11	-0.08	0.02	--	0.32	0.67	-0.01	-0.01	-0.03	0.03	-0.02	0.02	-0.01	0.92
Latex flow rate (stress)	0.34	0.49	0.13	-0.02	0.54	-0.12	-0.19	0.11	-0.06	0.02	-0.85	--	0.60	-0.01	-0.02	-0.02	0.04	-0.02	0.03	-0.01	0.96
Latex flow rate (peak)	0.70	0.40	0.12	-0.02	0.45	-0.08	-0.20	0.12	-0.09	0.02	-0.87	0.29	--	0.01	-0.01	-0.06	0.03	-0.02	0.01	-0.01	0.81
Plugging index (annual)	0.07	-0.24	-0.02	0.02	-0.26	0.09	0.04	0.07	-0.07	0.01	0.04	-0.06	0.07	--	0.05	-0.13	-0.01	0.01	-0.01	0.01	-0.36
Plugging index (stress)	0.05	-0.31	-0.03	0.03	-0.30	0.10	0.05	0.04	-0.05	0.01	0.16	-0.11	-0.04	0.07	--	-0.09	-0.02	0.01	-0.01	0.01	-0.45
Plugging index (peak)	-0.17	-0.10	-0.01	0.004	-0.16	0.04	0.03	0.07	-0.07	0.01	-0.15	0.03	0.23	0.06	0.03	--	0.01	-0.01	-0.01	0.01	-0.19
Girth	0.06	0.28	0.06	-0.02	0.34	-0.09	-0.10	0.03	-0.03	0.01	-0.48	0.20	0.31	-0.01	-0.01	-0.01	--	-0.05	0.04	-0.01	0.54
Girth increment rate	-0.05	0.20	0.04	-0.02	0.25	-0.07	-0.07	0.04	-0.01	0.01	-0.39	0.15	0.25	-0.01	-0.01	-0.02	0.06	-	0.03	-0.01	0.39
Tapping panel length	0.05	0.35	0.07	-0.02	0.38	-0.10	-0.09	0.04	-0.01	0.01	-0.47	0.22	0.25	-0.02	-0.02	0.03	0.06	-0.04	--	-0.01	0.67
Virgin bark thickness	-0.01	0.34	0.10	-0.01	0.41	-0.08	-0.15	0.09	-0.05	0.01	-0.57	0.25	0.35	-0.02	-0.01	0.02	0.03	-0.03	0.03	--	0.69

Residue = 0.06

Figure 13. Direct and indirect effects of components on dry rubber yield.

1. Dry rubber yield (stress)
2. Dry rubber yield (peak)
3. Yield depression (stress)
4. Volume of latex (annual)
5. Volume of latex (stress)
6. Volume of latex (peak)
7. Dry rubber content (annual)
8. Dry rubber content (stress)
9. Dry rubber content (peak)
10. Latex flow rate (annual)
11. Latex flow rate (stress)
12. Latex flow rate (peak)
13. Plugging index (annual)
14. Plugging index (stress)
15. Plugging index (peak)
16. Girth
17. Girth increment rate
18. Length of tapping panel
19. Virgin bark thickness

FIG.13. DIRECT AND INDIRECT EFFECTS OF COMPONENTS ON DRY RUBBER YIELD.



The second important component with a high positive direct effect on annual mean dry rubber yield (0.57) was annual mean volume of latex which exerts high positive indirect effects through latex flow rate during the peak period (0.54), dry rubber yield under stress (0.50), latex flow rate under stress (0.32) and peak dry rubber yield (0.13). The other components through which annual mean volume of latex exerts a relatively low but positive indirect effect on yield are plugging index during the peak yield period, annual mean D.R.C., girth, length of tapping panel and D.R.C. during the peak yield period. Annual mean volume of latex was found to exert relatively high negative indirect effects on yield through annual mean latex flow rate (-0.81), peak volume of latex (-0.20) and volume of latex under stress (-0.13) while its negative indirect effects through girth increment, virgin bark thickness, yield depression under stress, D.R.C. under stress, annual mean plugging index and plugging index under stress were relatively low.

Dry rubber yield under stress is the third important component that was found to exert a high positive direct effect on annual mean dry rubber yield (0.53). The positive indirect effects of this trait on annual mean dry rubber yield is manifested through annual mean volume of latex (0.54), latex flow rate during the peak period (0.53), latex flow rate under stress (0.320), peak dry rubber yield (0.12), annual mean D.R.C. (0.10), plugging index during the peak period (0.04), girth (0.03), panel length (0.03) and D.R.C. during the peak period (0.02). Dry rubber yield under stress also exerts relatively high negative indirect effects through annual mean latex flow rate (-0.79), annual mean plugging index (-0.34), volume of latex during the peak period (-0.19) and during the stress period (-0.13) and relatively low negative indirect effects through girth increment, virgin bark thickness, yield depression under stress, D.R.C. under stress and plugging index under stress.

Latex flow rate under stress is the next important component with a high positive direct effect on annual mean dry rubber yield (0.34). It exerts positive indirect effects through latex flow rate during the peak yield period (0.60), annual mean volume of latex (0.54), dry rubber yield under stress (0.49), peak dry rubber yield (0.13) and annual mean D.R.C. (0.11). The positive indirect effects of this trait through girth, length of tapping panel and D.R.C. during the peak period were comparatively low. The negative indirect effects of latex flow rate under stress on annual mean dry rubber yield were manifested mainly through annual mean latex flow rate (-0.85), volume of latex during the peak period (-0.10) and volume of latex under stress (-0.12). The negative indirect effects of this trait through girth increment, virgin bark thickness, yield depression under stress, D.R.C. under stress and plugging index during the three periods were relatively low.

Annual mean D.R.C. exerts the next highest direct positive effect on annual mean yield (0.22) with its positive indirect effects manifested through latex flow rate during the peak period (0.38), dry rubber yield under stress (0.23), annual mean volume of latex (0.19), latex flow rate under stress (0.16), peak dry rubber yield (0.08), annual mean plugging index (0.02), D.R.C. during the peak yield period (0.02), girth, length of tapping panel and plugging index under stress (0.01 in each case). Negative indirect effects of annual mean D.R.C. were manifested mainly through annual mean latex flow rate (-0.46), D.R.C. under stress (-0.16) and volume of latex during the peak period (-0.11). The negative indirect effects through plugging index during the peak period, girth increment, virgin bark thickness and yield depression under stress were relatively low.

Peak dry rubber yield was identified as the next important component that exerts a positive direct effect (0.14) on annual mean dry rubber yield. The positive indirect effects of this trait through latex flow rate during the peak period (0.60), annual mean volume of latex (0.53), dry rubber yield under stress (0.45), latex flow rate under stress (0.31) and annual mean D.R.C. (0.13) were relatively high while the positive indirect effects through girth, panel length and plugging index and D.R.C. during the peak yield period were relatively low. Peak dry rubber yield was found to exert high negative indirect effects through annual mean latex flow rate (-0.83) and volume of latex during the peak period (-0.22) and low negative indirect effects through girth increment, virgin bark thickness, yield depression under stress, volume of latex under stress, D.R.C. under stress, annual mean plugging index and plugging index under stress.

Other components which were found to exert a positive direct effect on annual mean dry rubber yield are annual mean plugging index (0.07), girth (0.06), yield depression under stress (0.05), plugging index under stress (0.05), length of tapping panel (0.05) and D.R.C. during the peak yield period (0.02).

Annual mean plugging index exerts positive indirect effects via. volume of latex under stress, annual mean D.R.C., latex flow rate during the peak period, plugging index under stress, annual mean latex flow rate, volume of latex during the peak period, yield depression under stress, D.R.C. during the peak yield period, girth increment and virgin bark thickness and negative indirect effects via. annual mean volume of latex, dry rubber yield under stress, plugging index during the peak yield period, D.R.C. under stress, latex flow rate under stress, peak dry rubber yield, panel length and girth increment rate.

Girth exerts positive indirect effects through annual mean volume of latex, latex flow rate during the peak yield period, dry rubber yield under stress, latex flow rate under stress, peak dry rubber yield, length of tapping panel, annual mean D.R.C. and D.R.C. during the peak yield period. Negative indirect effects of girth on yield were manifested through annual mean latex flow rate, girth increment rate, yield depression under stress, virgin bark thickness, volume of latex during the stress and peak periods, plugging indices during the three periods and D.R.C. under stress.

A high negative direct effect on annual mean dry rubber yield was found to be exerted by the annual mean latex flow rate (-0.89), but its positive indirect effects through nine traits (girth, length of tapping panel, dry rubber yield under stress, peak dry rubber yield, annual mean volume of latex, annual mean D.R.C., D.R.C. during the peak period and latex flow rate during the stress and peak periods) were greater than the negative direct effect and the negative indirect effects through nine traits (girth increment, virgin bark thickness, yield depression under stress, volume of latex during the stress and peak periods, D.R.C. under stress and plugging indices during the three periods).

Volume of latex during the peak period also had a relatively high negative direct effect (-0.22) on annual mean dry rubber yield. The total positive indirect effect of this trait through ten other traits (girth, tapping panel length, dry rubber yield during the stress and peak periods, annual mean volume of latex, annual mean D.R.C., D.R.C. during the peak period, latex flow rate during the stress and peak periods and plugging index during the peak period) was higher than the total negative indirect effect via girth increment, virgin bark thickness, yield depression under stress, volume of latex under stress, D.R.C. under stress, annual mean latex flow rate, annual mean plugging index and plugging index under stress.

Plugging index during the peak yield period is the next important component which was found to exert a negative direct effect (-0.17) on annual mean dry rubber yield. The negative indirect effects of this trait were manifested through plugging index during the peak yield period (-0.18), annual mean volume of latex (-0.16), annual mean latex flow rate (-0.15), dry rubber yield under stress (-0.10), D.R.C. under stress (-0.07), peak dry rubber yield (-0.01), length of the tapping panel (-0.01) and girth increment rate (-0.01). The positive indirect effects of this trait were manifested through girth, virgin bark thickness, yield depression under stress, volume of latex during the stress and peak periods, annual mean D.R.C., D.R.C. during the peak period, latex flow rate during the stress and peak periods, annual mean plugging index and plugging index under stress.

Other characters which had a negative direct effect on annual mean dry rubber yield were D.R.C. under stress (-0.16), volume of latex under stress (-0.14), girth increment rate (-0.05) and virgin bark thickness (-0.01).

The residual was very low (0.06) indicating that most of the genetic variability for rubber yield and its components has been accounted for by this model. The physiological components of yield in general exhibited higher magnitudes of direct effects on yield than the morphological and structural components. Latex flow rate during the peak yield period, annual mean, volume of latex, dry rubber yield under stress, latex flow rate under stress and annual mean D.R.C. in order, emerge as the most important components of annual mean dry rubber yield.

An analysis of the cause and effect relationships of the specific components of annual mean dry rubber yield, dry rubber yield under stress and peak dry rubber yield was also attempted separately and the results are presented in tables 16, 17 and 18 respectively. Path diagrams (Figures 14, 15 and 16) showing the direct effects and interrelationships are also presented.

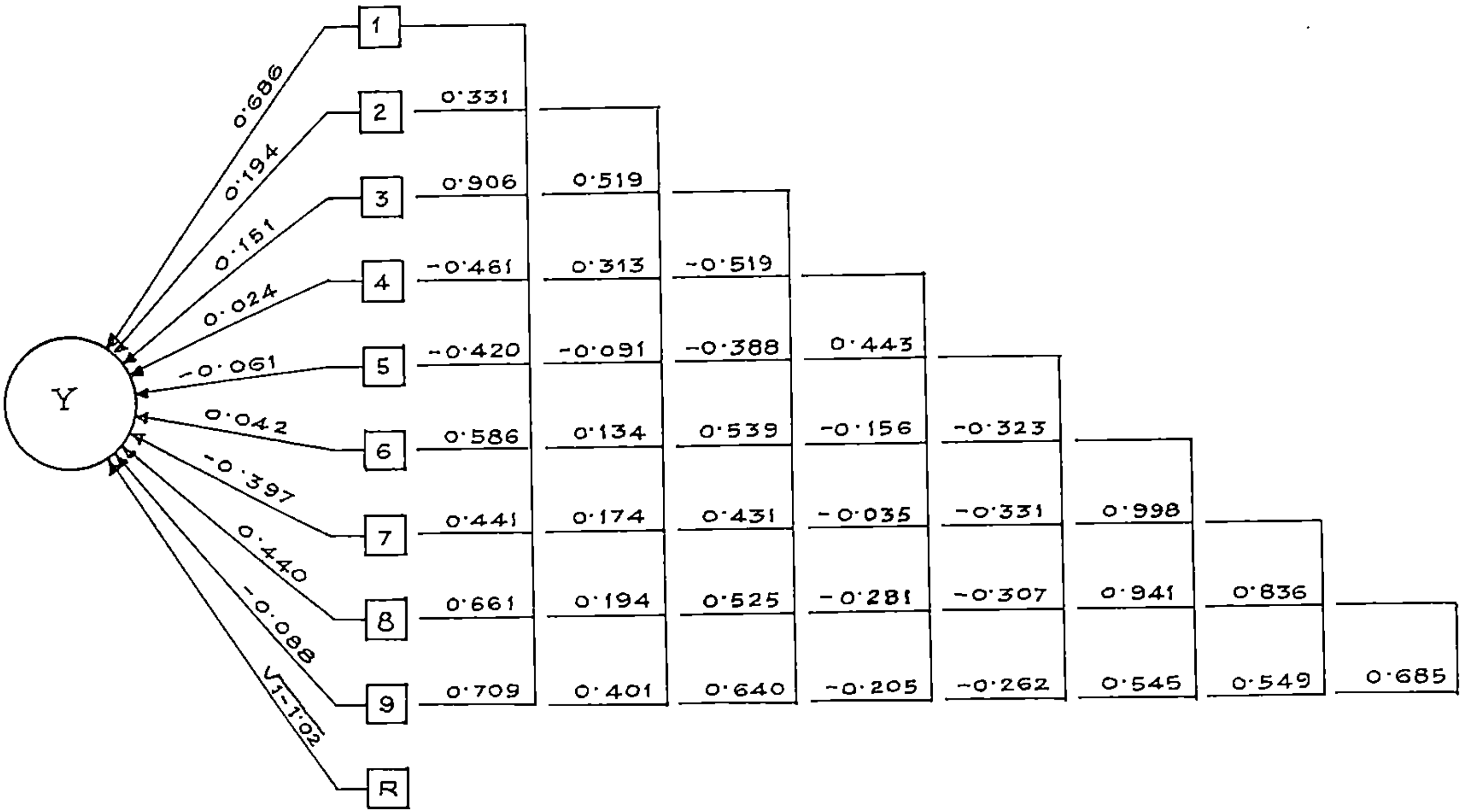
Annual mean values of volume of latex, D.R.C., latex flow rate and plugging index along with yield depression under stress, girth, girth increment rate, tapping panel length and virgin bark thickness were considered as the specific components of annual mean dry rubber yield. Volume of latex exerted the highest positive direct effect on annual mean dry rubber yield (0.696) followed by length of the tapping panel (0.440), D.R.C. (0.194) and latex

Table 16. Direct and indirect effects of components on annual mean dry rubber yield.

	Direct effect	Indirect effects via									Total genotypic correlation
		Volume of latex (annual)	Dry rubber content (annual)	Latex flow rate (annual)	Plugging index (annual)	Yield depression (stress)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	
Volume of latex (annual)	0.686	--	0.064	0.136	-0.011	0.026	0.024	-0.175	0.291	-0.062	0.979
Dry rubber content (annual)	0.194	0.227	--	0.078	0.007	0.006	0.006	-0.069	0.085	-0.035	0.498
Latex flow rate (annual)	0.151	0.621	0.101	--	-0.001	0.024	0.022	-0.171	0.231	-0.056	0.931
Plugging index (annual)	0.024	-0.316	0.061	-0.007	--	-0.027	-0.007	0.014	-0.124	0.018	-0.364
Yield depression (stress)	-0.061	-0.288	-0.018	-0.058	0.011	--	-0.013	0.132	-0.135	0.023	-0.409
Girth	0.042	0.402	0.026	0.081	-0.004	0.020	--	-0.396	0.415	-0.048	0.537
Girth increment rate	-0.397	0.302	0.034	0.065	-0.001	0.020	0.042	--	0.368	-0.048	0.385
Tapping panel length	0.440	0.453	0.038	0.079	-0.007	0.019	0.039	-0.332	--	-0.060	0.669
Virgin bark thickness	-0.088	0.486	0.078	0.096	-0.005	0.016	0.023	-0.218	0.302	--	0.690

Residual $= \sqrt{1-1.02}$

FIG.14. PATH DIAGRAM SHOWING THE DIRECT EFFECTS AND INTERRELATIONSHIPS OF ANNUAL MEAN DRY RUBBER YIELD AND ITS COMPONENTS.



DIRECT EFFECTS SHOWN ALONG ARROWS. INTERRELATIONSHIPS SHOWN IN STEPS.

Figure 14. Path diagram showing the direct effects and interrelationships of annual mean dry rubber yield and its components.

Y	Annual mean dry rubber yield
1	Volume of latex (annual)
2	Dry rubber content (annual)
3	Rate of latex flow (annual)
4	Plugging index (annual)
5	Yield depression under stress
6	Girth
7	Girth increment rate
8	Length of tapping panel
9	Virgin bark thickness
R	Residue

Table 17. Direct and indirect efects of components on dry rubber yield under stress.

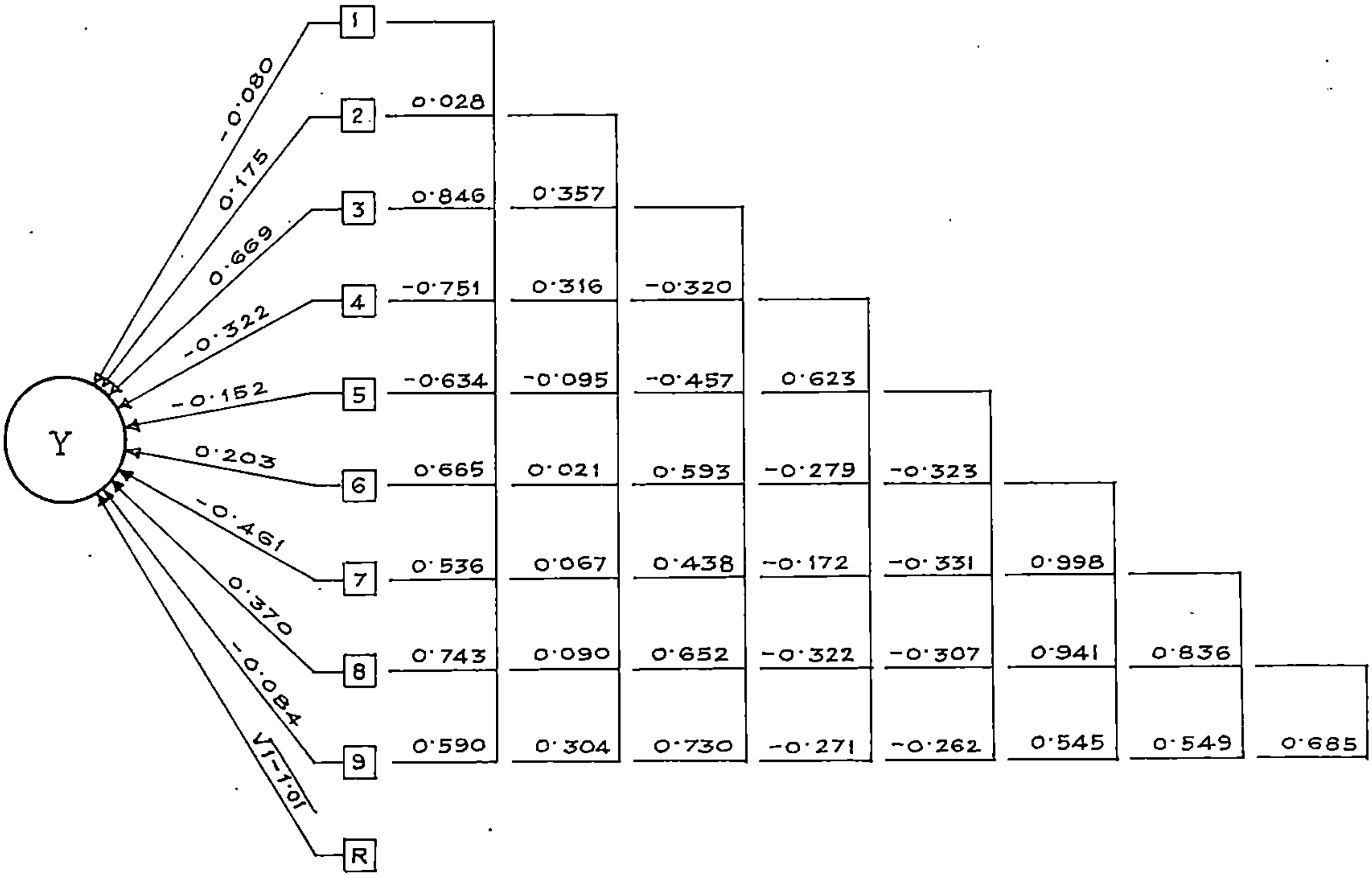
	Direct effect	Indirect effects via									Total genotypic correlation
		Volume of latex (stress)	D.R.C. (stress)	Latex flow rate (stress)	Plugging index (stress)	Yield depression (stress)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	
Volume of latex (stress)	-0.080	--	0.005	0.566	0.242	0.097	0.135	-0.247	0.275	-0.050	0.942
D.R.C. (stress)	0.175	-0.002	--	0.239	-0.102	0.014	0.004	-0.031	0.033	-0.026	0.305
Latex flow rate (stress)	0.669	-0.068	0.063	--	0.103	0.070	0.120	-0.202	0.241	-0.062	0.934
Plugging index (stress)	-0.322	0.060	0.055	-0.214	--	-0.095	-0.057	0.079	-0.119	0.023	-0.590
Yield depression (stress)	-0.152	0.051	-0.017	-0.306	-0.201	--	-0.066	0.153	-0.114	0.022	-0.629
Girth	0.203	-0.053	0.004	0.397	0.090	0.049	--	-0.460	0.348	-0.046	0.531
Girth increment rate	-0.461	-0.043	0.012	0.293	0.056	0.051	0.202	--	0.309	-0.046	0.372
Tapping panel length	0.370	-0.060	0.016	0.436	0.104	0.047	0.191	-0.386	--	-0.058	0.660
Virgin bark thickness	-0.084	-0.047	0.053	0.489	0.087	0.040	0.111	-0.253	0.253	--	0.648

Residual $= \sqrt{1-1.01}$

Figure 15. Path diagram showing direct effects and interrelationships of dry rubber yield and its components under stress.

Y	Dry rubber yield under stress
1	Volume of latex (stress)
2	Dry rubber content (stress)
3	Rate of latex flow (stress)
4	Plugging index (stress)
5	Yield depression under stress
6	Girth
7	Girth increment rate
8	Length of tapping panel
9	Virgin bark thickness
R	Residue

FIG.15. PATH DIAGRAM SHOWING THE DIRECT EFFECTS AND INTERRELATIONSHIPS OF DRY RUBBER YIELD AND ITS COMPONENTS UNDER STRESS.



DIRECT EFFECTS SHOWN ALONG ARROWS. INTERRELATIONSHIPS SHOWN IN STEPS.

Table 18. Direct and indirect effects of components on peak dry rubber yield.

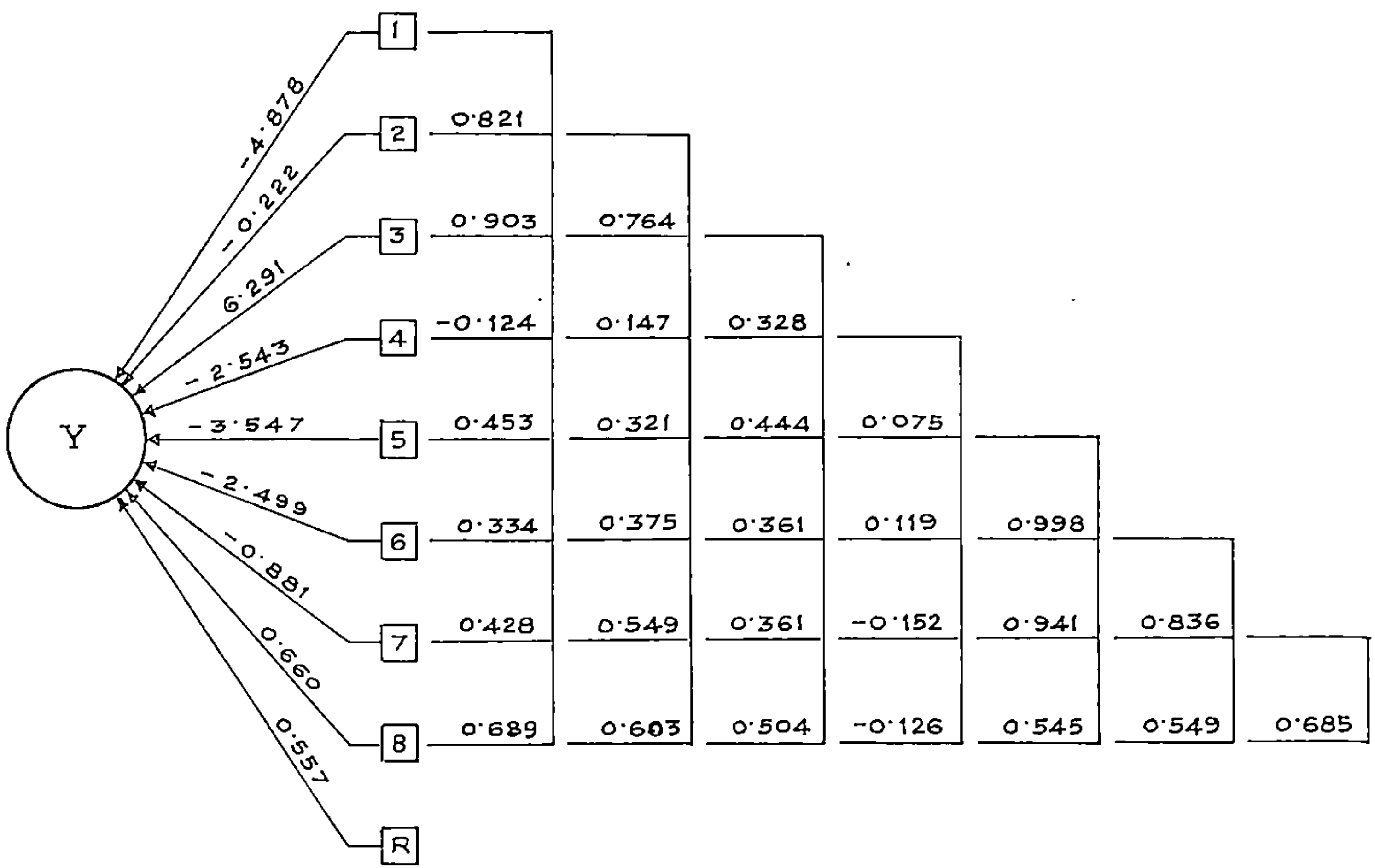
	Direct effect	Indirect effects via								Total genotypic correlation
		Volume of latex (peak)	D.R.C. (peak)	Latex flow rate (peak)	Plugging index (peak)	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	
Volume of latex (peak)	-4.878	--	-0.182	5.683	0.315	-1.606	0.834	0.377	0.454	0.998
D.R.C. (peak)	-0.222	-4.006	--	4.807	-0.375	-1.140	0.938	0.483	0.398	0.883
Latex flow rate (peak)	6.291	-4.406	-0.169	--	-0.835	-1.573	0.903	0.318	0.332	0.862
Plugging index (peak)	-2.543	0.605	-0.033	2.065	--	-0.265	0.297	-0.134	-0.083	-0.091
Girth	-3.547	-2.209	-0.071	2.790	-0.190	--	2.495	0.829	0.360	0.458
Girth increment rate	2.499	-1.628	-0.083	2.273	-0.302	-3.542	--	0.737	0.362	0.317
Tapping panel lenth	0.881	-2.086	-0.122	2.272	0.387	-3.339	2.090	--	0.452	0.536
Virgin bark thickness	0.660	-3.359	-0.134	3.169	0.321	-1.934	1.371	0.603	--	0.697

Residual = 0.557

Figure 16. Path diagram showing direct effects and interrelationships of peak dry rubber yield and its components.

Y	Peak dry rubber yield
1	Volume of latex (peak)
2	Dry rubber content (peak)
3	Rate of latex flow (peak)
4	Plugging index (peak)
5	Girth
6	Girth increment rate
7	Length of tapping panel
8	Virgin bark thickness
R	Residue

FIG.16. PATH DIAGRAM SHOWING THE DIRECT EFFECTS AND INTERRELATIONSHIPS OF PEAK DRY RUBBER YIELD AND ITS COMPONENTS.



DIRECT EFFECTS SHOWN ALONG ARROWS. INTERRELATIONSHIPS SHOWN IN STEPS.

flow rate (0.151). Girth increment rate exerted the maximum negative direct effect on annual mean rubber yield (-0.397) followed by virgin bark thickness (-0.088) and yield depression under stress (-0.061). The positive indirect effects of virgin bark thickness were manifested mainly through volume of latex and tapping panel length. The residual effect was not estimable indicating that a number of unaccounted factors are involved in the cause and effect relationships of annual mean dry rubber yield and its components.

The morphological components and virgin bark thickness along with yield depression under stress and the physiological components of rubber yield during the stress period were specifically examined for the cause and effect of relationships. Volume of latex showed a negative direct effect (-0.080) on dry rubber yield under stress. The maximum positive direct effect was exerted by latex flow rate (0.669) followed by tapping panel length (0.370) and girth (0.203). The traits which exerted the maximum negative direct effects were girth increment rate (-0.461) followed by plugging index (-0.322) and yield depression under stress (0.152). The indirect effects of most of the characters viz., volume of latex, D.R.C., girth, tapping panel length and virgin bark thickness were exerted through the rate of latex flow. The residual effect was not estimable indicating that a number of unaccounted components are also involved in the expression of genetic variability for dry rubber yield under stress.

The specific components of peak dry rubber yield considered for the study of cause and effect relationships were volume of latex, D.R.C., latex flow rate and plugging index during the peak period, girth, girth increment rate, tapping panel length and virgin bark thickness. Latex flow rate exerted the maximum positive direct effect (6.2910 followed by girth increment rate (2.499), tapping panel length (0.881) and virgin bark thickness (0.660). Volume of latex was found to exert a high negative direct effect (-4.878) followed by girth (-3.547), plugging index (-2.543) and D.R.C. (-0.222). The highest positive indirect effects of all the characters were mediated through latex flow rate during the peak yield period. The residual effect was 0.557 indicating that only 44.3 per cent of the variation for peak dry rubber yield could be accounted for by the components studied.

4.1.8. D^2 analysis

The genetic distances between the forty clones were estimated using the values of the uncorrelated linear combinations for 22 variables. The 780 D^2 values obtained by taking 40 clones in all possible paired combinations are presented in Appendix. The D^2 values ranged from 1347.69 to 225744.50.

4.1.8.1. Clone constellations

The clustering of clones was done employing the Tocher's method of classification in such a way that the intra cluster distances were smaller than the inter cluster distances. The critical D^2 value, employed for initiation of new clusters was 22023.02. Accordingly, the forty clones were grouped into eight clusters. The composition of each cluster is presented in table 19. There were fifteen clones in the first cluster (PR 107, PB 5/139, Ch 32, Lun N, HC 28, PB 5/60, Waring 4, Tjir 16, BD 10, Ch 4, PB 213, HC 55, Mil 3/2, Ch 29 and BD 5), eleven in the second (Gl 1, PB 206, AVROS 255, AVROS 352, PB 215, PB 5/51, LCB 1320, PB 28/83, PB 230, PB 5/163, and PB 5/76), six in the third (RRII 105, Ch 26, PB 252, PB 242, PB 217 and GT 1), three in the fourth (Ch 153, PB 6/50 and PB 86), one in the fifth (RSY 23), two in the sixth (AVT 73 and PB 28/59) and one each in the seventh (Ch 2) and eighth (PB 235).

The clones were found to form groups irrespective of their country of origin. Cluster I comprised seven Malaysian, four Indonesian and four Sri Lankan clones. Cluster II comprised eight Malaysian and three Indonesian clones. Cluster III comprised four Malaysian clones and one each of the Indian and Indonesian clones. Of the two clones in Cluster VI, one was Indian and the other, Malaysian. Thus the twenty five Malaysian clones were distributed in eight clusters, the eight Indonesian clones in three clusters, the four Sri Lankan clones in the same cluster and the three Indian clones in three different clusters.

Table 19. Composition of clusters.

Cluster No.	No. of clones	Clones included
I	15	PR 107, PB 5/139, Ch 32, Lun N, HC 28, PB 5/60, Waring 4, Tjir 16, BD 10, Ch 4, PB 213, HC 55, Mil 3/2, Ch 29, BD 5.
II	11	Gl 1, PB 206, AVROS 255, AVROS 352, PB 215, PB 5/51, LCB 1320, PB 28/83, PB 230, PB 5/163, PB 5/76.
III	6	RRII 105, Ch 26, PB 252, PB 242, PB 217, GT 1.
IV	3	Ch 153, PB 6/50, PB 86.
V	1	RSY 23
VI	2	AVT 73, PB 28/59
VII	1	Ch 2
VIII	1	PB 235

The mean inter and intra cluster distances are given in table 20. The intra cluster D^2 values ranged from 0.0 for the single clone clusters V, VII and VIII to 15609.3 for cluster IV. The inter cluster D^2 values ranged from 22729.0 (between clusters I and V) to 193069.4 (between clusters VI and VII.

The spatial arrangement of the eight clusters is presented diagrammatically in figure 17. The clusters are shown as being distributed in a multidimensional space based on the D^2 values to represent the relative disposition of the clusters. Since the clusters occupy a multidimensional space, the relative distance between the clusters in all the cases could not be shown to scale accurately in the two dimensional diagram in which case the distances have been indicated by broken lines.

The cluster means for yield (Table 21), physiological components of yield (Table 22) and morphological and structural attributes (Table 23) reveal that cluster VIII comprising a single clone (PB 235) exhibits superiority for sixteen traits viz. girth (96.33 cm), length of tapping panel (56.92 cm), height at first forking (3.8 m), virgin bark thickness (9.17 mm), renewed bark thickness (7.83 mm), annual mean dry rubber yield (77.01 g tree^{-1} tapping^{-1}), dry rubber yield under stress (58.11 g tree^{-1} tapping^{-1}) and during the peak period (85.76 g tree^{-1} tapping^{-1}), volume of latex under stress (166.63 ml tree^{-1} tapping^{-1}), annual mean D.R.C. (38.21%), D.R.C.

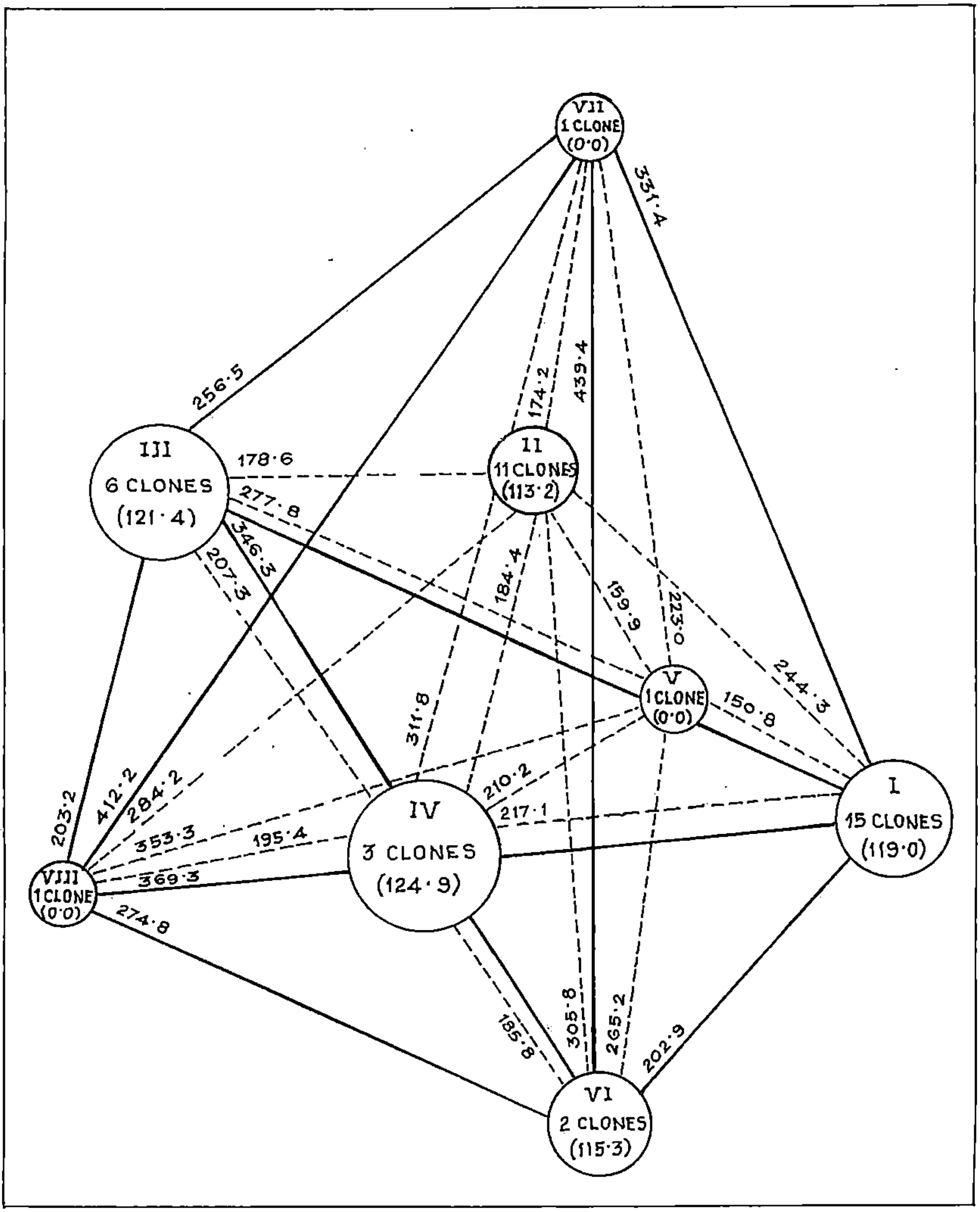
Table 20. Mean intra and inter cluster distances (D^2 and D values)

Clusters	I	II	III	IV	V	VI	VII	VIII
I	14156.14 (118.98)	59665.86 (244.27)	117924.17 (343.40)	47121.66 (217.08)	22729.02 (150.76)	41162.76 (202.89)	109828.45 (331.40)	136402.04 (369.33)
II		12811.79 (113.19)	31887.95 (178.57)	33997.32 (184.38)	25571.61 (159.91)	93541.00 (305.84)	30327.29 (174.15)	80750.13 (284.17)
III			14735.53 (121.39)	42987.59 (207.33)	77195.31 (277.84)	19909.65 (346.28)	65780.61 (256.48)	41302.87 (203.23)
IV				15609.26 (124.94)	44176.27 (210.18)	34533.31 (185.83)	97241.65 (311.84)	38186.63 (195.41)
V					0.00 (0.00)	70324.90 (265.19)	49735.46 (223.01)	124783.40 (353.25)
VI						13292.67 (115.29)	193069.40 (439.40)	75495.26 (274.76)
VII							0.00 (0.00)	169900.70 (412.19)
VIII								0.00 (0.00)

$D = \sqrt{D^2}$ values given in parenthesis.

Values along the diagonal are the intra cluster distances.

FIG. 17. DISTRIBUTION OF GENETICALLY DIVERGENT CLUSTERS.



INTER CLUSTER DISTANCE SHOWN ALONG LINES.
INTRA CLUSTER DISTANCE SHOWN IN PARENTHESIS.

Table 21. Cluster means for yield.

Sl. No.	Cluster No.	Dry rubber yield ($g\ tree^{-1}\ tapping^{-1}$)			Yield depression under stress (%)	Volume of latex ($ml\ tree^{-1}\ tapping^{-1}$)		
		Annual	Stress	Peak		Annual	Stress	Peak
1.	I	33.21	23.04	44.33	32.25	106.46	58.07	152.64
2.	II	51.89	36.16	72.02	31.32	156.49	86.35	225.41
3.	III	65.04	49.55	81.78	24.67	196.27	129.64	259.08
4.	IV	48.86	36.33	60.48	26.42	158.67	104.77	197.71
5.	V	40.58	30.14	57.55	25.11	121.24	69.90	190.96
6.	VI	39.23	30.79	44.24	26.52	131.83	104.77	150.77
7.	VII	46.87	25.25	73.88	45.63	148.01	48.71	242.29
8.	VIII	77.01	58.11	85.76	24.98	212.39	166.63	241.65

Table 22. Cluster means for the physiological components of yield.

Sl. No.	Cluster No.	D.R.C. (%)			Latex flow rate (ml min^{-1})			Plugging index		
		Annual	Stress	Peak	Annual	Stress	Peak	Annual	Stress	Peak
1.	I	33.78	36.30	32.23	3.63	3.14	4.15	4.81	7.21	3.13
2.	II	36.56	38.55	35.90	5.01	4.32	5.68	4.21	6.02	2.80
3.	III	34.94	36.16	35.45	6.11	5.38	6.72	3.66	4.85	2.68
4.	IV	33.43	34.72	33.20	5.21	4.87	5.64	4.34	6.24	3.14
5.	V	37.91	39.31	36.00	5.53	4.15	7.44	5.55	7.01	4.16
6.	VI	30.37	31.92	30.02	3.48	3.20	3.53	3.34	4.41	2.84
7.	VII	34.99	41.21	34.84	5.42	3.72	6.82	6.21	11.16	3.05
8.	VIII	38.21	38.30	39.36	6.15	6.37	5.89	3.15	4.13	2.60

Table 23. Cluster means for morphological and structural attributes.

Sl. No.	Cluster No.	Girth (cm)	Girth increment (cm year^{-1})	Tapping panel length (cm)	Forking height (m)	Bark thickness (mm)	
						Virgin	Renewed
1.	I	67.53	3.15	39.53	3.22	6.83	6.72
2.	II	72.86	3.82	42.55	3.40	7.64	7.14
3.	III	77.42	3.84	45.15	3.64	8.06	7.64
4.	IV	76.17	4.28	44.72	3.31	7.28	7.11
5.	V	78.25	5.58	39.58	3.30	7.08	7.50
6.	VI	79.21	5.40	44.2	3.24	7.00	7.59
7.	VII	75.08	4.75	42.92	3.49	7.67	7.00
8.	VIII	96.33	4.96	56.92	3.80	9.17	7.83

during the peak yield period (39.36%), annual mean latex flow rate (6.15 ml minute^{-1}), latex flow rate under stress (6.37 ml minute^{-1}), annual mean plugging index (3.15) and plugging index under stress (4.13). Cluster V comprising clone RSY 23 had the highest girth increment rate of 5.58 cm year^{-1}. Cluster III comprising six clones showed the least depression in dry rubber yield during the stress period (24.67%) and the highest volume of latex during the peak yield period (259.08 ml tree^{-1} tapping^{-1}). Cluster VI comprising two clones exhibited the lowest plugging index during the peak yield period (2.48). Cluster VII comprising clone Ch 2 had the highest D.R.C. under stress (41.21%) and latex flow rate during the peak yield period (6.82 ml minute^{-1}).

4.1.8.2. <u>Relative contribution of characters towards divergence</u>

The relative contribution of the various characters towards divergence was assessed by ranking them according to D^2 values. The highest D^2 value was ranked first while the lowest was given rank twenty two. Table 24 shows the percentage contribution of the characters towards divergence in terms of the number of times they appeared first in ranking along with the rank totals for each character. The rank totals provide indirect information on the order of priority of the characters for classification. It was evident from the rank totals and the percentage contribution of the characters that the annual mean volume of latex contributed most towards

Table 24. Relative contribution of characters towards divergence.

Sl. No.	Characters	No. of times appeared first in ranking	Rank total	Rank assigned
1.	Dry rubber yield (annual)	2 (0.26)	8278	10
2.	Dry rubber yield (stress)	-	10165	14
3.	Dry rubber yield (peak)	2 (0.26)	8940	13
4.	Yield depression under stress	-	11323	16
5.	Volume of latex (annual)	475 (60.90)	2248	1
6.	Volume of latex (stress)	32 (4.10)	6131	7
7.	Volume of latex (peak)	153 (19.62)	3971	3
8.	Dry rubber content (annual)	-	6330	8
9.	Dry rubber content (stress)	-	8039	9
10.	Dry rubber content (peak)	-	10672	15
11.	Latex flow rate (annual)	-	8296	11
12.	Latex flow rate (stress)	-	8859	12
13.	Latex flow rate (peak)	-	6016	6
14.	Plugging index (annual)	4 (0.51)	4022	4
15.	Plugging index (stress)	-	5572	5
16.	Plugging index (peak)	112 (14.36)	3505	2
17.	Girth	-	11367	17
18.	Girth increment rate	-	14646	20
19.	Length of tapping panel	-	13350	18
20.	Height at forking	-	15572	21
21.	Virgin bark thicknes	-	13839	19
22.	Renewed bark thickness	-	16199	22

Figures in parenthesis denote percentage contribution towards divergence in terms of the number of times the characters appeared first in ranking.

divergence and renewed bark thickness contributed the least. Volume of latex, plugging index, latex flow rate, D.R.C. and dry rubber yield contributed more towards divergence than the morphological and structural attributes. Among the morphological and structural attributes, girth, followed by length of tapping panel and virgin bark thickness contributed more towards divergence.

4.1.9. Factor analysis

Clusters I and II with a relatively larger number of clones (fifteen and eleven respectively) were subjected to factor analysis based on twelve variables viz. annual mean dry rubber yield, depression in dry rubber yield under stress, annual mean volume of latex, annual mean dry rubber content, annual mean latex flow rate, annual mean plugging index, girth, girth increment rate, length of tapping panel, virgin bark thickness, renewed bark thickness and height at forking. Principal factor analysis was applied to each factor separately.

4.1.9.1. Cluster I

Table 25 represents the environment correlation matrix of cluster I. The correlation estimates ranged from 0.01 between renewed bark thickness and yield depression under stress to 0.98 between dry rubber yield and volume of latex.

Principal factor analysis of the environment correlation matrix

Table 25. Environment correlation matrix - Cluster I.

	Dry rubber yield	Yield depression under stress	Volume of latex	Dry rubber content	Latex flow rate	Plugging index	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	Renewed bark thickness
Yield depression under stress	-0.3105										
Volume of latex	0.9830	-0.3385									
Dry rubber content	0.1556	0.0595	0.1393								
Latex flow rate	0.8459	-0.2666	0.8326	0.1911							
Plugging index	-0.6836	0.4097	-0.7125	0.0951	-0.3793						
Girth	0.8437	-0.0431	0.8529	0.2751	0.7790	-0.5397					
Girth increment rate	0.7196	-0.0747	0.6988	0.1898	0.6447	-0.4103	0.6004				
Tapping panel lenth	0.7714	-0.0886	0.7817	0.1569	0.7190	=0.5724	0.8924	0.5562			
Virgin bark thickness	0.0679	0.,1988	0.1098	0.2957	0.0734	-0.0974	0.3483	0.0196	0.3598		
Renewed bark thickness	0.6624	0.0081	0.6156	0.3253	0.5877	-0.4472	0.6084	0.4531	0.5981	0.3657	
Height at forking	-0.0158	-0.0372	0.0360	0.1079	-0.0258	-0.0238	0.1220	-0.3185	-0.0348	0.1136	-0.0238

of order 12 was done with the squared multiple correlation coefficients (SMC) as first estimates of communalities and a three factor solution was extracted. Twenty six iterations were needed for the convergence of communalities with a difference of five units in the third decimal place. Varimax rotation of the factor loadings in the 26th iteration helped to derive a more meaningful interpretation of the factors. The results are summarised in table 26.

The important characters contributing to each factor were isolated in accordance with the procedure of Harman (1967) based on their association with each factor as determined by the common factor coefficients. The variables associated with the three factors are given below:

Factor I	Dry rubber yield
	Volume of latex
	Girth
	Latex flow rate
	Length of tapping panel
	Girth increment rate
	Plugging index
	Renewed bark thickness
Factor II	Virgin bark thickness
	Dry rubber content
	Yield depression under stress
Factor III	Height at forking

Table 26. Factor pattern - Cluster I.

Sl. No.	Variable	Common factor coefficients 1	2	3	Communality
1.	Dry rubber yield	0.996	0.027	0.045	0.995
2.	Yield depression under stress	-0.325	0.408	-0.231	0.326
3.	Volume of latex	0.996	0.030	0.131	1.010
4.	Dry rubber content	0.124	0.416	-0.030	0.189
5.	Latex flow rate	0.828	0.122	-0.022	0.701
6.	Plugging index	-0.682	0.101	-0.168	0.504
7.	Girth	0.836	0.467	0.123	0.931
8.	Girth increment rate	0.716	0.035	-0.333	0.625
9.	Tapping panel length	0.795	0.366	0.009	0.766
10.	Virgin bark thickness	0.086	0.646	0.036	0.426
11.	Renewed bark thickness	0.625	0.399	-0.240	0.607
12.	Height at forking	-0.088	0.188	0.769	0.635
	Proportionate variance accounted by each factor.	0.459	0.111	0.073	

The factor pattern along with communalities of each variable and the proportionate variance accounted by each factor is presented in table 26. The first factor accounted for 46 per cent of the variation, the second factor accounted for 11 per cent and the third factor, 7 per cent. The three factors together explained 64 per cent of the variation in Cluster I.

Factor I had a bipolar composition, consisting of yield and its components viz. volume of latex, latex flow rate, renewed bark thickness and plugging index along with girth and related variables like girth increment and length of tapping panel. Virgin bark thickness, dry rubber content and yield depression under stress were associated with factor II while height at forking formed a separate factor by itself.

4.1.9.2. Cluster II

The environment correlation matrix of cluster II is presented in table 27. The correlation estimates ranged from 0.001 between girth and height at forking to 0.952 between dry rubber yield and volume of latex.

Using principal factor analysis to the environment correlation matrix of order 12, a three factor model was fitted with the squared multiple correlation coefficients as estimates of communality. Convergence of communalities with a difference of five units in the third decimal place was obtained after thirteen iterations. The

Table 27. Environment correlation matrix - Cluster II

	Dry rubber yield	Yield depression under stress	volume of latex	Dry rubber content	Latex flow rate	Plugging index	Girth	Girth increment rate	Tapping panel length	Virgin bark thickness	Renewed bark thickness
Yield depression under stress	-0.5901										
Volume of latex	0.9522	-0.6188									
Dry rubber content	0.6306	-0.5735	0.6043								
Latex flow rate	0.9426	-0.6345	0.9332	0.6328							
Plugging index	-0.5130	0.5637	-0.6033	-0.5072	-0.4140						
Girth	0.2064	-0.4636	0.2563	0.1635	0.2533	-0.2988					
Girth increment rate	0.1234	-0.1723	-0.0067	0.1598	0.1096	0.1924	0.2414				
Tapping panel length	0.8309	-0.5381	0.8041	0.5094	0.8460	-0.4646	0.4029	0.0645			
Virgin bark thickness	0.5724	-0.5983	0.5845	0.3631	0.6169	-0.3166	0.4568	0.0125	0.6535		
Renewed bark thickness	0.5471	-0.3985	0.6145	0.5298	0.5732	-0.2499	0.1038	0.0466	0.4202	0.6633	
Height at forking	0.1995	-0.1195	0.3186	0.1799	0.1413	-0.4190	0.0009	-0.5270	0.1659	0.2622	0.2412

results obtained from varimax rotation of the factor loadings, in the 13th iteration are summarised in table 28. The important characters associated with each of the three factors as isolated in accordance with Harman (1967) are given below:

Factor I	Dry rubber yield
	Latex flow rate
	Volume of latex
	Length of tapping panel
	Dry rubber content
	Renewed bark thickness
	Virgin bark thickness
	Plugging index
Factor II	Height at forking
	Girth increment rate
Factor III	Girth
	Yield depression under stress

The factor pattern along with the communalities of each variable and the proportionate variance accounted by each factor is presented in table 23. Factor I accounted for 42 per cent of the variation, factor II for 11 per cent of the variation and factor III for 13 per cent of the variation. Thus 66 per cent of the variation was explained by the three factors in cluster II.

Table 28. Factor pattern - Cluster II.

Sl. No.	Variable	Common factor coefficients 1	2	3	Communality
1.	Dry rubber yield	0.965	0.013	0.122	0.946
2.	Yield depression under stress	-0.562	-0.008	-0.563	0.633
3.	Volume of latex	0.941	-0.158	0.189	0.946
4.	Dry rubber content	0.647	-0.019	0.204	0.461
5.	Latex flow rate	0.959	0.068	0.160	0.949
6.	Plugging index	-0.456	0.380	-0.366	0.487
7.	Girth	0.112	0.115	0.781	0.635
8.	Girth increment rate	0.080	0.729	0.175	0.568
9.	Tapping panel length	0.767	-0.011	0.339	0.704
10.	Virgin bark thickness	0.567	-0.104	0.468	0.552
11.	Renewed bark thickness	0.608	-0.085	0.137	0.396
12.	Height at forking	0.203	-0.774	0.079	0.647
Proportionate variance accounted by each factor		0.418	0.111	0.131	

The first factor had a bipolar composition consisting of yield and its components such as volume of latex, dry rubber content, latex flow rate and plugging index along with characters like length of tapping panel, virgin bark thickness and renewed bark thickness. The characters associated with factor II were the height at first forking and girth increment rate while girth and yield depression under stress were associated with factor III.

4.2. Prepotency

Twenty clones were evaluated with respect to seed attributes and the vigour and yield of seedling progenies at the juvenile stage . Prepotency was determined through the performance index and the extent of recovery of superior seedlings within each progeny.

4.2.1. Seed attributes

The data pertaining to seed weight, germination percentage and number of days to germination are presented in table 29.

4.2.1.1. Seed weight

The mean weight per seed among the twenty clones ranged from 3.50 g (PB 206) to 6.46 g (RRII 105) with a general mean of 4.93 g. Nine clones viz., RRII 105, PB 86, PB 230, LCB 1320, PB 215, BD 5, Ch 153, PB 5/76 and AVT 73 showed a higher mean seed weight than the general mean.

Table 29. Seed characters of clones under open pollination.

Sl. No.	Clone	Seed weight (g seed^{-1})	Days to germination	Germination (%)
1.	RRII 105	6.46	4	54.28
2.	PB 242	4.65	7	43.93
3.	AVT 73	4.94	7	44.33
4.	PB 252	4.50	9	52.20
5.	PB 235	4.49	4	61.30
6.	LCB 1320	5.83	7	51.53
7.	Ch 32	4.19	11	35.36
8.	PB 217	4.18	9	62.88
9.	PB 28/83	4.91	11	47.00
10.	PB 5/51	4.07	10	46.52
11.	Ch 2	4.09	8	29.63
12.	PB 215	4.59	8	59.63
13.	Ch 26	4.65	16	38.17
14.	PB 230	5.92	11	70.38
15.	PB 5/76	5.09	10	68.35
16.	PB 206	3.50	10	75.16
17.	Gl 1	4.67	11	42.86
18.	PB 86	6.17	8	63.18
19.	Ch 153	5.32	7	58.86
20.	BD 5	5.40	9	44.38
General Mean		4.93	8.8	52.50

4.2.1.2. Days to germination

In general, the seeds of the twenty clones took 8.8 days from sowing for germination with a range of 4 days (RRII 105 and PB 235) to 16 days (Ch 26). Seeds of ten clones viz., RRII 105, PB 235, PB 242, AVT 73, LCB 1320, Ch 153, Ch 2, PB 215, PB 86 and PB 252 germinated within periods lower than the general mean.

4.2.1.3. Germination percentage

The mean percentage of seed germination was 52.5 with a range of 29.63 (Ch 2) to 75.16 (PB 206). Nine clones exhibited higher germination percentages than the general mean. These were PB 206, PB 230, PB 5/76, PB 86, PB 217, PB 235, PB 215, Ch 153 and RRII 105.

4.2.2. Seedling progeny analysis at the age of one year

4.2.2.1. Genetic variability

The mean values for plant height, girth, bark thickness, number of leaf flushes produced, number of flushes retained, number of leaves and rubber yield on test incision are presented in table 30. The variability among progenies for girth, bark thickness, number of leaf flushes and rubber yield on test incision is presented in figures 18 to 23.

Analysis of variance revealed no significant differences between

Table 30. Juvenile traits and rubber yield of progenies at the age of one year.

Sl. No.	Progenies	Plant height (cm)	Girth (cm)	Bark thickness** (mm)	No. of flushes produced**	No. of flushes retained**	No. of leaves**	Rubber yield on test incision** (mg)
1.	RRII 105	249	11.0	2.34	8.5	3.9	41	116
2.	PB 242	242	10.1	2.08	8.5	3.9	48	87
3.	AVT 73	295	11.6	2.30	9.3	4.2	47	128
4.	PB 252	259	11.1	2.00	9.0	4.0	48	82
5.	PB 235	249	10.5	2.24	9.1	3.7	38	62
6.	LCB 1320	272	10.6	2.23	9.7	4.3	47	65
7.	Ch 32	250	10.0	2.11	9.1	4.2	53	88
8.	PB 217	248	9.6	2.08	8.9	4.0	45	78
9.	PB 28/83	239	10.0	2.19	8.4	3.7	45	92
10.	PB 5/51	252	9.7	1.98	8.3	3.8	46	59
11.	Ch 2	268	10.3	2.03	9.1	4.2	42	63
12.	PB 215	289	10.8	2.32	9.1	4.2	54	88
13.	Ch 26	234	9.8	2.16	8.7	3.8	43	77
14.	PB 230	244	9.5	1.73	8.7	3.5	41	76
15.	PB 5/76	232	9.4	1.99	8.7	3.4	37	51
16.	PB 206	236	9.9	2.06	8.8	4.2	46	63
17.	Gl 1	230	9.5	1.98	8.1	3.4	37	59
18.	PB 86	258	9.8	2.15	8.9	3.7	43	95
19.	Ch 153	254	10.2	2.19	9.3	4.2	47	70
20.	BD 5	260	10.5	2.05	8.7	3.7	40	87
General mean		251.2	10.27	2.11	8.80	3.86	43.7	79.3
C.D. (0.05)		-	-	0.264	0.80	0.50	7.8	30.0

** Progeny differences significant at P = 0.01.

Figure 18. Girth and girth increment in progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

FIG.18. GIRTH AND GIRTH INCREMENT IN PROGENIES.

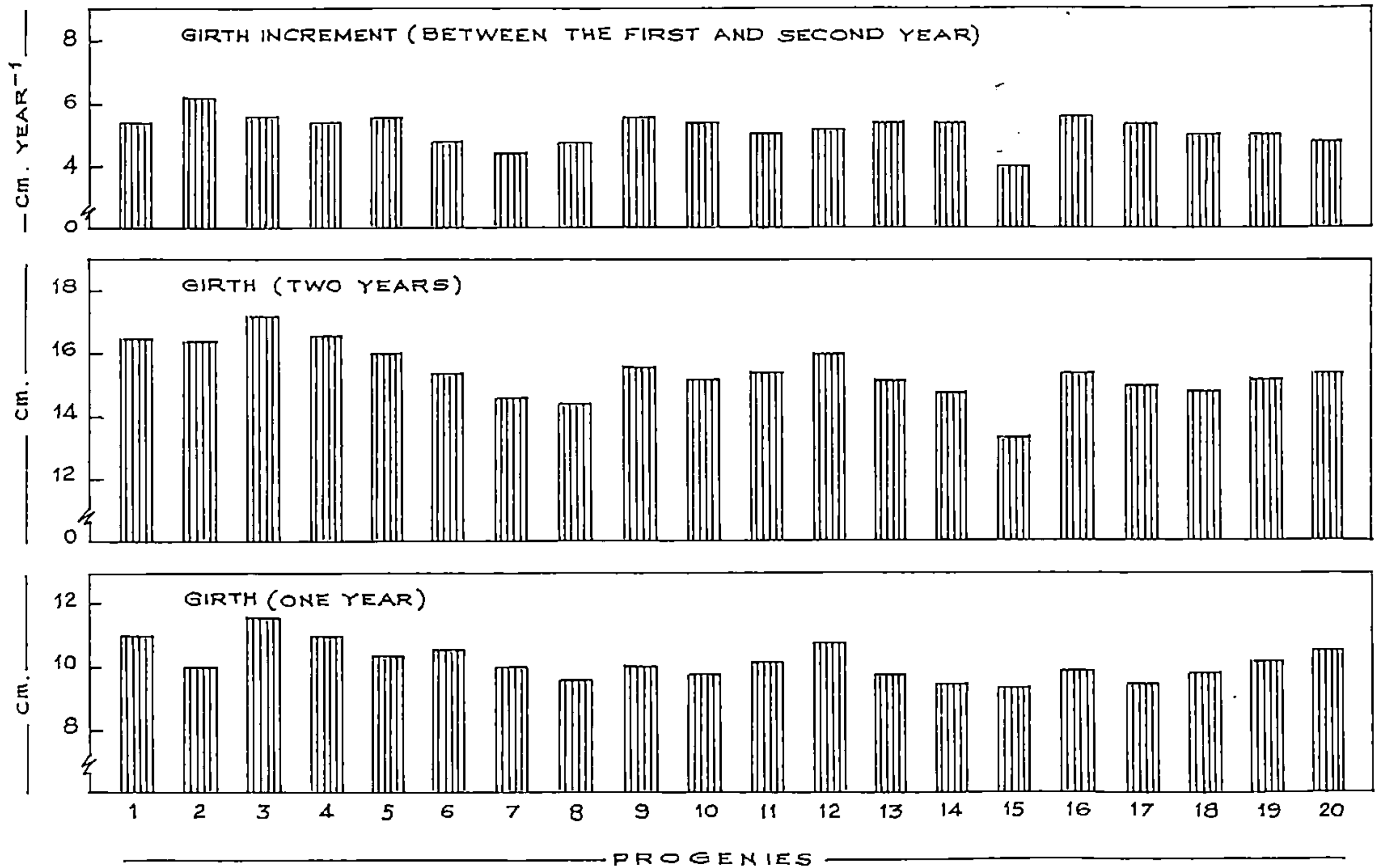


Figure 19. Superior seedling progeny showing less variable girth.

Figure 20. Inferior seedling progeny showing highly variable girth.

Figure 19

Figure 20

Figure 21. Structural traits in progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

FIG.21.STRUCTURAL TRAITS IN PROGENIES.

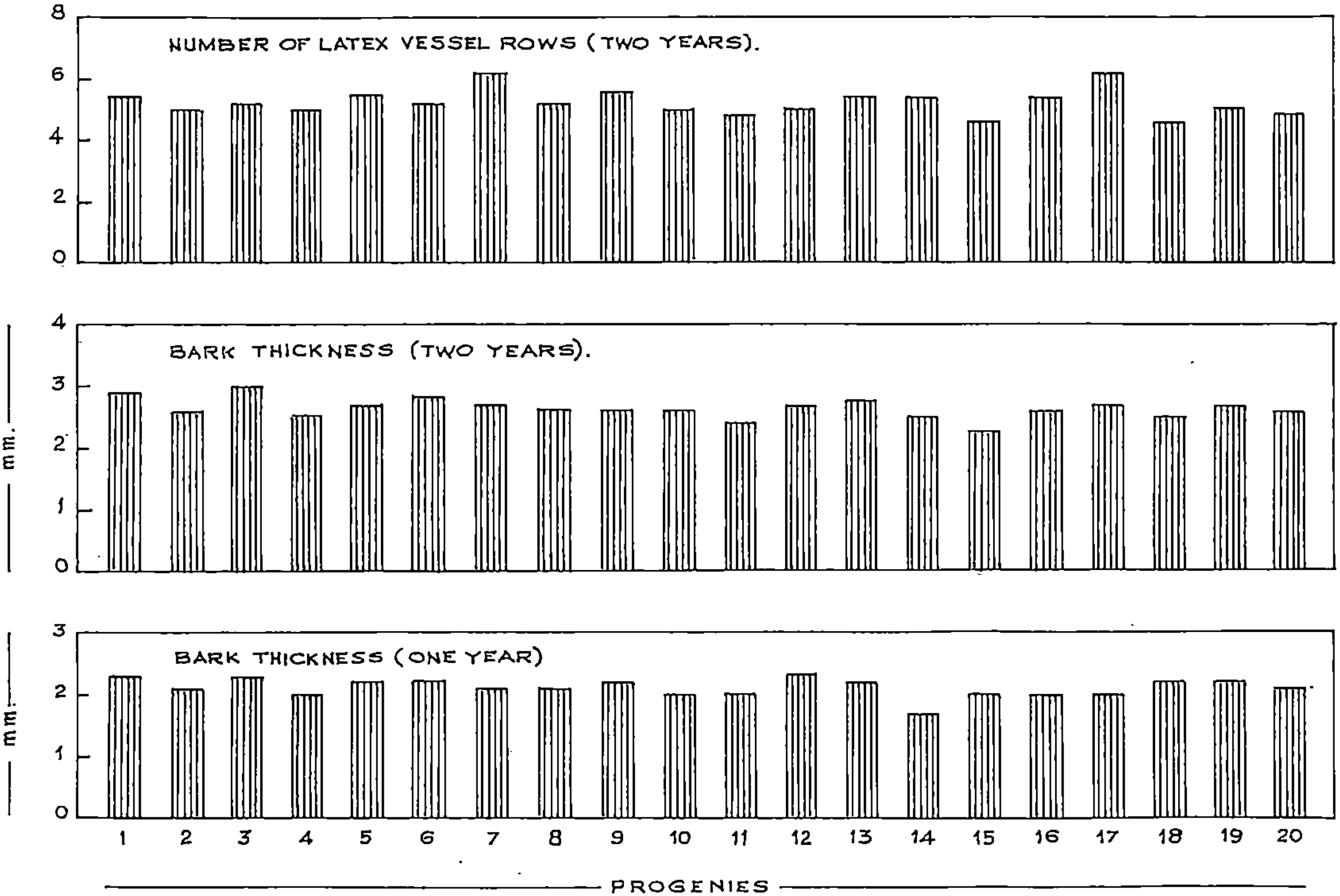


Figure 22. Number of leaf flushes in progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

FIG.22. NUMBER OF LEAF FLUSHES IN PROGENIES.

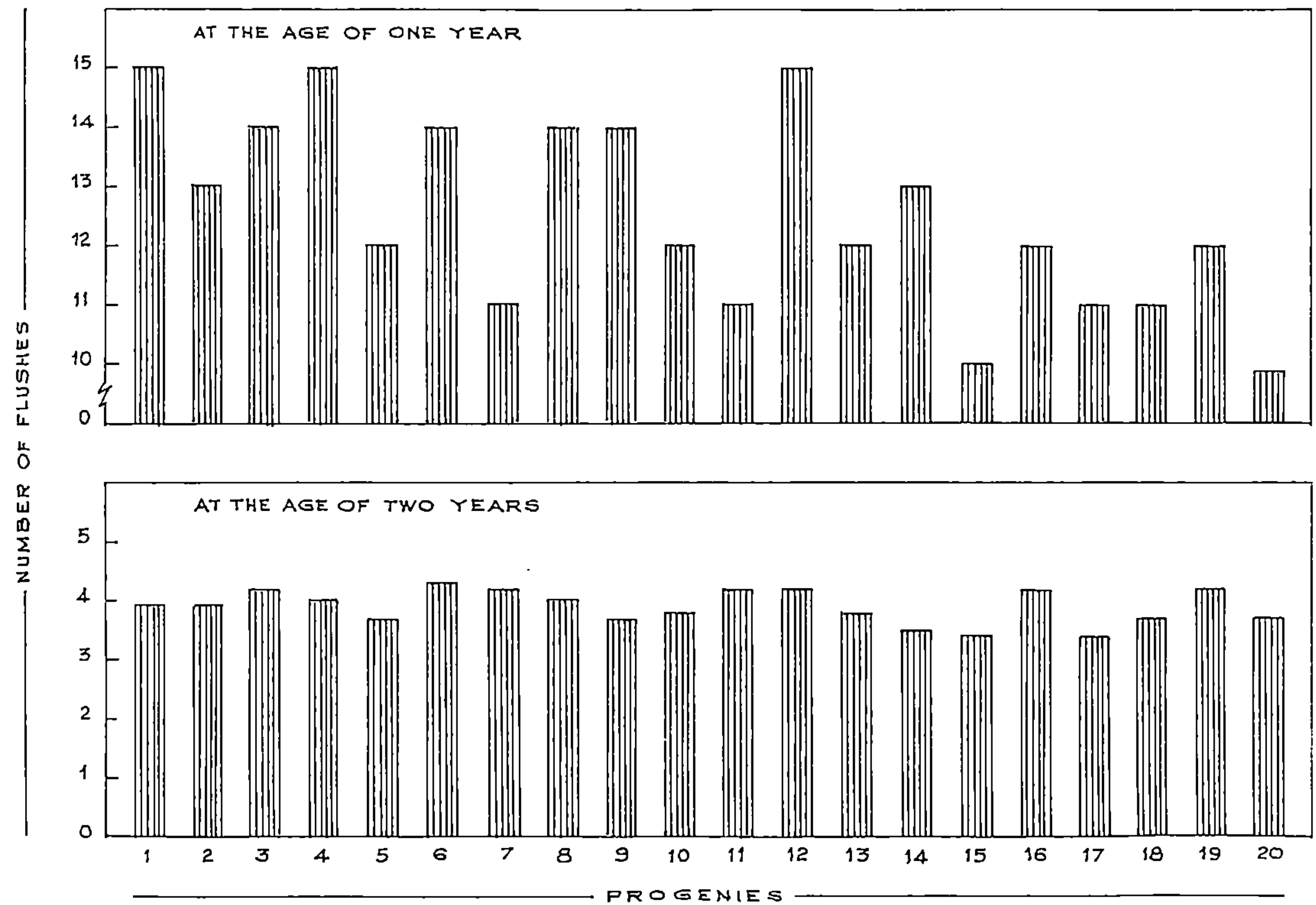
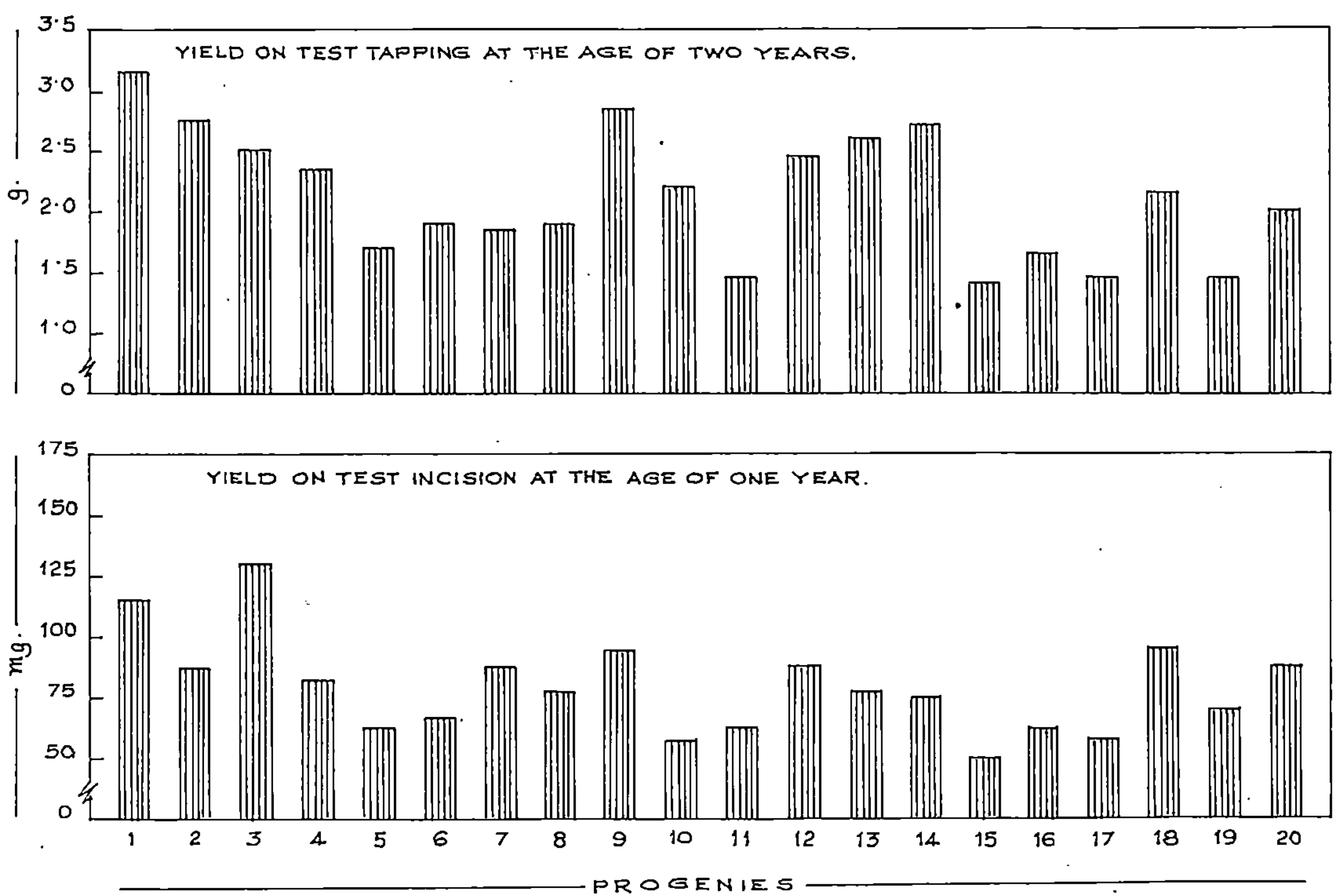


Figure 23. Juvenile rubber yield in progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

FIG.23. JUVENILE RUBBER YIELD IN PROGENIES.



progenies with respect to plant height. The progenies in general exhibited a mean plant height of 251.2 cm. In terms of numerical differences, progeny of AVT 73 and PB 215 showed higher mean values of 295 and 289 cm respectively for plant height.

In respect of girth, there was no significant variation among progenies. Progenies of AVT 73 (11.6 cm), PB 252 (11.1 cm) and RRII 105 (11.0 cm) were numerically superior to the rest. The general mean girth was 10.27 cm.

Differences among progenies were highly significant for bark thickness which was 2.11 mm for the progenies in general. Progeny of RRII 105 showed the highest mean value of 2.34 mm. This was on par with those of PB 215, AVT 73, PB 235, LCB 1320, Ch 153, PB 28/83, Ch 26, PB 86, Ch 32, PB 217 and PB 242. The lowest value of 1.73 mm was recorded by the progeny of PB 230.

The three foliar traits viz. number of leaf flushes produced, number of flushes retained and number of leaves showed highly significant differences between progenies. Ten progenies viz. LCB 1320, Ch 153, AVT 73, Ch 2, PB 215, PB 235, PB 252, Ch 32, PB 217 and PB 86 in order of superiority were on par for the number of leaf flushes produced. With respect to the number of flushes retained at the 12th month, progeny of clone LCB 1320 showed the highest mean value of 4.33 followed by twelve progenies viz. Ch 32, PB 215, Ch 153, AVT 73, PB 206, Ch 2, PB 217, PB 252, RRII 105, PB 242, PB 5/51 and Ch 26 which were on par with LCB 1320.

Progeny of clone PB 215 with a mean value of 54 leaves per plant was superior. This was closely followed by eight progenies viz. Ch 32, PB 242, PB 252, AVT 73, Ch 153, PB 206, LCB 1320 and PB 5/51 which were on par with PB 215. Progeny of Gl 1 was the most inferior in respect of all the three foliar traits.

Highly significant variation among progenies was evident for rubber yield on test incision. Progeny of AVT 73 and RRII 105 showed the highest mean values of 128 mg and 116 mg respectively and were significantly superior to the rest. The lowest values were recorded by progeny of PB 5/76, Gl 1 and PB 5/51. The general mean was 79.3 mg.

4.2.2.2. Correlations

Phenotypic correlations among the seven traits viz. plant height, girth, bark thickness, number of leaf flushes produced, number of flushes retained, number of leaves and rubber yield on test incision are presented in table 31.

Significant positive correlations were observed among all the traits except between the number of leaf flushes produced and yield and also between bark thickness and the number of leaves. A strong positive association between plant height and girth was indicated by the highest positive correlation estimate of $r = 0.810^{**}$.

The trait with the highest positive association with juvenile

Table 31. Correlations among juvenile traits and yield at the age of one year.

	Plant height	Girth	Bark thickness	Flushes produced	Flushes retained	Number of leaves
Girth	0.810**					
Bark thickness	0.334**	0.541**				
Flushes produced	0.453**	0.380**	0.252*			
Flushes retained	0.513**	0.483**	0.323**	0.606**		
No. of leaves	0.637**	0.476**	0.184	0.323**	0.584**	
Juvenile yield	0.556**	0.629**	0.396**	0.091	0.264*	0.466**

* Significant at P = 0.05.

** Significant at P = 0.01.

yield was girth ($r = 0.629^{**}$) followed by plant height ($r = 0.556^{**}$) number of leaves ($r = 0.466^{**}$) and bark thickness ($r = 0.396^{**}$).

4.2.2.3. Performance index

Table 32 presents the clones ranked on the basis of performance indices of their seedling progeny. Nine clones exhibited performance indices greater than the mean value of 272.93. These were AVT 73, RRII 105, PB 86, PB 215, PB 28/83, Ch 32, PB 242, BD 5 and PB 252 in order of superiority.

4.2.3. Seedling progeny analysis at the age of two years

4.2.3.1. Genetic variability

Table 33 presents the mean values with respect to plant height, girth, girth increment between the first and second year of growth, bark thickness, number of latex vessel rows, number of leaf flushes retained at the 24th month and rubber yield on test tapping for the twenty progenies assessed. Figures 18 to 23 depict the performance of the progenies for these traits also.

Progeny differences for plant height were not significant. In terms of phenotypic differences, progeny of PB 215, AVT 73 and PB 217 with mean values of 4.8 m, 4.7 m and 4.5 m respectively were comparatively better than the rest with respect to plant height.

The progenies recorded significant variation for girth with the progeny of AVT 73 having the highest mean girth of 17.2 cm. This

Table 32. Progenies ranked on the basis of Performance Index at the age of one year.

Rank	Progeny/clone	Performance Index
1.	AVT 73	386.95
2.	RRII 105	359.02
3.	PB 86	306.21
4.	PB 215	301.57
5.	PB 28/83	299.83
6.	Ch 32	294.60
7.	PB 242	288.85
8.	BD 5	285.99
9.	PB 252	277.06
10.	PB 217	269.31
11.	Ch 26	267.86
12.	Ch 153	257.49
13.	LCB 1320	250.75
14.	PB 230	250.53
15.	PB 206	238.80
16.	PB 235	238.07
17.	Ch 2	237.07
18.	PB 5/51	223.42
19.	Gl 1	220.18
20.	PB 5/76	205.07
Mean Index Value		272.93

Table 33. Juvenile traits and rubber yield of progenies at the age of two years.

Sl. No.	Progenies	Plant height (m)	Girth* (cm)	Girth increment (cm $year^{-1}$)	Bark thickness (mm)	No.of latex vessel rows*	No. of flushes retained*	Rubber yield on test tapping* (mg)
1.	RRII 105	4.4	16.5	5.5	2.88	5.5	15	3.15
2.	PB 242	4.4	16.4	6.3	2.55	5.1	13	2.75
3.	AVT 73	4.7	17.2	5.6	2.96	5.3	14	2.53
4.	PB 252	4.5	16.5	5.4	2.52	5.0	15	2.36
5.	PB 235	4.3	16.1	5.6	2.74	5.5	12	1.69
6.	LCB 1320	4.2	15.5	4.9	2.75	5.2	14	1.88
7.	Ch 32	4.2	14.7	4.7	2.66	6.2	11	1.86
8.	PB 217	4.5	14.5	4.9	2.63	5.2	14	1.93
9.	PB 28/83	4.3	15.7	5.7	2.63	5.6	14	2.84
10.	PB 5/51	4.4	15.2	5.5	2.56	5.0	12	2.20
11.	Ch 2	4.3	15.4	5.1	2.74	4.8	11	1.47
12.	PB 215	4.8	16.1	5.3	2.84	4.9	15	2.45
13.	Ch 26	4.3	15.2	5.4	2.84	5.4	12	2.59
14.	PB 230	4.4	14.9	5.4	2.52	5.4	13	2.69
15.	PB 5/76	4.0	13.5	4.1	2.27	4.6	10	1.43
16.	PB 206	4.2	15.5	5.6	2.62	5.4	12	1.67
17.	Gl 1	4.1	15.0	5.5	2.67	6.2	11	1.95
18.	PB 86	4.2	14.8	5.0	2.52	4.6	11	2.38
19.	Ch 153	4.3	15.2	5.0	2.71	5.1	12	1.47
20.	BD 5	4.3	15.4	4.9	2.55	4.8	9	2.02
General Mean		4.34	15.47	5.27	2.638	5.24	12.4	2.164
C.D. (0.05)			1.75	-	-	0.88	3.5	0.979

* Progeny differences significant at P = 0.05.

was closely followed by those of RRII 105 (16.5 cm), PB 252 (16.5 cm), PB 242 (16.4 cm), PB 215 (16.1 cm), PB 235 (16.1 cm), PB 28/83 (15.7 cm), LCB 1320 (15.5 cm) and PB 206 (15.5 cm) which were on par with AVT 73. The progeny of PB 5/76 was the most inferior in terms of girth.

There was no significant variation among progenies with respect to girth increment. The progeny of PB 242 and PB 235 displayed a relatively higher girth increment than the rest.

No significant variation among progenies was evident for bark thickness. However in terms of numerical differences, AVT 73, RRII 105 and Ch 26 were apparently superior with mean bark thickness of 2.96 mm, 2.88 mm and 2.84 mm respectively.

Significant progeny differences were evident for the number of latex vessel rows. Nine progenies were superior and on par, with mean values of 6.2 (Gl 1 and Ch 32), 5.6 (PB 28/83), 5.5 (RRII 105 and PB 235), 5.4 (PB 230, Ch 26 and PB 206) and 5.3 (AVT 73). The lowest number of latex vessel rows (4.6) was recorded by progenies of PB 86 and PB 5/76.

There were significant differences among progenies for the number of leaf flushes retained, with 14 progenies being uniformly superior. Progenies of RRII 105, PB 252 and PB 215 with a mean number of 15 flushes per plant were the best followed by those of AVT 73, LCB 1320, PB 217 and PB 28/83 with a mean value of 14 flushes, those of PB 242 and PB 230 with 13 flushes and those of PB 235, PB 5/51, Ch 26, PB 206 and Ch 153 with 12 flushes per plant.

The progenies exhibited significant variation with respect to rubber yield on test tapping. Progeny of RRII 105 with a mean yield of 3.15 g per plant per 10 tappings was the best followed by nine progenies which were on par with it viz., PB 28/83 (2.84 g), PB 242 (2.75 g), PB 230 (2.6 g), Ch 26 (2.59 g), AVT 73 (2.53 g), PB 215 (2.45 g), PB 86 (2.38 g), PB 252 (2.36 g) and PB 5/51 (2.20 g). The progeny of PB 5/76 was the most inferior in terms of juvenile yield.

4.2.3.2. Genetic parameters

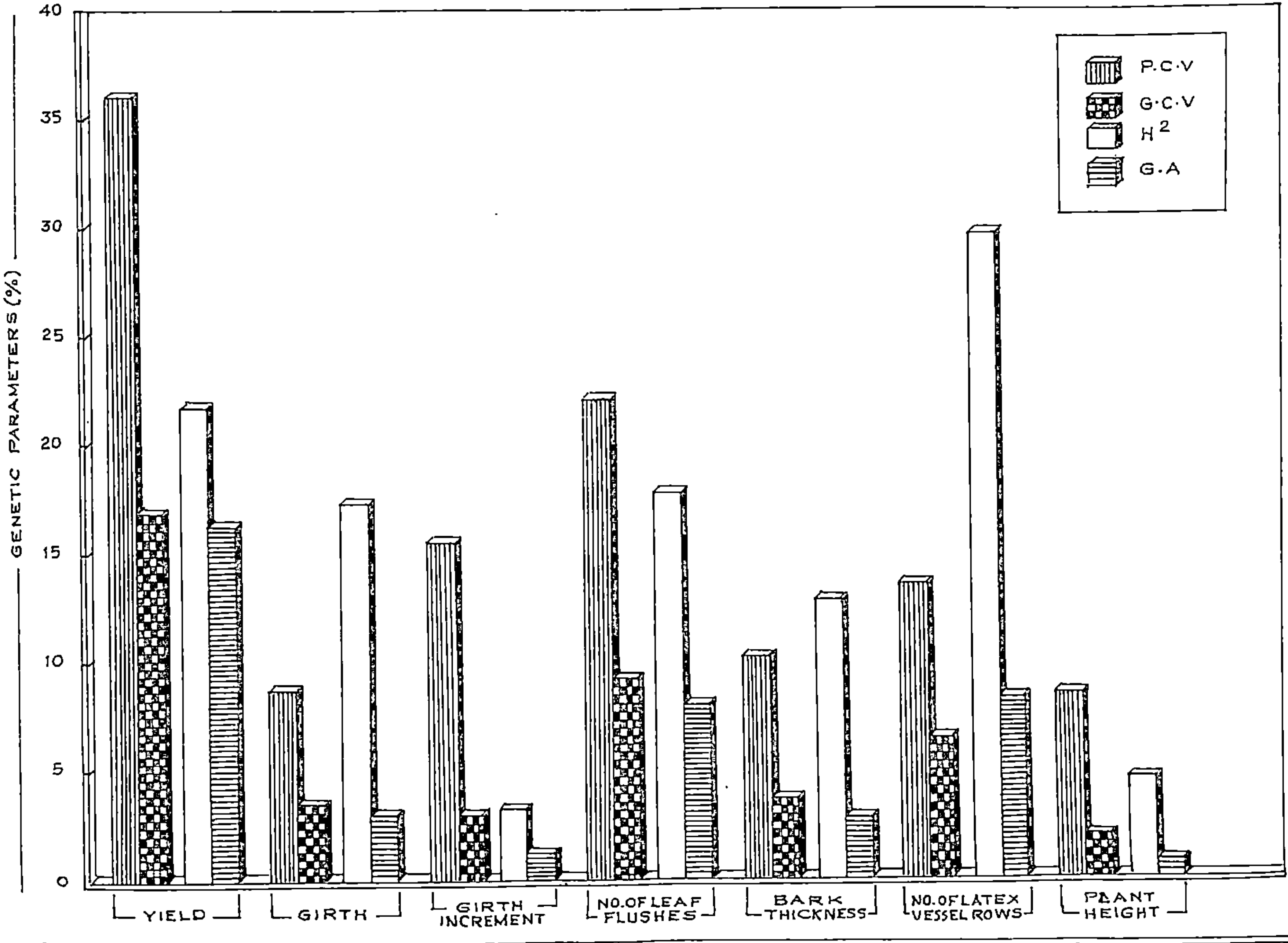
The range, mean, S.E. of mean and the genetic parameters such as genotypic and phenotypic coefficients of variation (G.C.V. and P.C.V.), broad sense heritability (H^2) and genetic advance (G.A.) for the best 5 per cent of the values as percentage of mean are presented in table 34. The histogram representing the genetic parameters (P.C.V., G.C.V., H^2 and G.A.) in the open pollinated progeny is presented in figure 24.

The G.C.V. was highest for rubber yield on test tapping (16.85) followed by the number of leaf flushes (9.25) and the number of latex vessel rows (6.42). Plant height recorded the lowest G.C.V.

Table 34. Estimates of genetic parameters for juvenile traits in progenies at the age of two years.

Sl. No.	Trait	Range	Mean	S.E.	Coefficient of variation		Heritability (%)	Genetic advance (%)
					Genotypic	Phenotypic		
1.	Rubber yield (g)	1.43-3.15	2.16	0.346	16.85	36.12	21.8	16.22
2.	Girth (cm)	13.51-17.22	15.47	0.618	3.66	8.79	17.3	3.13
3.	Girth increment (cm $year^{-1}$)	4.13-5.85	5.23	0.401	2.84	15.60	3.2	1.03
4.	Bark thickness (mm)	2.27-2.96	2.64	0.128	3.79	10.37	12.7	2.72
5.	Number of latex vessel rows	4.55-6.24	5.24	0.309	6.42	13.44	29.5	8.17
6.	Number of flushes retained	8.85-14.64	12.40	1.240	9.25	21.98	17.7	8.01
7.	Plant height (m)	3.98-4.84	4.34	0.183	1.86	8.65	4.6	0.80

FIG.24. GENETIC PARAMETERS FOR JUVENILE TRAITS IN TWO YEAR OLD PROGENIES.



estimate of 1.86. The P.C.V. was also highest for rubber yield on test tapping (36.12) followed by the number of leaf flushes (21.98).

The number of latex vessel rows recorded the highest heritability estimate of 29.5. This was followed by rubber yield on test tapping (21.8), the number of leaf flushes (17.7) and girth (17.30).

The estimate of genetic advance under selection was highest for rubber yield under test tapping (16.22) followed by the number of latex vessel rows (8.17) and the number of leaf flushes (8.01).

4.2.3.3. Coefficient of variation within progenies

The coefficient of variation within progenies with respect to rubber yield under test tapping, girth, number of latex vessel rows and number of leaf flushes are presented in table 35.

The C.V. for rubber yield ranged from 65.65 (PB 28/83) to 135.53 (PB 235). Ten progenies viz. PB 28/83, Ch 26, PB 5/51, AVT 73, PB 252, Ch 153, PB 206, LCB 1320, Ch 2 and BD 5 recorded C.V. values less than the general mean of 84.91.

The general mean C.V. for girth was 22.32 with a range of 19.28 (AVT 73) to 28.34 (PB 230). Twelve progenies viz. AVT 73, RRII 105, PB 235, LCB 1320, PB 217, PB 5/51, Ch 2, Ch 26, PB 5/76, PB 206, Ch 153 and BD 5 exhibited a lower coefficient of variation

Table 35. Coefficient of variation within progenies for yield and yield attributes at the age of two years.

Sl. No.	Clones/ progenies	Rubber yield on test tapping	Girth	No.of latex vessel rows	No.of leaf flushes
1.	RRII 105	88.40	22.30	33.94	47.47
2.	PB 242	92.07	22.92	28.43	56.03
3.	AVT 73	71.09	19.28	29.06	54.82
4.	PB 252	77.57	24.29	27.21	41.71
5.	PB 235	135.53	21.58	20.42	51.07
6.	LCB 1320	81.21	20.30	22.56	54.95
7.	Ch 32	92.70	24.67	29.78	61.06
8.	PB 217	88.81	17.88	25.15	35.14
9.	PB 28/83	65.65	22.54	26.29	44.63
10.	PB 5/51	73.75	21.82	22.70	53.08
11.	Ch 2	74.95	19.20	25.43	46.28
12.	PB 215	89.44	26.01	24.40	46.17
13.	Ch 26	67.57	20.56	23.71	46.03
14.	PB 230	89.18	28.34	35.19	56.48
15.	PB 5/76	91.34	21.84	24.80	47.34
16.	PB 206	76.89	19.59	27.74	43.17
17.	Gl 1	88.56	26.01	23.70	53.91
18.	PB 86	100.75	24.32	33.20	56.65
19.	Ch 153	70.02	21.18	33.10	56.53
20.	BD 5	82.67	21.77	27.08	42.62
General Mean		84.91	22.32	27.19	49.76

than the general mean.

With respect to the number of latex vessel rows a general mean C.V. of 27.19 ranging from 20.42 (PB 235) to 35.19 (PB 230) was observed. Eleven progenies viz. PB 235, LCB 1320, PB 217, PB 28/83, PB 5/51, Ch 2, PB 215, Ch 26, PB 5/76, Gl 1 and BD 5 had lower C.V. than the general mean.

The general mean C.V. for the number of leaf flushes was 49.76 with a range of 35.14 (PB 217) to 56.65 (PB 86). Ten progenies viz. PB 217, BD 5, PB 206, PB 28/83, Ch 26, PB 215, Ch 2, PB 252, RRII 105 and PB 5/76 showed lower coefficient of variation than the general mean.

Figures 25 to 28 depict the mean values plotted against the C.V. for the four traits in the 20 progenies.

Progenies of AVT 73, PB 252, PB 28/83, PB 5/51 and Ch 26 have shown a high and low C.V. value for juvenile yield.

With respect to girth, progenies of RRII 105, AVT 73, PB 235, LCB 1320 and PB 206 were found to be in the high mean and low C.V. group.

Progenies of six clones viz., PB 235, LCB 1320, PB 217, PB 28/83, Ch 26 and Gl 1 occurred in the high mean and low C.V. group with respect to the number of latex vessel rows.

Figure 25. Mean vs C.V. for rubber yield in two year old progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

Group I - High mean and low C.V.; Group II - Low mean and low C.V.;
Group III - High mean and high C.V.; Group IV - Low mean and high C.V.

FIG.25. MEAN Vs. C·V FOR RUBBER YIELD IN TWO YEAR OLD PROGENIES.

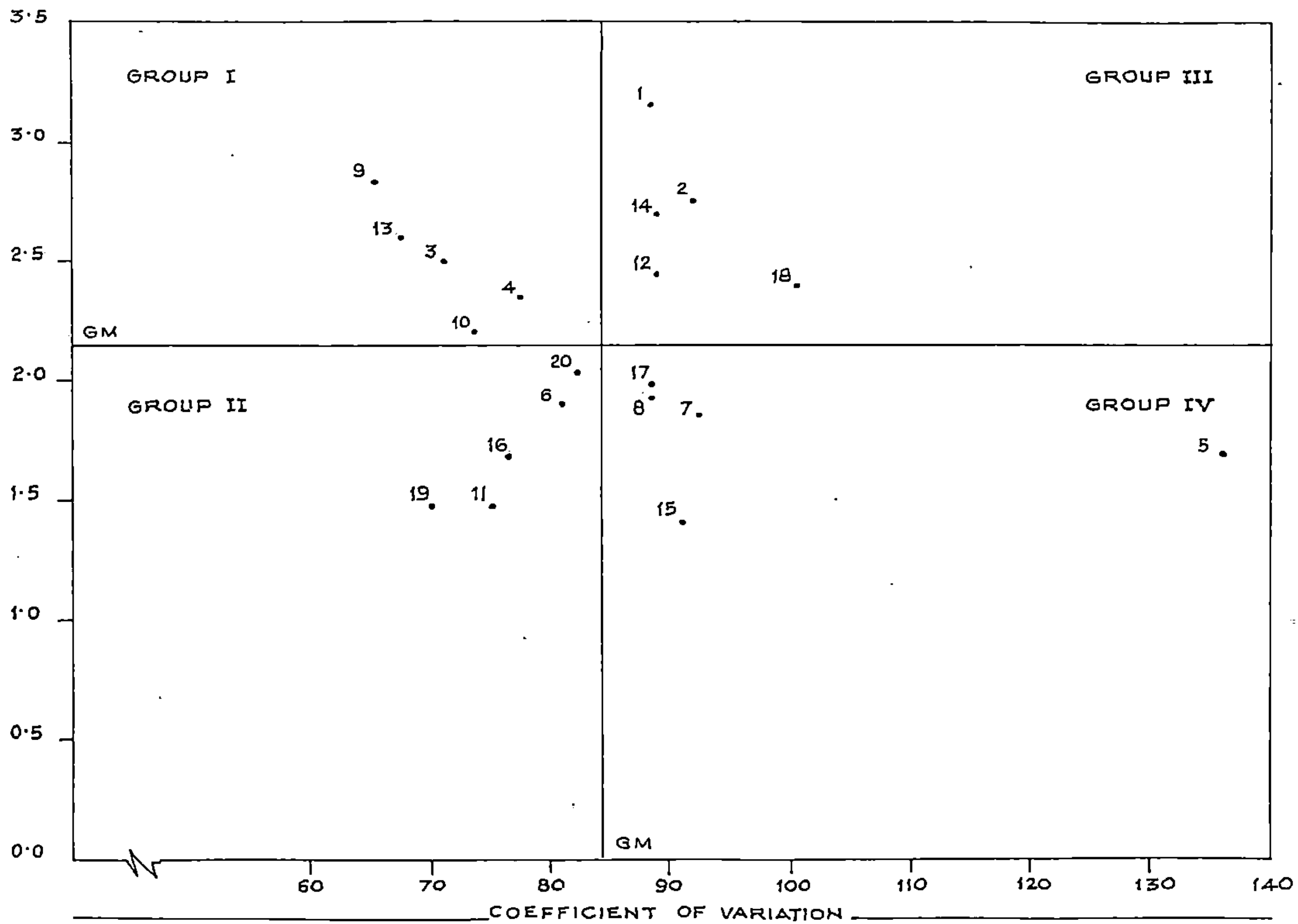


Figure 26. Mean vs C.V. for girth in two year old progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

Group I - High mean and low C.V.; Group II - Low mean and low C.V.;
Group III - High mean and high C.V.; Group IV - Low mean and high C.V.

FIG.26. MEAN Vs. CV. FOR GIRTH IN TWO YEAR OLD PROGENIES.

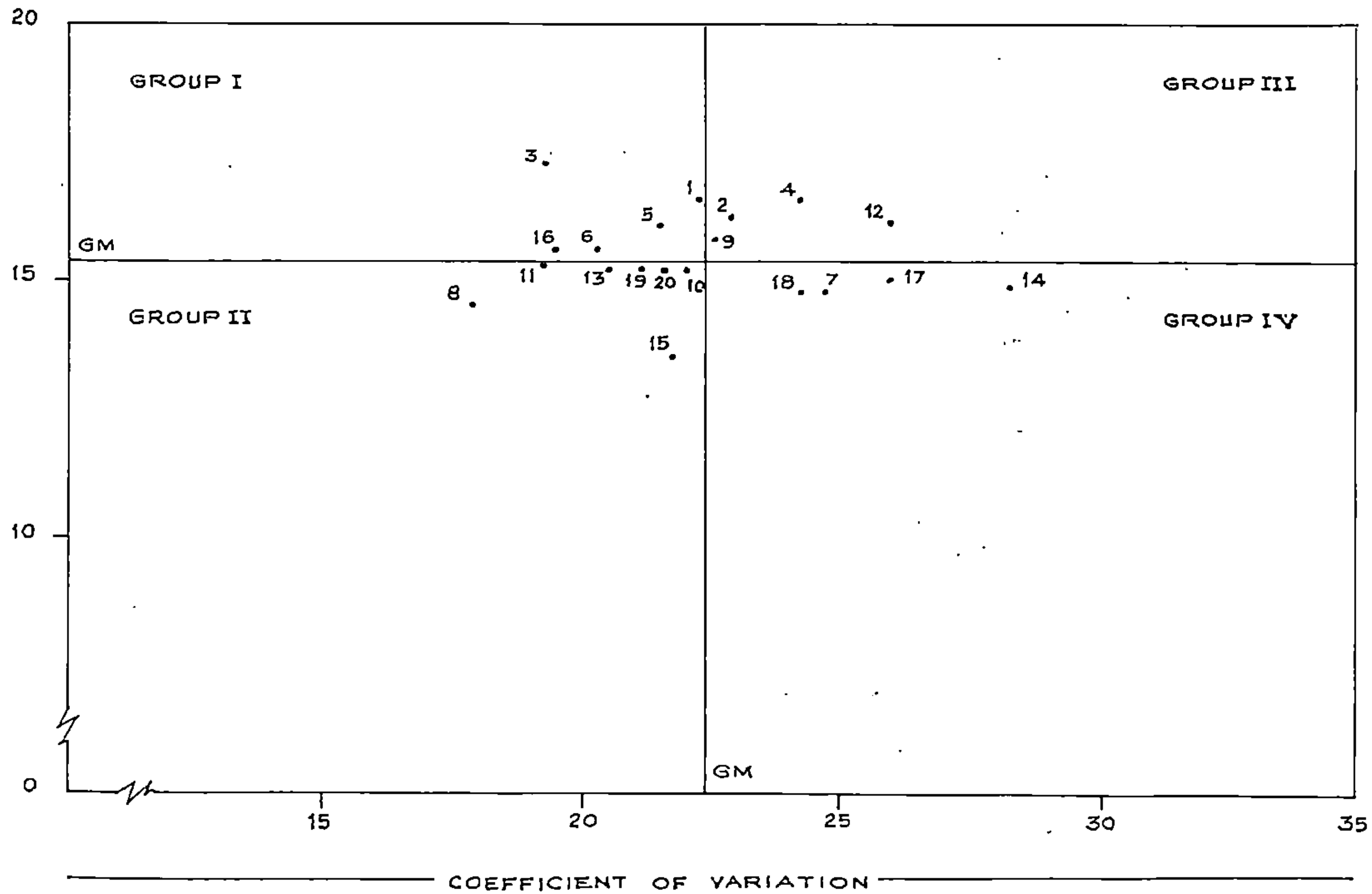


Figure 27. Mean vs C.V. for the number of latex vessel rows in two year old progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

Group I - High mean and low C.V.; Group II - Low mean and low C.V.;

Group III - High mean and high C.V.; Group IV - Low mean and high C.V.

FIG.27. MEAN Vs. C.V. FOR THE NUMBER OF LATEX VESSEL ROWS IN TWO YEAR OLD PROGENIES.

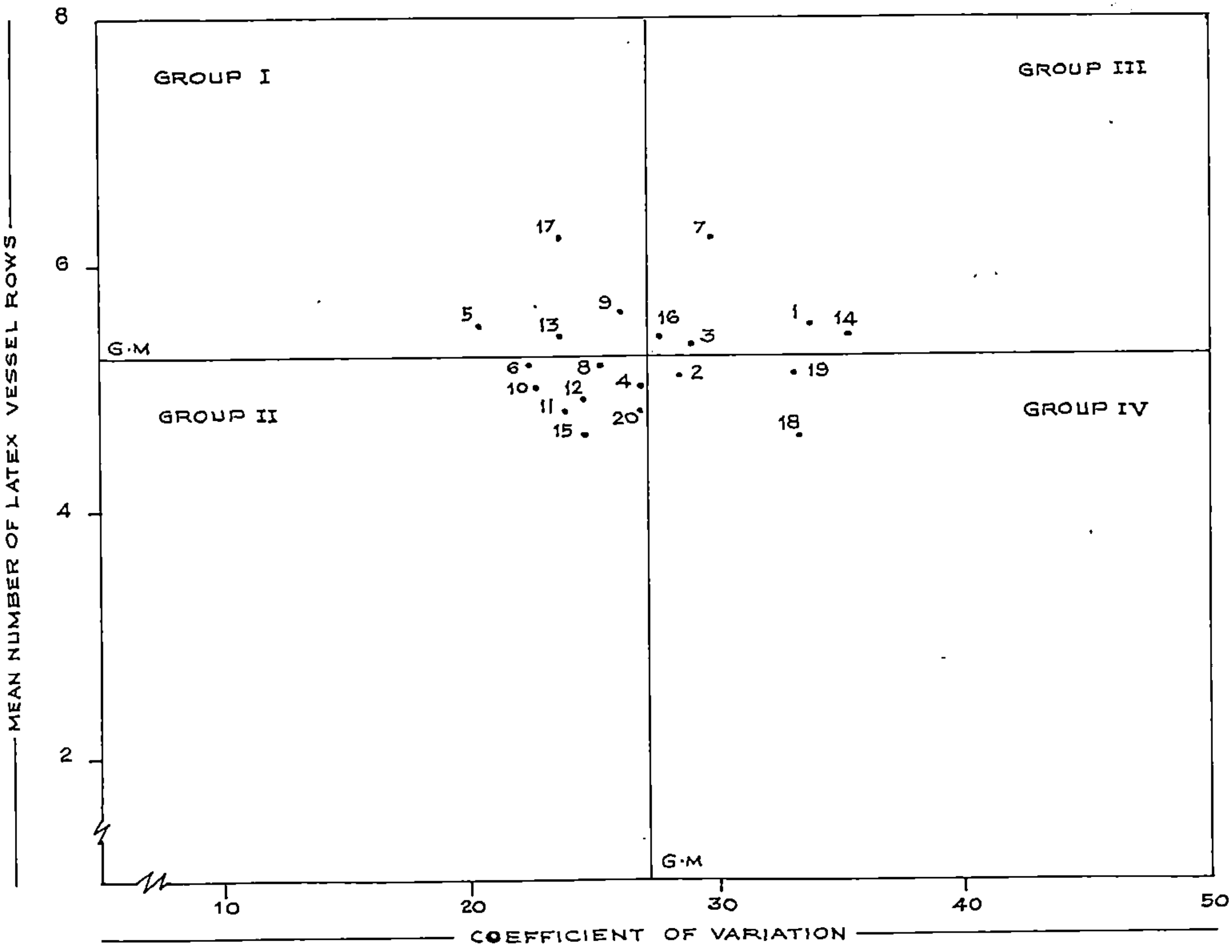
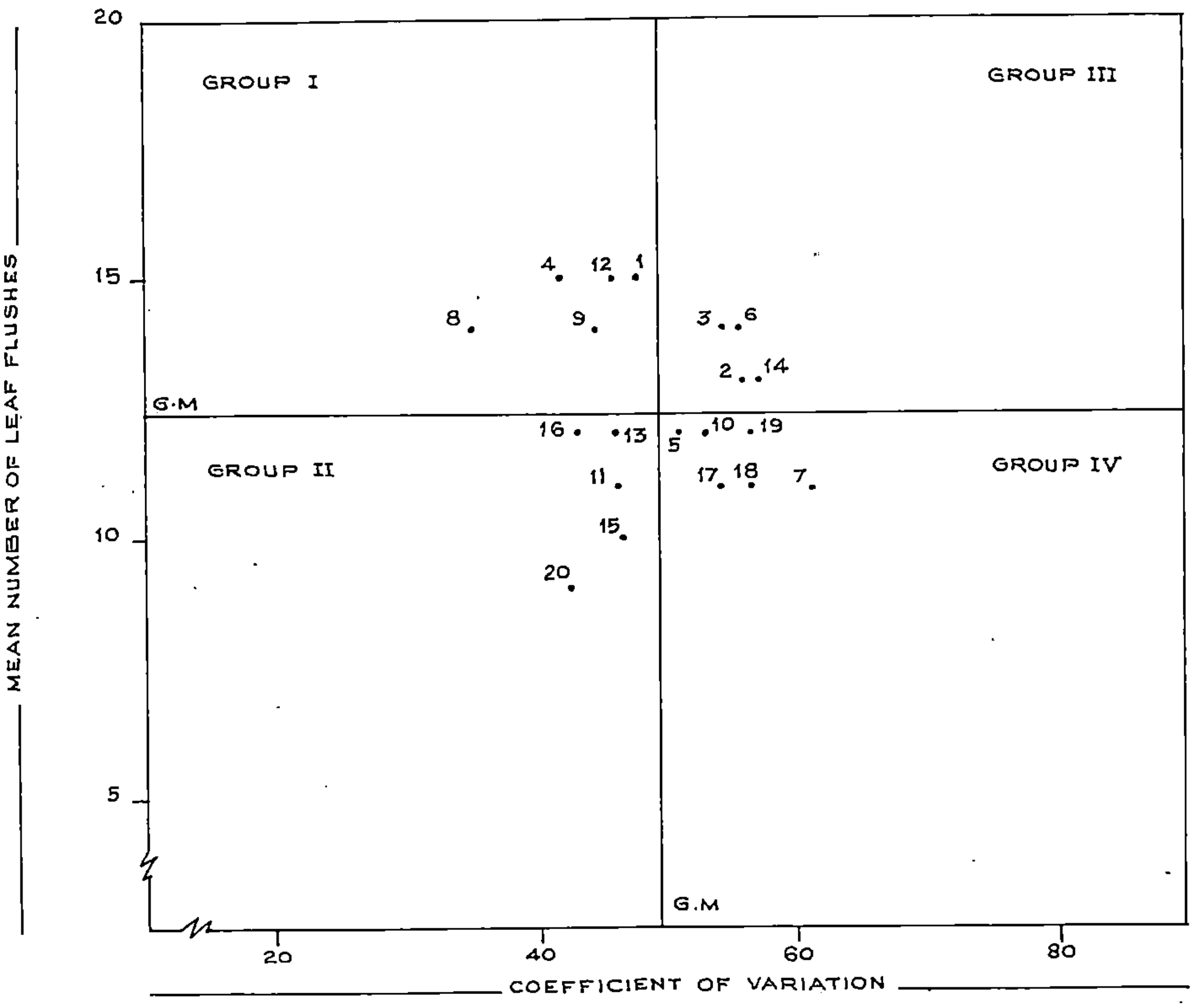


Figure 28. Mean vs C.V. for the number of leaf flushes in two year old progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

Group I - High mean and low C.V.; Group II - Low mean and low C.V.;
Group III - High mean and high C.V.; Group IV - Low mean and high C.V.

FIG.28. MEAN Vs. C·V. FOR THE NUMBER OF LEAF FLUSHES IN TWO YEAR OLD PROGENIES.



Seven progenies viz. RRII 105, PB 252, PB 217, PB 28/83, PB 215, Ch 26 and PB 206 were in the high mean and low C.V. group for the number of leaf flushes retained.

4.2.3.4. Correlations

Phenotypic correlations among the seven traits at the age of two years are presented in table 36 and figure 29.

Significant positive correlations were observed for all combinations of the traits except for plant height with the number of latex vessel rows and for the number of flushes retained with girth increment and number of latex vessel rows.

The relationship of juvenile yield with all the traits was highly significant except in the case of the number of flushes retained for which the correlation was significant only at 5 per cent level. Girth showed the strongest association with yield (r = 0.667**) followed by plant height (r = 0.544*) and girth increment (r = 0.484**).

All the six traits showed highly significant association with girth. Bark thickness (r = 0.620**), plant height (r = 0.620**) and girth increment (r = 0.604**) recorded high correlations with this trait.

The relationship of bark thickness with girth increment (r = 0.580**) and number of latex vessel rows (r = 0.0556**) was also strong.

Table 36. Correlations among juvenile traits and yield at the age of two years.

	Plant height	Girth	Girth increment	Bark thickness	No. of latex vessel rows	No. of flushes retained
Girth	0.620**					
Girth increment	0.283*	0.604**				
Bark thickness	0.368**	0.620**	0.580**			
Number of latex vessel rows	0.184	0.383**	0.460**	0.556**		
Number of flushes retained	0.340**	0.391**	0.050	0.308**	0.139	
Rubber yield on test tapping	0.544**	0.667**	0.484**	0.371**	0.312**	0.272*

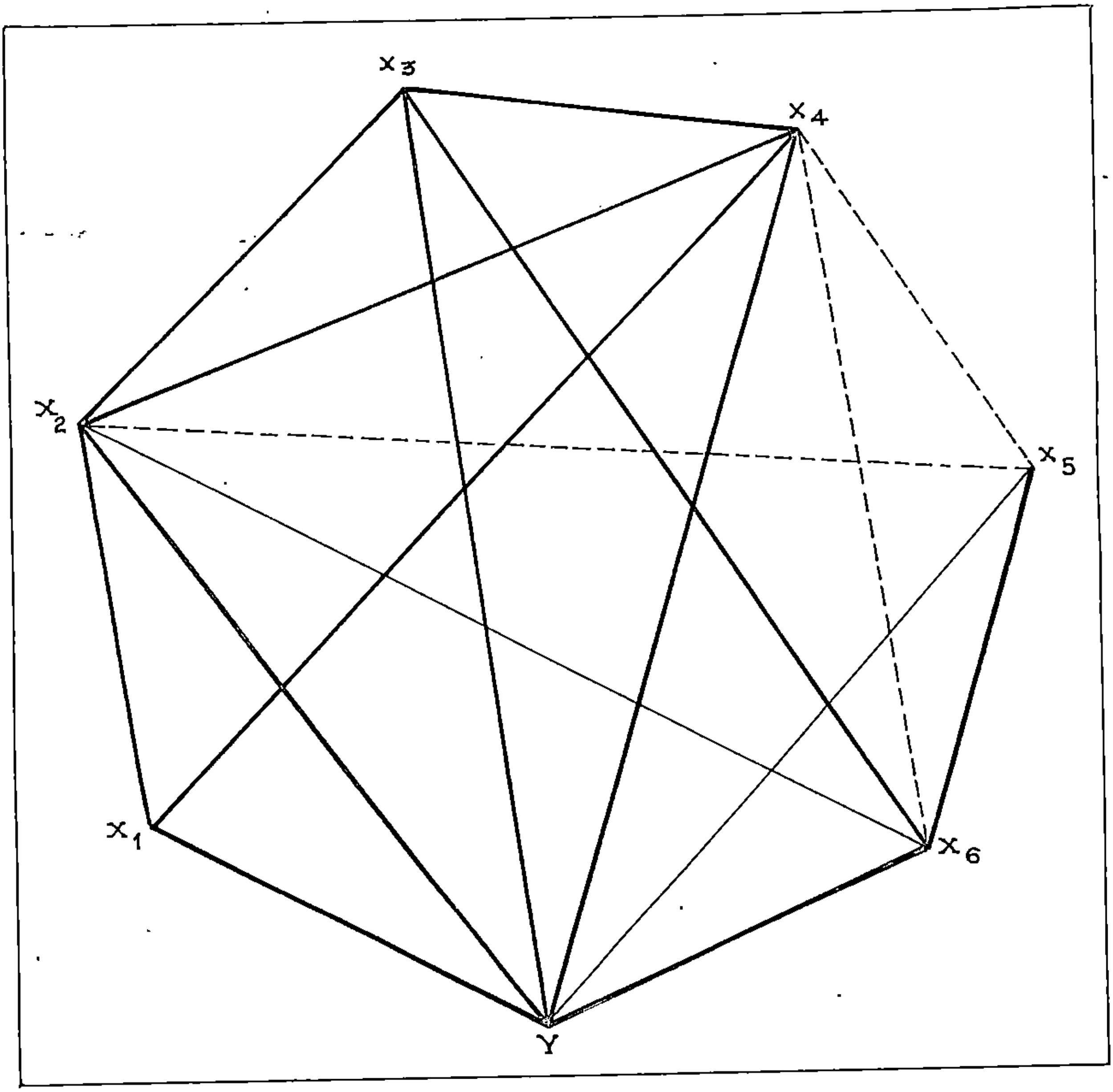
* Significant at P = 0.05.

** Significant at P = 0.01.

Figure 29. Associations among juvenile traits in two year old progenies.

Y	Dry rubber yield on test tapping
X_1	Girth
X_2	Girth increment
X_3	Bark thickness
X_4	Number of latex vessel rows
X_5	Number of leaf flushes
X_6	Plant height

FIG.29 ASSOCIATIONS AMONG JUVENILE TRAITS IN TWO YEAR OLD PROGENIES.



POSITIVE SIGNIFICANT AT P=0·01

POSITIVE SIGNIFICANT AT P=0·05

POSITIVE NON-SIGNIFICANT

4.2.3.5. Performance index

The performance indices of the twenty progenies computed giving emphasis to rubber yield on test tapping, girth, number of latex vessel rows and number of leaf flushes retained are presented in table 37 and figure 30.

The performance indices ranged from 23.04 (PB 5/76) to 35.13 (PB 28/83) with a general mean of 30.09. The progenies of PB 28/83, RRII 105 (34.11) and PB 242 (33.22) recorded high performance indices while those of PB 5/76 and Ch 153 (23.07) had low indices. Thirteen progenies viz. PB 28/83, RRII 105, PB 242, AVT 73, PB 215, Ch 32, Gl 1, Ch 26, PB 252, PB 230, PB 206, PB 217 and PB 5/51 recorded performance indices higher than the general mean index value.

4.2.3.6. Recovery of superior seedlings

The recovery of superior seedlings in each progeny was determined in terms of the performance of each seedling with respect to rubber yield under test tapping, girth, number of latex vessel rows and number of leaf flushes. Table 38 presents the class intervals used in the formulation of index scores for each trait.

The percentage recovery of superior seedlings is also presented in table 37 and figure 30. The progenies, in general, recorded 44.5 per cent recovery of superior seedlings, the individual progeny

Table 37. Performance index and recovery of superior seedlings in progenies at the age of two years.

Sl. No.	Clones/ progenies	Performance Index		Recovery of superior seedlings	
		Value	Rank	%	Rank
1.	RRII 105	34.11	2	62.5	1
2.	PB 242	33.22	3	57.5	2
3.	AVT 73	32.78	4	57.5	2
4.	PB 252	31.20	9	47.5	4
5.	PB 235	29.65	15	47.5	4
6.	LCB 1320	29.48	16	42.5	6
7.	Ch 32	32.23	6	42.5	6
8.	PB 217	30.18	12	45.0	5
9.	PB 28/83	35.13	1	62.5	1
10.	PB 5/51	30.15	13	47.5	4
11.	Ch 2	24.64	18	35.0	8
12.	PB 215	32.75	5	50.0	3
13.	Ch 26	31.26	8	45.0	5
14.	PB 230	30.98	10	37.5	7
15.	PB 5/76	23.04	20	30.0	9
16.	PB 206	30.61	11	37.5	7
17.	Gl 1	31.47	7	37.5	7
18.	PB 86	26.32	17	37.5	7
19.	Ch 153	23.07	19	20.0	10
20.	BD 5	29.69	14	47.5	4
General Mean		30.09		44.5	

Figure 30. Performance index and recovery of superior seedlings in two year old progenies.

Number	Clone/Progeny	Number	Clone/Progeny
1.	RRII 105	11.	Ch 2
2.	PB 242	12.	PB 215
3.	AVT 73	13.	Ch 26
4.	PB 252	14.	PB 230
5.	PB 235	15.	PB 5/76
6.	LCB 1320	16.	PB 206
7.	Ch 32	17.	Gl 1
8.	PB 217	18.	PB 86
9.	PB 28/83	19.	Ch 153
10.	PB 5/51	20.	BD 5

FIG.30. PERFORMANCE INDEX AND RECOVERY OF SUPERIOR SEEDLINGS IN TWO YEAR OLD PROGENIES.

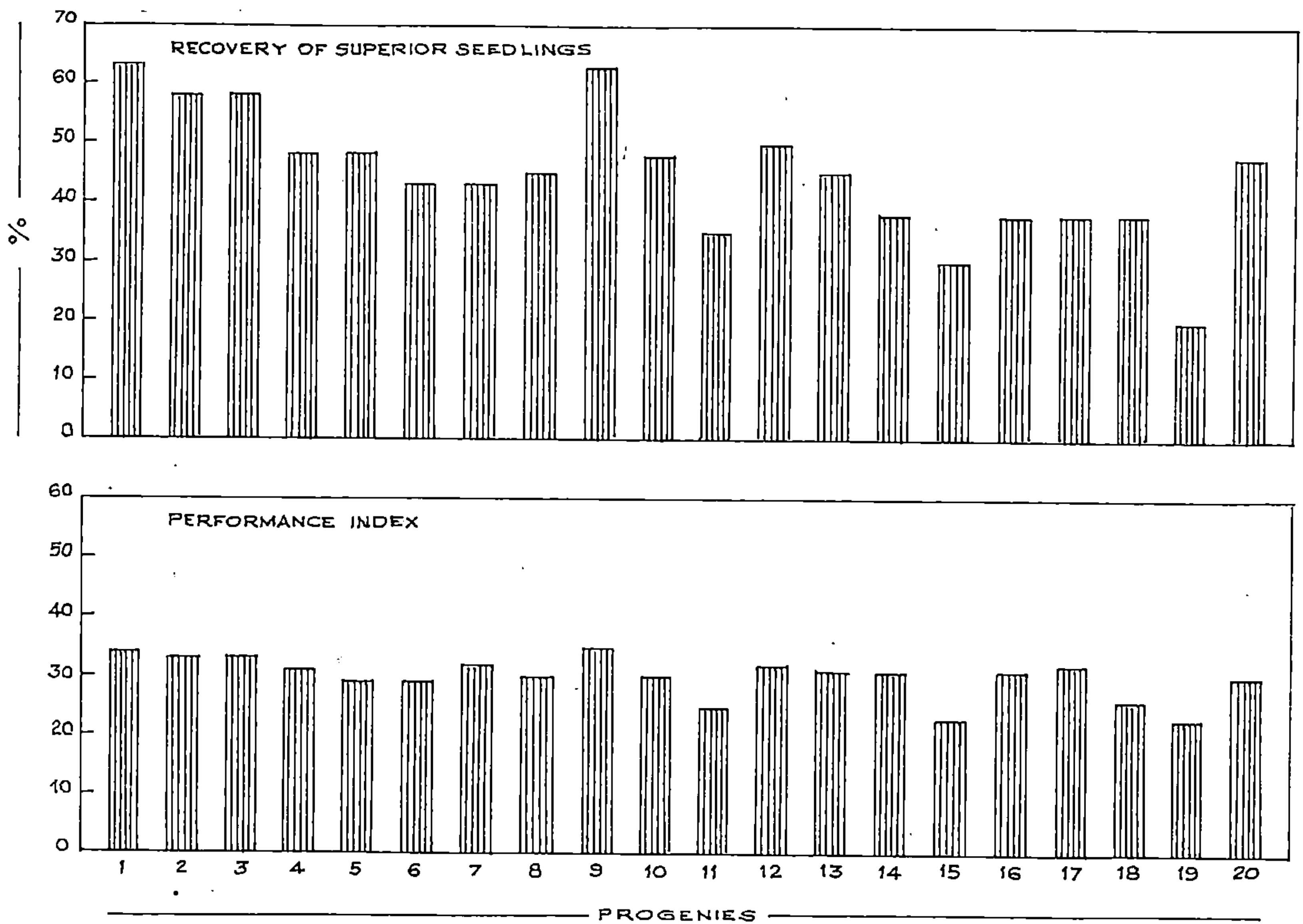


Table 38. Index score table for two year old progenies.

Sl. No.	Character	Score 1	Score 2	Score 3
1.	Rubber yield on test tapping (g plant^{-1} 10 tappings^{-1})	$<$ 1.47	1.47-2.86	$>$ 2.86
2.	Girth (cm)	$<$ 14.23	14.23-16.71	$>$16.71
3.	No. of latex vessel rows	$<$ 4.62	4.62-5.86	$>$ 5.86
4.	No. of leaf flushes	$<$ 9.94	9.94-14.90	$>$14.90

values ranging from 30 per cent for PB 5/76 to 62.5 per cent for RRII 105 and PB 28/83. However, no significant differences among progenies was evident on this aspect. Eleven progenies showed a higher recovery of superior seedlings than the general mean viz., PB 28/83 and RRII 105 with 62.5 per cent, PB 242 and AVT 73 with 57.5 per cent, PB 215 with 50 per cent, PB 252, PB 235, PB 5/51 and BD 5 with 47.5 per cent and PB 217 and Ch 26 with 45 per cent.

4.2.4. Correlations among performance indices, recovery of superior seedlings, juvenile traits and seed attributes

In order to explore the possibility of identifying likely pre-potents from seed attributes or early seedling attributes, the inter relationships among seed attributes, growth attributes and yield in the first and second year of growth and the criteria for pre-potency were studied. Estimates of phenotypic correlations among thirteen attributes viz. performance indices at the age of one year and two years, percentage recovery of superior seedlings in the second year, juvenile yield at the age of one year and two years, girth at the age of one year and two years, bark thickness at the age of one year, the number of latex vessel rows at the age of two years, girth increment between the first and second year of growth, seed weight, seed germination percentage and the number of days for seed germination are presented in table 39.

Performance index in the first year of growth showed a highly

Table 39. Correlations among performance indices, recovery of superior seedlings, juvenile traits and seed attributes.

	Performance Index (1 year)	Performance Index (2 years)	Recovery of superior seedlings (2 years)	Rubber yield (1 year)	Rubber yield (2 years)	Girth (1 year)	Girth (2 years)	Girth incre-ment (1-2 years)	Bark thick-ness (1 year)	Latex vessel rows (2 years)	Seed weight	Seed germin-ation %
Performance index (2 years)	0.635**											
Recovery of superior seedlings (2 years)	0.646**	0.849**										
Rubber yield (1 year)	0.781**	0.706**	0.803**									
Rubber yield (2 years)	0.658**	0.821**	0.766**	0.712**								
Girth (1 year)	0.697**	0.367	0.536**	0.485*	0.330							
Girth (2 years)	0.652**	0.581**	0.672**	0.502*	0.519*	0.890**						
Girth increment (1 year - 2 years)	0.190	0.592**	0.542**	0.192	0.447*	0.307	0.675**					
Bark thickness (1 year)	0.604**	0.314	0.417	0.302	0.185	0.612**	0.522*	0.095				
Latex vessel rows (2 years)	0.061	0.521*	0.202	0.098	0.159	0.114	0.102	0.432	0.031			
Seed weight	0.042	0.091	0.092	0.235	0.441	0.208	0.084	-0.325	0.244	-0.205		
Seed germination %	-0.186	-0.216	-0.276	-0.206	-0.100	-0.244	-0.236	-0.146	-0.128	-0.247	0.220	
No. of days for germination	-0.308	0.038	-0.194	-0.097	0.029	-0.591**	-0.484*	-0.067	-0.466*	0.204	-0.312	-0.194

* Significant at P = 0.05. ** Significant at P = 0.01

significant positive correlation with index in the second year (r = 0.635), the percentage recovery of superior seedlings (r = 0.646), yield on test tapping in the second year (r = 0.658) and girth in the second year (r = 0.652). Though a negative association with the number of days to 50 per cent seed germination and positive associations with the number of latex vessel rows in the second year, girth increment and seed weight were indicated, the correlations were not significant.

Rubber yield on test incision in the first year showed a significant positive correlation with yield on test tapping in the second year (r = 0.713), performance index (r = 0.705), percentage recovery of superior seedlings in the second year (r = 0.803) and girth in the second year (r = 0.502).

Girth in the first year showed a significant positive correlation with the percentage recovery of superior seedlings in the second year (r = 0.536). Positive, but non-significant associations of this trait with performance index, bark thickness and yield in the second year and seed weight were indicated. A highly significant negative association of this trait with the number of days to 50 per cent germination (r = -0.591) was evident.

Bark thickness in the first year had a significant positive correlation with girth in the second year (r = 0.522) and a significant negative correlation with the number of days to 50 per cent seed germination (r = -0.466).

Girth increment and the number of latex vessel rows in the second year showed positive but non-significant associations with growth attributes, performance index and yield in the first year.

None of the seedling attributes were significantly associated with seed weight and germination percentage. The number of days to 50 per cent seed germination was negatively associated with the two other seed attributes and all the seedling traits in the first year of growth but the correlations were significant only with respect to girth and bark thickness in the first year. A significant negative association of this trait with girth in the second year was also obtained. However, a non-significant but positive association with performance index, yield and number of latex vessel rows in the second year was observed.

4.3. Inbreeding depression

Eighteen clones included in the study were subjected to selfing.

4.3.1. Fruit set

A comparison of fruit set under selfing and open pollination is presented in table 40 and figure 31. Fruit set under selfing (1.01 per cent) was lower than that under open pollination (2.24 per cent) for the clones in general. Clones PB 215, PB 217, PB 5/76 and PB 235 did not set fruit under selfing while clones Gl 1, PB 206 and Ch 26 showed a very low fruit set percentage under selfing

Table 40. Fruit set under selfing and open pollination.

Sl. No.	Clone	Selfing: Number of flowers pollinated	Selfing: Fruitset No.	Selfing: Fruitset %	Open pollination: Number of flowers pollinated	Open pollination: Fruitset No.	Open pollination: Fruitset %	Chi Square (selfing vs. open pollination)
1.	RRII 105	517	5	0.97	578	6	1.04	0.01
2.	AVT 73	546	3	0.52	525	18	3.43	11.54**
3.	PB 242	510	24	4.71	500	25	5.00	0.05
4.	PB 252	519	30	5.78	542	36	6.64	0.34
5.	PB 86	623	6	0.96	483	14	2.90	5.74*
6.	PB 215	508	0	0.00	514	10	1.95	9.98**
7.	BD 5	504	2	0.40	500	3	0.60	0.21
8.	Gl 1	511	1	0.20	355	2	0.56	0.82
9.	LCB 1320	258	2	0.78	211	2	0.95	0.04
10.	PB 217	566	0	0.00	517	1	0.19	1.10
11.	PB 5/51	663	5	0.75	533	21	3.94	14.10**
12.	PB 28/83	559	6	1.07	247	19	7.69	24.97**
13.	PB 206	388	1	0.26	504	2	0.40	0.13
14.	PB 230	445	4	0.90	562	8	1.42	0.58
15.	Ch 26	515	1	0.19	523	4	0.76	1.76
16.	Ch 32	496	3	0.60	589	4	0.68	0.02
17.	PB 5/76	490	0	0.00	569	10	1.76	8.69**
18.	PB 235	390	0	0.00	513	2	0.39	1.52
General Mean				1.01			2.24	

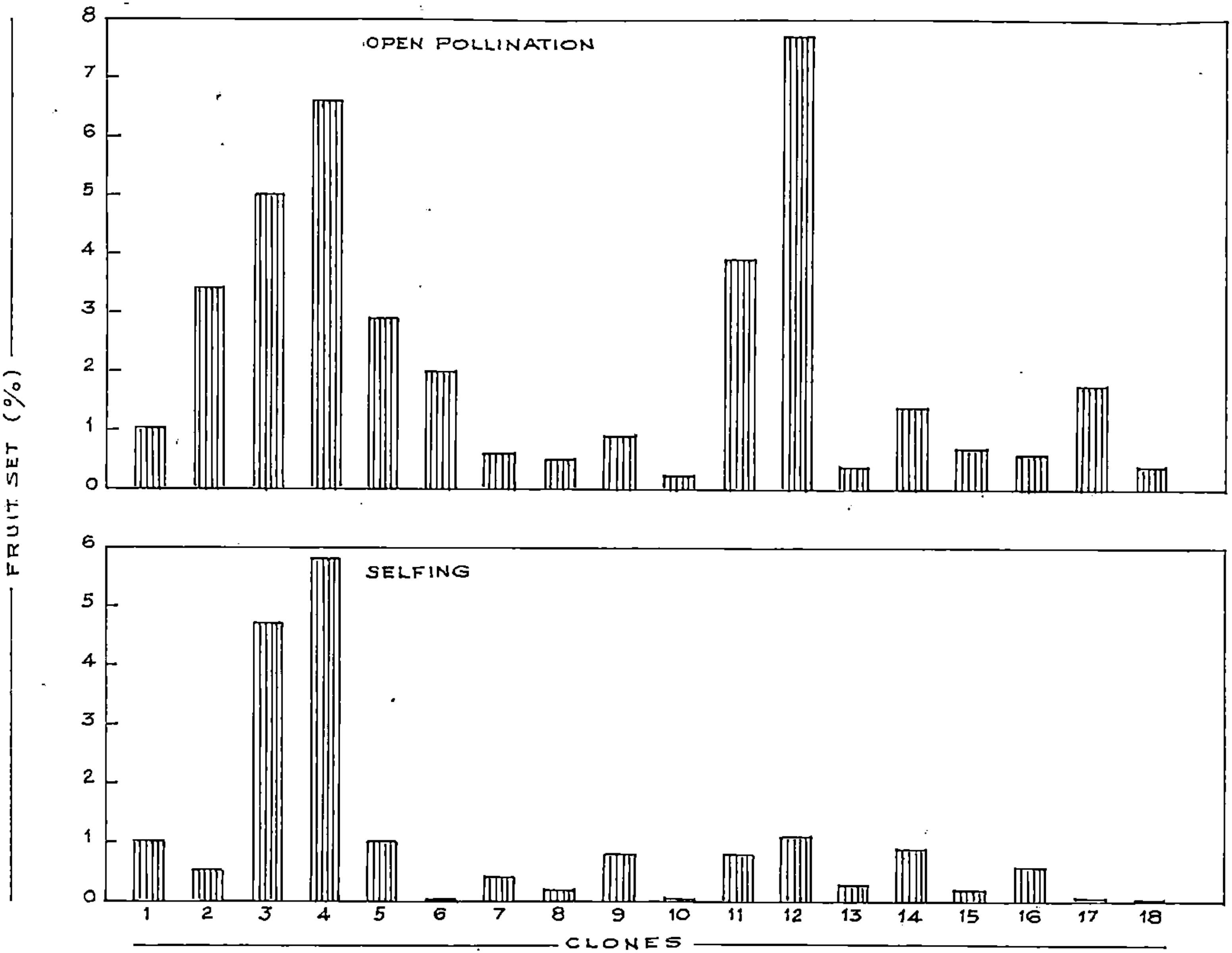
* Significant at P = 0.05

** Significant at P = 0.01

Figure 31. Fruit set under selfing and open pollination.

Number	Clone	Number	Clone
1.	RRII 105	10.	PB 217
2.	AVT 73	11.	PB 5/51
3.	PB 242	12.	PB 28/83
4.	PB 252	13.	PB 206
5.	PB 86	14.	PB 230
6.	PB 215	15.	Ch 26
7.	BD 5	16.	Ch 32
8.	Gl 1	17.	PB 5/76
9.	LCB 1320	18.	PB 235

FIG. 31. FRUIT SET UNDER SELFING AND OPEN POLLINATION.



(0.2, 0.26 and 0.19 respectively). Relatively high fruit set under selfing was recorded by clones PB 252 (5.78 per cent) and PB 242 (4.71 per cent).

Clone PB 28/83 recorded a relatively high fruit set of 7.69 per cent under open pollination followed by PB 252 (6.64 per cent) and PB 242 (5 per cent). Clones Ch 2 and PB 217 showed a relatively low fruit set of 0.15 per cent and 0.19 per cent respectively under open pollination.

In comparison with open pollination, fruit set under selfing was significantly low in six clones viz. AVT 73, PB 86, PB 215, PB 5/51, PB 28/83 and PB 5/76.

4.3.2. Seed germination

A comparison of germinability and earliness of germination between selfed and open pollinated seeds of fourteen clones is given in table 41. The selfed seeds in general took a slightly longer time (18 days) to germinate when compared to the open pollinated seeds (16 days). Germinability was higher for the open pollinated seeds (63.79 per cent) than the selfed seeds (37.43 per cent) of the clones in general .

Both selfed and open pollinated seeds of clone PB 252 germinated in 8 days which was the earliest. Seeds of PB 235 also showed early germination (8 days for open pollinated seeds and 11 days

Table 41. Germination of selfed and open pollinated seeds.

Sl. No.	Clone	Days to germination (days after sowing)		Germination %	
		Selfed	Open pollinated	Selfed	Open pollinated
1.	RRII 105	18	17	33	35
2.	AVT 73	16	16	70	85
3.	PB 242	18	20	32	45
4.	PB 252	8	8	63	85
5.	PB 86	23	19	62	90
6.	PB 215	Failed to set fruitunder selfing			
7.	BD 5	17	10	16	68
8.	Gl 1	22	16	16	49
9.	LCB 1320	17	17	11	33
10.	PB 217*	20	10	34	93
11.	PB 5/51	23	20	42	61
12.	PB 28/83	--	17	0	35
13.	PB 206	19	17	100	100
14.	PB 230	--	22	0	27
15.	Ch 26	Trees destroyed by wind prior to fruit collection			
16.	Ch 32	-do-			
17.	PB 5/76	Failed to set fruit under selfing			
18.	PB 235*	11	8	45	87
General Mean		17.67	15.50	37.43	63.79

* Selfed seeds were collected from monoclonal areas of the clone.

for selfed seeds). Selfed seeds of PB 86 and PB 5/51 germinated relatively late (23 days) while their open pollinated seeds germinated in 19 days and 20 days respectively. Germination of selfed seeds was late compared to the open pollinated seeds of most of the clones except in the case of PB 242 where the selfed seeds germinated slightly earlier than the open pollinated seeds and AVT 73, PB 252 and LCB 1320 of which the selfed and open pollinated seeds germinated at the same time.

Germination percentage ranged from 0.0 (PB 230 and PB 28/83) to 100 (PB 206) for selfed seeds and 27 (PB 230) to 100 (PB 206) for open pollinated seeds. Selfed seeds in all cases showed a lower germinability than open pollinated seeds except in the clone PB 206 for which both selfed and open pollinated seeds recorded 100 per cent germination.

4.3.3. Juvenile attributes and yield

Inbreeding depression with respect to plant height, girth, number of leaf flushes, number of leaves and dry rubber yield on test incision was worked out. Selfed seedlings of PB 5/51 were weak and did not survive in the field.

4.3.3.1. Plant height

Mean plant height for selfed seedlings ranged from 139.2 cm (LCB 1320) to 226.0 cm (PB 235) with a general mean of 175.65 cm

(Table 42). Among open pollinated seedling progeny for which the clones in general recorded a plant height of 172.89 cm, the minimum height of 126.5 cm was recorded by PB 242 and the maximum by PB 252 (225.5 cm). Though selfed seedlings of four clones were inferior to their respective open pollinated seedling progeny with respect to plant height, inbreeding depression was significant only in the case of PB 252.

4.3.3.2. Girth

In selfed seedlings the progeny in general recorded lower girth (5.94 cm) than the open pollinated progeny (6.40 cm) (Table 42). Girth in the selfed progeny ranged from 4.56 cm (PB 252) to 7.54 cm (BD 5) and in the open pollinated progeny ranged from 4.75 cm (RRII 105) to 7.28 cm (PB 252). Eight clones exhibited inbreeding depression for girth but significant depression was recorded only by PB 252.

4.3.3.3. Number of leaf flushes

Selfed and open pollinated seedling progeny did not vary with respect to the number of leaf flushes. Six clones exhibited non-significant inbreeding depression for this trait (Table 43).

4.3.3.4. Number of leaves

The selfed progeny in general recorded lower number of leaves

Table 42. Inbreeding depression for plant height and girth.

Sl. No.	Clone	Plant height			Girth		
		X̄S (cm)	X̄OP (cm)	I.D. (%)	X̄S (cm)	X̄OP (cm)	I.D. (%)
1.	RRII 105	142.0	119.5	--	5.70	4.75	--
2.	AVT 73	183.7	185.8	1.12	6.10	6.43	5.13
3.	PB 242	199.0	126.5	--	4.77	6.10	21.80
4.	PB 252	154.9	225.5	31.33*	4.56	7.28	37.36*
5.	PB 86	194.3	220.9	12.06	6.18	7.08	12.71
6.	PB 215	Failed to set fruit under selfing.					
7.	BD 5	175.2	157.6	--	7.54	7.17	--
8.	Gl 1	171.0	169.6	--	5.95	6.26	4.95
9.	LCB 1320	139.2	169.3	17.74	5.26	6.75	22.07
10.	PB 217	187.2	170.6	--	5.90	5.94	0.67
11.	PB 5/51	Seedlings failed to survive					
12.	PB 28/83	Selfed seeds failed to germinate.					
13.	PB 206	159.6	143.9	--	6.52	5.73	--
14.	PB 230	Selfed seeds failed to germinate.					
15.	Ch 26	Trees destroyed by wind prior to fruit collection					
16.	Ch 32	-do-					
17.	PB 5/76	Failed to set fruit under selfing.					
18.	PB 235	226.0	212.6	--	6.85	6.90	0.72
General Mean		175.65	172.89		5.94	6.40	

* Significant at P = 0.05.

Table 43. Inbreeding depression for foliar traits.

Sl. No.	Clone	No. of leaf flushes			No. of leaves		
		$\bar{X}S$	$\bar{X}OP$	I.D. (%)	$\bar{X}S$	$\bar{X}OP$	I.D. (%)
1.	RRII 105	3.0	2.3	--	14.0	13.8	--
2.	AVT 73	4.0	3.3	--	23.3	20.3	--
3.	PB 242	1.7	2.0	17.00	14.3	18.0	20.39
4.	PB 252	2.8	3.3	16.82	16.9	25.8	34.56
5.	PB 86	2.8	3.5	21.43	21.3	19.6	--
6.	PB 215	--	--	--	--	--	--
7.	BD 5	3.6	3.1	--	16.0	19.9	19.44
8.	Gl 1	3.3	2.8	--	19.3	19.4	0.57
9.	LCB 1320	2.1	2.6	19.77	10.4	13.5	22.67
10.	PB 217	3.3	2.4	--	23.4	21.8	--
11.	PB 5/51	--	--	--	--	--	--
12.	PB 28/83	--	--	--	--	--	--
13.	PB 206	2.6	3.4	24.20	18.6	19.0	2.11
14.	PB 230	--	--	--	--	--	--
15.	Ch 26	--	--	--	--	--	--
16.	Ch 32	--	--	--	--	--	--
17.	PB 5/76	--	--	--	--	--	--
18.	PB 235	3.9	4.2	5.76	22.1	25.0	11.48
General Mean		3.01	3.00		18.15	19.65	

(18.15) than the open pollinated progeny (19.65). The number of leaves ranged from 10.4 (LCB 1320) to 23.4 (PB 217) for the selfed progeny and from 13.5 (LCB 1320) to 25.8 (PB 252) for the open pollinated progeny. Seven clones exhibited non-significant inbreeding depression for this trait (Table 43).

4.3.3.5. Juvenile yield

Dry rubber yield under test incision did not differ between the selfed and open pollinated progeny of the clones in general. Juvenile yield ranged from 0.015 g $plant^{-1}$ (LCB 1320) to 0.057 g $plant^{-1}$ (AVT 73) for the selfed progeny and from 0.022 g $plant^{-1}$ (PB 242) to 0.063 g $plant^{-1}$ (AVT 73) for the open pollinated progeny. Six clones exhibited non-significant inbreeding depression for yield (Table 44).

4.3.3.6. Occurrence of offtypes

The occurrence of offtypes among the selfed progeny (Figure 32) and open pollinated progeny is shown in table 45. Six clones showed the presence of chlorotic seedlings in their selfed progeny at the initial stages of growth to the extent of 12.27 per cent in general. Clone PB 86 showed 50 per cent chlorotic seedlings followed by PB 242 (25 per cent) and PB 252 (23 per cent). Clones AVT 73, BD 5, Gl 1, LCB 1320 and PB 206 did not show the occurrence of chlorotic plants. In the open pollinated progeny of PB 252,

Table 44. Inbreeding depression for juvenile rubber yield.

Sl. No.	Clone	Rubber yield (g plant^{-1})		
		$\bar{X}S$	$\bar{X}OP$	I.D.(%)
1.	RRII 105	0.044	0.025	--
2.	AVT 73	0.057	0.063	9.52
3.	PB 242	0.019	0.022	13.64
4.	PB 252	0.039	0.054	27.78
5.	PB 86	0.041	0.041	--
6.	PB 215	--	--	--
7.	BD 5	0.053	0.057	7.02
8.	Gl 1	0.041	0.041	--
9.	LCB 1320	0.015	0.026	42.31
10.	PB 217	0.048	0.029	--
11.	PB 5/51	--	--	--
12.	PB 28/83	--	--	--
13.	PB 206	0.044	0.039	--
14.	PB 230	--	--	--
15.	Ch 26	--	--	--
16.	Ch 32	--	--	--
17.	PB 5/76	--	--	--
18.	PB 235	0.041	0.049	16.33
General Mean		0.040	0.041	

Figure 32. Offtypes among inbred progeny.

Figure 32.1 A stunted seedling

Figure 32.2 A chlorotic seedling.

Figure 32.3 Weak and chlorotic seedlings.

Figure 32. Offtypes among inbred progeny.

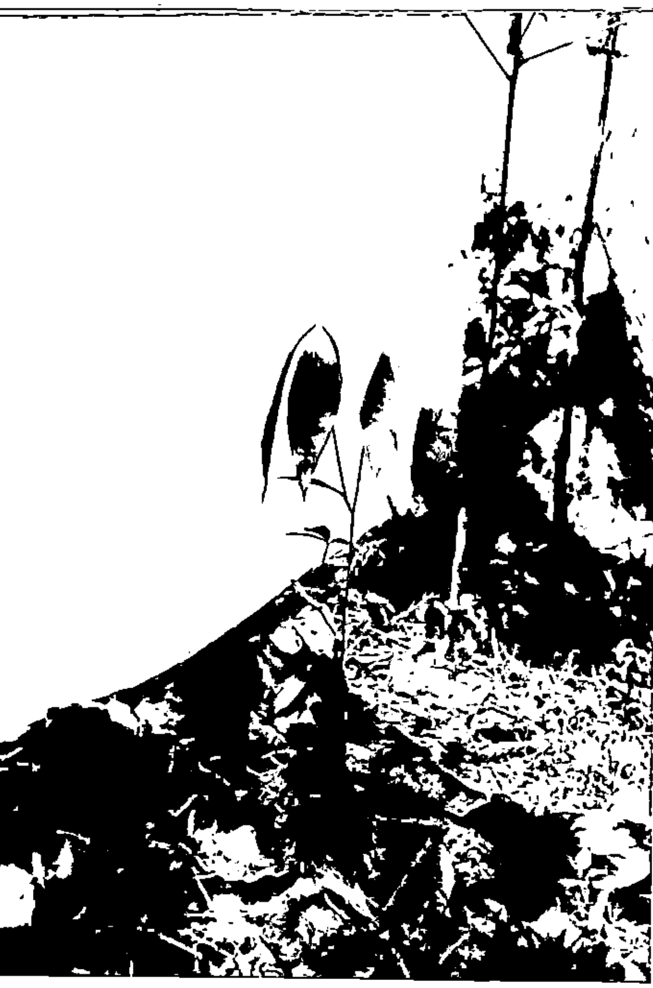


Figure 32.1

Figure 32.2

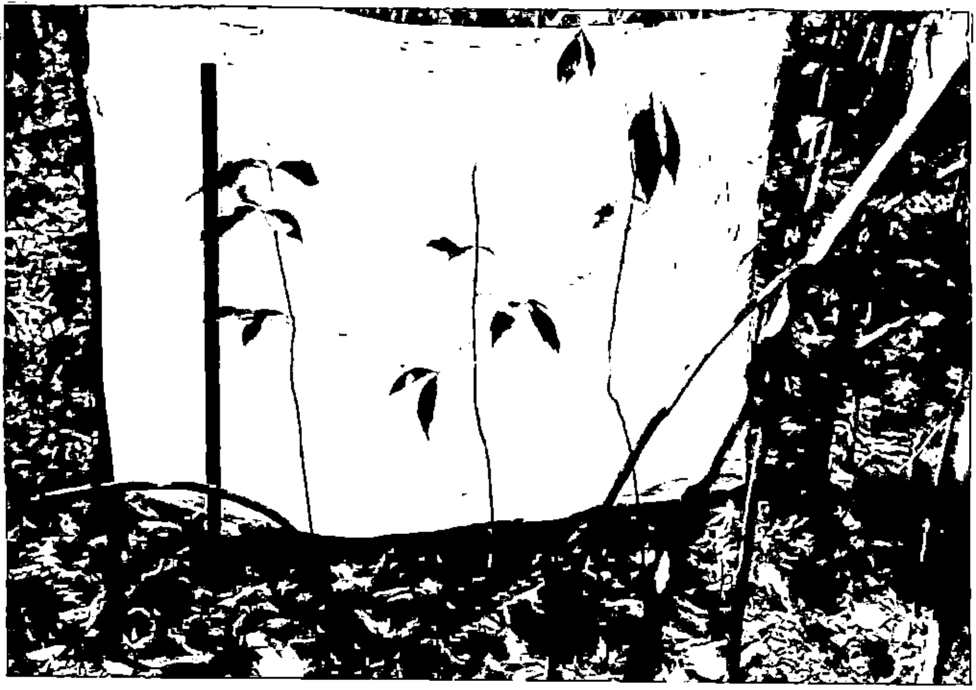


Figure 32.3

Table 45. Occurrence of offtypes among inbred progeny.

Sl. No.	Clone	Chlorotic plants (%)		Stunted plants (%)	
		Selfed	Open pollinated	Selfed	Open pollinated
1.	RRII 105	20	--	--	25
2.	AVT 73	--	--	33	--
3.	PB 242	25	--	67	--
4.	PB 252	23	8	38	8
5.	PB 86	50	--	46	--
6.	PB 215	--	--	--	--
7.	BD 5	--	--	--	--
8.	Gl 1	--	--	38	9
9.	LCB 1320	--	--	56	13
10.	PB 217	10	--	--	--
11.	PB 5/51	--	--	--	--
12.	PB 28/83	--	--	--	--
13.	PB 206	--	--	20	14
14.	PB 230	--	--	--	--
15.	Ch 26	--	--	--	--
16.	Ch 32	--	--	--	--
17.	PB 5/76	--	--	--	--
18.	PB 235	7	--	7	--
General Mean		12.27	2.5	27.2	5.0

8 per cent of the plants were chlorotic. No chlorotic plants were found in the open pollinated progeny of the other clones.

The clones in general showed a greater proportion of weak and stunted plants in the selfed progeny (27.2 per cent) than in the open pollinated progeny (5 per cent). Clone PB 242 showed the highest incidence of weak plants in the selfed progeny (67 per cent) while none of the plants in its open pollinated progeny were weak or stunted. Clone LCB 1320 showed 56 per cent of weak and stunted plants in the selfed progeny while clones PB 86 (46 per cent), PB 252 (38 per cent) and Gl 1 (38 per cent) also showed the occurrence of such offtypes in their selfed progeny. There were no stunted plants in the progeny of BD 5 and PB 217.

DISCUSSION

DISCUSSION

The rubber tree is a major cash crop of India. With the expansion of rubber cultivation to the non-traditional zones of India where the crop is subjected to a variety of biotic and abiotic stresses, it has become imperative to evolve planting material with greater heterogeneity and stability of performance. The scope for evolving new planting material depends on the available genetic variability, associations among characters, their heritability and genetic advance. Knowledge of the yielding ability of clones, their superiority in various economic attributes, the extent of genetic diversity among them, their general combining ability/ prepotency and inbreeding depression are essential for the success of rubber breeding programmes.

The present study was conducted with the objectives of evaluating forty clones of rubber with respect to genetic variability for rubber yield and its physiological, morphological and structural components, determination of associations among traits through correlations and path coefficient analysis and estimation of genetic divergence. Twenty clones with promising early yield were subjected to seedling progeny analysis for the assessment of prepotency and inbreeding depression. Likely prepotents from genetically divergent clusters were identified as parents suited to a polycross breeding programme. The results of the study are discussed and conclusions drawn as follows.

5.1. Genetic divergence

Assessment of genetic divergence between populations is vital to the success of plant breeding programmes designed to exploit gene recombination and heterosis. Strong positive relationships have been found between genetic distance and heterosis in a broad range of crop species (Balasch et al., 1984; Shamsuddin, 1985). Measures of genetic distance have most value to breeding when they are based on a broad range of characteristics relevant to breeding objectives. Heterosis breeding programmes in rubber aim at a combination of desired economic traits through hybridisation followed by clonal selection. This necessitates the identification of traits amenable to improvement by both gene recombination and heterosis. The polycross breeding approach lays emphasis on achieving a combination of yield components along with stability of performance. The extent of genetic variability among forty clones was determined in the present study. The relative importance of traits in their contribution to dry rubber yield was determined through correlations and path coefficient analysis. Genetic divergence was estimated through D^2 analysis and the factors of divergence were identified through principal factor analysis.

5.1.1. Genetic variability among clones

Significant clonal variation in respect of twenty five characters among the forty clones revealed the existence of tremendous genetic variability. The vast differences in the mean values of clones for most of the characters further confirms the same. While early work in rubber (Whitby, 1919), mainly assessed the variability in seedling populations, attention was later given to the analysis of variability among clones evolved through hybridisation and clonal selection (Ross and Brookson, 1966; Simmonds, 1969; Nazeer et al., 1986). Nga and Subramaniam (1974) reported high genetic variability for yield in rubber which is in conformity with the present results. Gilbert et al. (1973) and Tan et al. (1975) also reported high genetic variability for yield.

Results of the present study, while confirming the existence of considerable genetic variability for dry rubber yield, yield depression under stress, volume of latex, dry rubber content, rate of latex flow, plugging index, girth, girth increment rate, length of the tapping panel, height at forking, virgin bark thickness, renewed bark thickness and chlorophyll content, also enabled the identification of clones with superiority for the various components and yield *per se*. The results are summarised in table 46. Ten clones viz., PB 235, PB 217, RRII 105, PB 252, Ch 26, PB 5/76, PB 28/83, PB 242, PB 230 and LCB 1320 were classified as high yielders in terms of dry rubber yield.

The rubber tree is deciduous. Refoliation after wintering is accompanied by flowering and fruit development. These together impose competition for nutrients within the tree and affects the partitioning of assimilates towards rubber production. The period from January to March also coincides with the occurrence of powdery mildew, a disease which affects young leaves soon after bud burst following wintering (Johnston, 1989). In South India, the period from February to May is marked by the lowest precipitation and high temperature (Sethuraj, 1977; Markose, 1984). Therefore this period could be considered as the stress period when biotic and abiotic stresses are imposed on the rubber tree. Yield decrease during or soon after wintering has been reported by Dijkman (1951), Wimalaratna and Pathiratna (1974) and Sethuraj (1977). Polhamous (1962) and Ninane (1967) also reported that the summer months are lean in terms of crop production. All the clones in the present study showed a reduction in dry rubber yield during the stress period but the extent of yield depression under stress showed highly significant clonal variation. Marked differences between clones in the extent of yield depression during refoliation was reported by Webster and Paardekooper (1989). Seven clones viz., PB 235, PB 217, RRII 105, Ch 26, PB 242, PB 28/83 and PB 252 exhibited high mean yields coupled with a low yield depression under stress and could be considered to possess stability for yield.

Genetic parameters like genotypic coefficient of variation (G.C.V.), phenotypic coefficient variation (P.C.V.), heritability

(H^2) and genetic advance (G.A.) enable the partitioning of genetic variability into heritable and non-heritable components. The G.C.V. provides a valid basis for comparing and assessing the range of genetic variability for quantitative characters while P.C.V. measures only the extent of total variability. The genotypic coefficient of variation was lower than the phenotypic coefficient of variation for all the characters studied indicating the influence of the environment on the genotype in the expression of the characters. Comparatively high values of G.C.V. and P.C.V. were recorded for annual mean dry rubber yield, dry rubber yield under stress, peak dry rubber yield, yield depression under stress, plugging index under stress, annual mean volume of latex, volume of latex under stress and latex flow rate during the three periods indicating scope for selection for these traits in improvement programmes. The high genetic variability for dry rubber yield is in agreement with the findings of Nga and Subramaniam (1974). Contrary to the same report, genetic variability for girth was relatively low among the clones studied in the present experiment. The relatively high estimates of G.C.V. and P.C.V. for dry rubber yield and volume of latex and the low G.C.V. and P.C.V. for girth, dry rubber content (D.R.C.) and bark thickness (virgin and renewed) observed in the present study corroborates the findings of Markose (1984). Alika and Onokpise (1982) also reported negligible genotypic variation for girth.

The estimation of heritable variation is not possible with the help of genotypic coefficient of variation alone. Burton (1952) suggested that genotypic coefficient of variation together with heritability estimates would give a better idea of selection advance to be expected. Selection acts on genetic differences and gains from selection for a specific character depends largely on the heritability of the character (Allard, 1960). The degree to which the variability for a quantitative character is transmitted to the progeny is referred to as heritability and it measures the heritable portion of variability. In an asexually propagated crop like rubber, the estimation of heritability in the broad sense is meaningful since all the genetic variability is usable between asexual generations by means of selection. The heritability estimates were moderate to high for a majority of the clonal characters in the present experiment. This is in agreement with the view of Simmonds (1989) that heritability of economic characters in rubber is generally high. The high estimates of heritability for dry rubber yield during the three periods, latex flow rate during the three periods and plugging index under stress indicate that the observed variability for the traits is often heritable. But traits such as dry rubber content, girth, annual mean plugging index, girth increment rate, virgin bark thickness and renewed bark thickness recorded moderate to high heritability estimates in spite of a low genotypic coefficient of variation. This indicates that a large proportion of the variability observed for these traits is heritable and the influence of environment in their expression is negligible. High heritability for yield and girth has previously been reported by Nga and Subramaniam (1974), Liang et al. (1980), Markose and George (1980) and Markose (1984). On the contrary, moderate to low estimates of heritability for rubber yield was reported by Liu et al. (1980) and Alika (1982 and 1985). The moderate to high heritability observed in the present study for girth increment, virgin bark thickness and four years' renewed bark thickness are in agreement with previous reports (Tan et al., 1975; Alika and Onokpise, 1982).

Johnson et al. (1955) pointed out that high heritability estimates along with high genetic advance were more useful than heritability value alone in predicting the resultant effect of selection. While discussing the heritability of certain characters in red pepper, Ramanujam and Thirumalachar (1967) explained the limitations of heritability in the broad sense since it includes both additive and epistatic gene effects. They suggested that broad sense heritability will be reliable if accompanied by high genetic advance. The genetic advance was high for dry rubber yield, latex flow rate during the three periods, volume of latex under stress and plugging index under stress while it was low for chlorophyll content, bark thickness, length of tapping panel, girth and dry rubber content during the three periods.

The moderate to high heritability coupled with high genetic advance for dry rubber yield, volume and flow rate of latex over the three periods, girth increment under tapping, annual mean plugging index and plugging index under stress indicates the predominance of additive gene action in the inheritance of these traits and implies scope for improvement of these traits through selection. Dry rubber content during the three periods, girth, virgin bark thickness and renewed bark thickness showed moderate to high estimates of heritability with low genetic advance which could be attributed to non-additive gene effects as suggested by Panse (1957). Exploitation of heterosis for these traits could be possible if dominance is involved in the non-additive gene effects (Singh and Choudhary, 1979). The low estimates of heritability and genetic advance under selection observed for chlorophyll content indicate high influence of environmental factors in its expression and offers no scope for improvement through selection.

5.1.2. Correlation

Correlation provides information on the nature and extent of relationship between characters. The success in a Hevea breeding programme largely depends on the efficiency of clonal selection and ortet selection/plus tree selection from polycross progeny. When the breeder applies selection pressure for a trait, the population while being improved for that trait is also improved in respect of other characters associated with it. Thus correlation facilitates simultaneous improvement of two or more characters. Knowledge of the relationships among yield and its components is essential for the formulation of breeding programmes aimed at achieving a desired combination of the various components of rubber yield. The estimates of genotypic and phenotypic correlation co-efficients between various characters reveal the extent and direction of associations. The phenotypic correlations better serve the purpose of orientation, whereas the genotypic correlations are more reliable in the prediction of the resultant effect of selection. The genotypic correlations provide a reliable measure of genetic association between characters and help to differentiate the vital associations useful in breeding from the non-vital ones (Falconer, 1981). Therefore, the analysis of rubber yield in terms of genotypic and phenotypic correlation coefficients of component characters leads to an understanding of the relative importance of characters that can form the basis of selection. The genotypic and phenotypic correlations between rubber yield and its components were computed as part of this study. In general, the genotypic correlation co-efficients were higher than the phenotypic correlation coefficients for most of the traits studied. Low phenotypic correlations have been explained as due to the masking or modifying effect of the environment in genetic associations between characters (Johnson et al., 1955; Oraon et al., 1977).

At both genotypic and phenotypic levels, volume of latex, dry rubber content and latex flow rate during the three periods along with girth, girth increment rate, length of tapping panel and virgin bark thickness exhibited positive correlations with dry rubber yield during the three periods. The phenotypic correlations were highly significant and strong genotypic correlations were indicated by the low S.E. estimates. Annual mean dry rubber yield, dry rubber yield under stress and peak dry rubber yield were also positively correlated. While peak dry rubber yield and dry rubber yield under stress showed a very high genotypic correlation with the annual mean yield, the correlation between dry rubber yields during the stress and peak periods was slightly lower. The present results are in agreement with the findings of Dijkman and Ostendorf (1929), Narayanan et al. (1973) and Tan et al. (1975). Narayanan et al. (1974), Tan and Subramaniam (1976) and Liu (1980) reported a positive correlation of yield with girth of the tree while Wycherley (1969) and Markose (1984) obtained a negative correlation between girth and yield. Ho et al. (1973) and Ho (1976) found yield to be positively correlated with girth during the initial years of tapping but as tapping proceeded, girth assumed lesser importance in determining yield. They presumed that plant assimilates are partitioned in favour of latex formation rather than growth, particularly in the case of high yielding clones leading to a negative association of girth and girth increment with rubber yield. In the present study, the positive correlations of girth and girth increment with dry rubber yield, though significant were not as high as those of the physiological components with yield.

Yield depression under stress and plugging index during the three periods recorded negative correlations with dry rubber yield during the three periods both at the genotypic and phenotypic levels. Dry rubber yield has been reported to be positively correlated to the initial rate of latex flow (Paardekooper and Samosorn, 1969) and negatively correlated to plugging index (Milford et al., 1969; Sethuraj et al., 1974). The yield of rubber obtained from a tree each time it is tapped is determined by the volume of latex collected and its dry rubber content. The volume of latex depends on the rate and duration of flow. The rate of flow is determined by the length of the tapping cut which in turn is related to the girth of the tree, a character which reflects growth. Sethuraj (1981) in a theoretical analysis of yield components of rubber has elucidated the relationships of latex flow rate, length of the tapping panel, dry rubber content and plugging index with dry rubber yield. The relationships indicate that the yield of rubber from a tree per tapping is proportional to the initial rate of latex flow, length of the tapping cut, the rubber content of the latex and inversely proportional to the plugging index.

The correlation estimates obtained in the present study lend further support to the view that volume of latex, dry rubber content, rate of latex flow, girth, girth increment rate, length of the tapping panel and bark thickness are components positively associated with dry rubber yield while the extent of yield depression under stress and plugging index have a negative relationship with dry rubber yield irrespective of the seasonal variations.

5.1.3. Cause and effect relationships

Genotypic and phenotypic correlations measure the interdependence of biological characters at the genotypic and phenotypic levels respectively. A positive genotypic correlation between two variables can be counteracted by a negative environmental correlation. Further, selection for a trait in one direction may cause an undesired diminution of another trait by direct or indirect effects through a third variable. The path coefficient analysis devised by Wright (1921) is an effective means of examining the direct and indirect relationships. Permitting a critical examination of the specific factors that produce a genetic correlation, this technique proved useful in the statistical analysis of cause and effect in a system of correlated variables. Path analysis is a standardized partial regression analysis which specifies the relative importance and measures the direct influence of one variable upon another besides partitioning of the correlation coefficients into direct and indirect effects (Dewey and Lu, 1959). An analysis of the cause and effect relationships of dry rubber yield during the stress and peak periods, volume of latex, dry rubber content, rate of latex flow and plugging index during the three periods along with girth, girth increment rate, length of the tapping panel and virgin bark thickness with the annual mean dry rubber yield was attempted in this study.

Dry rubber yield under stress, annual mean volume of latex and latex flow rate during the peak yield period emerged as the more important traits with high positive direct effects on annual mean dry rubber yield. A major proportion of the indirect effects of all the other traits on annual mean dry rubber yield was observed to be manifested through these three traits. Latex flow rate under stress also had a high positive direct effect on annual mean dry rubber yield. Though dry rubber yield during the stress and peak periods had equally high genotypic correlations with the annual mean yield, dry rubber yield under stress had a high positive direct effect while peak dry rubber yield had only a low positive direct effect. Volume of latex during the stress and peak periods showed high positive genotypic correlations with annual mean dry rubber yield but their direct effects were negative indicating that the indirect effects exerted mainly through annual mean volume of latex and latex flow rate during the stress and peak periods were the cause of the correlations. This again emphasised the importance of dry rubber yield under stress, annual mean volume of latex and latex flow rate during the stress and peak yield periods. These characters could be accorded simultaneous emphasis in selection programmes for the improvement of rubber yield. The genotypic correlation between peak latex flow rate and annual mean dry rubber yield was almost equal to its direct effect. This suggests that a direct selection for this trait will be effective in improvement of rubber yield. The magnitude of direct effects reveal the physiological components to be relatively more important than girth, girth increment rate, tapping panel length and virgin bark thickness in the determination of dry rubber yield. The low residual indicated that the various components studied during the three periods were able to account for a major proportion of the variability for annual mean dry rubber yield.

Separate analyses of the cause and effect relationships among dry rubber yield and its components during the stress and peak periods and also the mean during the fourth year of tapping were attempted. In the case of the annual mean values, the direct effect of volume of latex on dry rubber yield was positive and high accounting for a major proportion of the genotypic correlation between the two traits. This agrees with the finding of Markose (1984) that volume of latex has a positive direct effect on dry rubber yield. During the stress and peak periods, though the positive genotypic correlations of volume of latex with dry rubber yield were high, the direct effects were negative indicating that the indirect effects are the causes of the correlations. The nature and magnitude of the indirect effects of volume of latex through other traits differed during the stress and peak periods.

Dry rubber content showed a moderate to high positive genotypic correlation with dry rubber yields during the three periods, but its direct effect during the peak period was negative. The direct effects of latex flow rate during the three periods reflected its positive genotypic correlation with dry rubber yield except for the annual mean values for which the direct effect was far less than the correlation estimate. The negative genotypic correlations between plugging index and dry rubber yield was explained by the negative direct effects during the stress and peak periods. Yield depression under stress also had a negative genotypic correlation coupled with a negative direct effect on annual mean dry rubber yield and dry rubber yield under stress.

Girth and girth increment rate had positive genotypic correlations with dry rubber yield during the three periods, but the direct effect of girth on peak dry rubber yield and that of girth increment on annual mean dry rubber yield and dry rubber yield under stress were negative. The positive genotypic correlations of length of the tapping panel with dry rubber yield during the three periods were accounted by the positive direct effects. The negative direct effect of girth increment on dry rubber yield is in agreement with the findings of Markose (1984). Virgin bark thickness though positively correlated with dry rubber yield during the three periods had an equivalent and positive direct effect only during the peak yield period indicating that a direct selection for this trait will be effective in improving peak dry rubber yield.

The negative direct effect of virgin bark thickness on annual mean dry rubber yield observed in the present study is in conformity with the results obtained by Markose (1984).

The residual was not estimable in the case of annual mean and stress periods indicating the involvement of a number of un-accounted traits. The traits studied were able to account for only a part of the variability for peak dry rubber yield as indicated by the relatively high residual. However when the various traits during the three periods were considered collectively as components of annual mean dry rubber yield, the residual was low. This indicates that the expression of each component during the different periods is important in the expression of annual mean dry rubber yield.

The varying magnitude and direction of the cause and effect relationships of dry rubber yield and its components during the three periods imply the involvement of separate genetic control in the inheritance of these traits under varying seasons. It is well established in a number of crop plants that the response of a genotype to environmental variation and its basic yield potential are governed by separate gene systems (Finlay and Wilkinson, 1963; Bucio-Alanis et al., 1969; Bains, 1976).

From the results of the present study, the peak dry rubber yield which indicates the yield potential of clones under a favourable environment appeared less important than dry rubber yield under stress in respect of its contribution to annual mean dry rubber yield. For the improvement of dry rubber yield under stress, selection for a high latex flow rate, girth, length of tapping panel, a low plugging index and yield depression under stress appears feasible. The correlations and cause and effect relationships revealed that a clone capable of maintaining a high rate of latex flow during the stress and peak yield periods, a high volume yield of latex and a high yield of dry rubber during the stress period would be able to give a high annual mean yield of rubber during the fourth year of tapping.

5.1.4. Genetic distance

The utility of multivariate analysis and the use of generalized distance (D^2) as a quantitative measure of genetic divergence are well illustrated in crop plants (Vairavan et al., 1973; Bavappa and Mathew, 1982; Singh and Gupta, 1984). The various approaches to genetic improvement in rubber demand judicious selection of genetically diverse parents which on crossing could bring about substantial heterotic effects. Awareness of the origin of the present day rubber clones from a limited number of seedlings referred to as the 'Wickham base' (Simmonds, 1989) has led to efforts to broaden the genetic base by incorporating more genetically diverse germplasm from Brazil, the primary centre of diversity. However, only a beginning has been made (Ong et al., 1983;

Chevallier, 1988) and it will be a long time before the wild germplasm is domesticated and evaluated to produce any worthwhile impact on improvement programmes. In the present experiment, genetic divergence among forty 'Wickham clones' of Indian, Indonesian, Malaysian and Sri Lankan origin was estimated based on twenty two variables to enable the identification of divergent clones for use in heterosis and polycross breeding programmes.

The significant clonal variation for all the twenty two morphological, structural and physiological attributes indicated genetic differences among the clones and implied that it would be worthwhile to classify them on the basis of the characters chosen. As established by Bains (1976) and Verma et al. (1978), the involvement of separate gene systems in the response of clones to seasonal variations and the expression of their basic yield potential was indicated from the cause and effect relationships in the present study. Therefore when clones which are diverse for various morphological characters and yield are selected, it is not necessary that they express diversity for response to seasonal variations and vice versa. Hence in the present study, morphological and structural attributes were utilized along with yield and its components over two specific seasonal conditions viz., the stress period and the peak yield period, for the estimation of genetic divergence. The identification of parent clones which are divergent with respect to various traits and for response to varying seasons and their incorporation in hybridisation programmes will enable the production of progenies with heterosis for yield as well as stability of performance under seasonal variations.

The wide range in D^2 values between individual clones and within and among the eight different clusters indicated the existence of considerable genetic diversity which is in agreement with the findings of Markose (1984) from a study based on 20 clones of rubber. The report of Chevallier (1988) based on isozyme studies also lends support to the existence of considerable genetic diversity among Wickham clones.

The forty clones were grouped into eight clusters irrespective of their country of origin indicating the absence of any relationship between geographic diversity and genetic divergence. Similar observations were made in rubber (Markose, 1984) and other crops (Vairavan *et al.*, 1973; Bavappa and Mathew, 1982). On the contrary, isozyme studies on the wild *Hevea* germplasm collected from Brazil have revealed distinct genetic divergence between material collected from the geographically distant states of Acre and Mato Grosso, while the material from Rondonia which is geographically intermediate to the other two states showed an intermediate genetic constitution (Chevallier, 1988). The grouping of clones from different countries in the same cluster and clones from the same country in different clusters is to be expected in view of the origin of the clones in the present study from a limited number of seeds collected from a restricted area in Brazil (Schultes, 1977; Webster and Paardekooper, 1989). Thus representation of eco-geographic diversity in the primary centre of origin among the Wickham clones is inadequate while the wild germplasm evaluated by Chevallier (1988) represents a random sample of the entire genetic diversity in the different geographic regions of the primary centre of diversity. Moreover, directional selection for high yield in breeding programmes and the extensive use of clonal propagation in rubber seemed to mitigate the effect of natural selection viz., genetic drift among clones evolved in the various countries representing the secondary centres of diversity. The free exchange of breeding material among different rubber growing countries also facilitated the distribution of genes in various clones irrespective of their country of origin. Moreover, as explained by Simmonds (1985), in relation to the Wickham base generation the current clones are only two or three cycles of selection ahead of the original material. Hence clones in the secondary centres of diversity have not been able to evolve into genetically distinct and divergent types.

It is known that selection of parents on the basis of their genetic distances helps in a better realization of heterosis. but desirable and high magnitudes of heterosis are not directly related to extreme parental divergence as discussed by Arunachalam et al. (1984). Intermediate divergent clones would have a high probability of producing heterotic hybrids (Thakur and Zarger, 1989). Selection of parents based on individual attributes may not be as advantageous as that based on a number of important components collectively, particularly when the aim is to achieve improvement in a complex quantitative trait such as rubber yield. Hence, it would be appropriate to select parents for breeding programmes based on their superiority for the various yield contributing characters from clusters separated by intermediate to high genetic distances. Among the eight clusters, in the order of magnitude of genetic distances, clusters VI and VII were the most divergent, followed by clusters VII and VIII, I and VIII, V and VIII, III and VI, I and III, I and VII, V and VII, II and VI and II and VIII which showed intermediate to high divergence.

An examination of the characters studied revealed the important contribution of volume of latex followed by plugging index, dry rubber content, latex flow rate and dry rubber yield towards genetic divergence. Contrary to this result, Markose (1984) reported that morphological characters like girth, branching height and girth increment contributed more towards genetic divergence than D.R.C. and volume of latex. Among the morphological traits, girth, length of tapping panel and virgin bark thickness contributed more towards divergence.

The present results summarised in table 46 provide information on genetically divergent clones with superiority in respect of various yield components. Parents for biparental crosses could be selected giving primary importance to genetic divergence along with superiority of traits. Parents for polycross breeding programmes could ideally be selected from the various clusters provided they possessed high general combining ability and superiority for yield and the various yield components.

5.1.5. Factors of divergence

Yield in rubber is a complex character contributed by a number of inter related traits. For estimation of genetic divergence through multivariate analysis it is essential to identify traits contributing to divergence to avoid wasteful observations. Factor analytic techniques provide supplementary information on diversity with a lesser number of causative factors. The present results helped in identifying the factors of divergence and their associated traits in two genetically divergent clusters.

For both clusters I and II a three factor model was obtained from the 'eigen' structure of the environment correlation matrix. The first factor in both the clusters was strongly associated with dry rubber yield, volume of latex and rate of latex flow. The other common variables associated with factor I in both the clusters were the length of tapping panel, renewed bark thickness and plugging index. These variables comprise yield and its components and so the factor may be designated as the yield factor. In both the clusters, factor I i.e. the yield factor accounted for the highest proportion of variation.

The yield depression under stress along with virgin bark thickness and D.R.C. formed factor II in cluster I and accounted for 11 per cent of the variation while the same character along with girth formed factor III in cluster II and accounted for 13 per cent of the variation. It could be inferred that yield depression under stress stands out as an important variable contributing to a separate factor accounting for 11-13 per cent of the variation in combination with only two traits in cluster I and one trait in cluster II.

Similarly height at forking alone accounted for 7 per cent of the variation in cluster I forming a separate factor and in cluster II the same trait along with girth increment formed factor II accounting for 11 per cent of the variation. Forking height could therefore be considered as another important character contributing to divergence. This is in agreement with the observations of Markose (1984).

The factor patterns and the constitution of each factor in the two clusters indicate dry rubber yield, volume of latex, rate of latex flow, yield depression under stress and height at forking to be the important contributors to the factors of genetic divergence. The rate of latex flow which formed a component of the yield factor along with dry rubber yield and volume of latex is an attribute which is practically difficult to measure and hence could be given less importance than the other two components.

It could be concluded from the present results that the yield factor is the main factor of divergence and for future studies on genetic divergence emphasis should be laid on dry rubber yield, volume of latex, yield depression under stress and height at forking.

5.2. Prepotency

The predominant out breeding nature of rubber and the observations that in rubber, the variance for G.C.A. effects is several times higher than that for S.C.A. effects (Swaminathan, 1975; Tan and Subramaniam, 1976) and that heritabilities with respect to female parents are higher than that with respect to male parents for most of the traits (Tan et al., 1975) indicate scope for the identification and utilisation of prepotents. Identification of prepotent parents through seedling progeny analysis is widely practised in coconut (Ninan and Pankajakshan, 1961; Liyanage, 1967; Nampoothiri et al., 1975; Sathyabalan and Mathew, 1977; Sathyabalan and Rajagopal, 1985). In rubber, though scattered reports on GCA estimates from diallel matings (Tan and Subramaniam, 1976) and vigour of seedling progeny (Alika, 1980; Saraswathyamma et al., 1984; Markose, 1984) are available, no study conducted to date has indicated the scope of exploitation of prepotency. In the present study, twenty clones having a promising early yield trend were subjected to seedling progeny analysis at the age of one year and two years, the results of which are discussed in the forthcoming pages.

5.2.1. Genetic variability in seedling progeny

Analysis of variance among one year old seedling progenies with respect to juvenile rubber yield under test incision, growth parameters and foliar traits revealed no significant variability among progenies with respect to plant height and girth. This is in agreement with an earlier report based on 10 months' growth of clonal seedlings (Markose, 1984) and indicates that the age of one year is too early for expression of genotypic differences among progenies for height and girth. On the contrary, highly significant variation among progenies was observed for bark thickness, number of leaf flushes produced, number of leaf flushes retained, number of leaves and rubber yield on test incision. This implies the early expression of genetic variability among progenies for these traits and indicates scope for utilising the traits for identifying superior progenies at the age of one year.

Seedling morphology is very important in the improvement of perennial crops and seedling vigour indicates the vigour of clones after budding (Haskell, 1961). Good immature vigour is one of the most important attributes associated with yield potential in rubber (Tan, 1987) and is one of the early selection criteria in Hevea breeding programmes. Test incision of one year old seedlings was found to be as effective as the conventional test tapping of seedlings at the age of two years for early detection of superior genotypes (Annamma et al., 1989).

At the age of two years, the progenies did not exhibit significant variability with respect to plant height and girth increment. Genetic variability for girth, however became evident at the age of two years, but no significant variability among progenies was evident with respect to bark thickness. Significant variability among progenies was recorded for the number of leaf flushes, number of latex vessel rows and rubber yield on test tapping. Significant variability among progenies for juvenile traits has been reported by Saraswathyamma and Panikkar (1989). Girth, bark thickness, number of latex vessel rows, latex vessel density and one to three years' yield are reported to be correlated with yield potential (Goncalves, 1982; Paiva, 1982; Premakumari et al., 1989) and are used by breeders for preliminary selection in small scale trials. Rubber yield on test tapping nursery plants has been reported to show highly significant positive association with mature yield of both clones and seedling trees (Ho, 1972 and 1979; Tan, 1987) and is employed as the most popular early selection criterion in rubber (Tan, 1978 a and b). Nursery test tapping of rubber seedlings give quite good estimates of family means (Simmonds, 1989). However, juvenile yield per se is a complex character contributed by a number of component traits like girth, vegetative vigour and the latex vessel distribution. Nearly 80 per cent of the variation in yield at the nursery stage is accountable by the four traits, bark thickness, number of latex vessel rows, girth increment and plugging index (Narayanan et al., 1974). The number of latex vessel rows at the juvenile phase is an important trait with a significant positive association with mature yield (Ho, 1972). But it is practically difficult to measure this trait before the seedlings attain at least two years' growth.

Genetic variability so essential for selection is not directly accessible to measurement. Only the external expression i.e. genetic variance as modified by the environment is measurable as phenotypic variance. The variability available in a population has therefore to be partitioned into heritable and non-heritable components with the aid of genetic parameters like genotypic coefficient of variation (GCV), heritability (H^2) and genetic advance (GA) which can be used as reliable guidelines in selection. The importance of rubber yield under consecutive test tappings and the number of latex vessel rows, both of which can be determined only at the age of two years has already been mentioned. Hence, in the present study, juvenile rubber yield and growth parameters at the age of two years were analysed for the components of variation.

The genotypic coefficient of variation was lower than the phenotypic coefficient of variation for all the juvenile traits indicating the influence of the environment on the genotype in the expression of the traits. The GCV and PCV were highest for juvenile yield followed by the number of leaf flushes and number of latex vessel rows. Heritability was highest among seedling characters for the number of latex vessel rows followed by juvenile yield, the number of leaf flushes and girth. These traits showed relatively high estimates of genetic advance, except for girth for which genetic advance was low. These results indicate predominance of additive gene action in the inheritance of juvenile rubber yield, number of latex vessel rows and number of leaf flushes. This corroborates the findings of Tan and Subramaniam (1976) that predominant additive gene effects govern yield, bark thickness and the number of latex vessel rows in the nursery.

As expressed by Swaminathan (1975), heritability values for yield and yield components in rubber at the nursery stage are encouraging. In addition to the magnitude of correlated responses between seedling characters and adult plant yield, the effectiveness of juvenile selection also depends on the genetic source of variability. It is well known that progressive selection through generations is successful only when the character selected is highly heritable and determined by additive gene action. Under such situations selection is effective, response is rapid and continuous, family performance is predictable and there is a high correlation between parental phenotype and its breeding behaviour. Simmonds (1985) had reported that yield in rubber is unusually highly heritable and yield potential is expressed early enough in life that nursery selection is effective. The present results imply scope for improvement of rubber yield, number of latex vessel rows and vegetative vigour in terms of the number of leaf flushes through selection.

On the other hand, though girth recorded moderately high heritability, GCV and genetic advance were relatively low indicating that genetic variability for the trait at the seedling stage is insufficient to render selection effective. This also implies non-additive inheritance which could be exploited through hybridisation. On the contrary, Tan and Subramaniam (1976) reported predominant additive gene effects for girth.

5.2.2. Correlations among juvenile traits

A knowledge of correlation of rubber yield with other juvenile traits is essential for formulation of selection indices for seedling populations. Rubber yield on test incision at the age of one year had significant phenotypic association with girth, bark thickness, number of leaf flushes, number of leaves and plant height. So also, rubber yield from consecutive test tappings at the age of two years showed highly significant positive correlation with plant height, girth, girth increment, bark thickness, number of latex vessel rows and number of leaf flushes. Positive correlations of plant height, girth, bark thickness and number of latex vessels with juvenile yield under test tapping of seedlings have previously been reported (Tan and Subramaniam, 1976; Licy and Premakumari, 1988: Annamma et al., 1989). The present results showed that inter-relationships among the different growth parameters were positive in both one year old and two year old progenies. At the age of two years only a non-significant positive association of the number of leaf flushes and plant height with the number of latex vessel rows was observed. Alika (1980) studied the inter-relationships between different growth parameters in nursery plants and found plant height to be positively correlated with stem diameter and leaf area. As opined by Jayasekara and Senanayake (1971), since height is more difficult to measure, stem diameter would suffice as a measure of growth vigour in young plants. Girth exhibited the strongest association with juvenile rubber yield both at the age of one year and two years and hence could be considered along with rubber yield in family selection. The present results imply that height, girth, girth increment, foliar attributes, bark thickness and the number of latex vessel rows contribute to juvenile vigour which in turn determine the rubber yield potential.

5.2.3. Estimates of prepotency

A prepotent parent is one which produces superior progeny irrespective of the genotype of the male parent. As established by Liyanage (1967), prepotent coconut palms combined high yield and superiority of progeny characteristics. The open pollinated progenies of such palms were consistently high yielding with a low coefficient of variation.

Though significant variation among progenies was evident for most of the juvenile traits, the magnitude of genetic variability between progenies was not very high. This could have been due to the highly heterozygous nature of the parent clones coupled with open (cross) pollination which leads to tremendous heterogeneity within each progeny. Hence a performance index with simultaneous emphasis on a number of traits which exhibited significant variability, heritability and positive correlation with yield was computed for determining the relative merit of progenies. Construction of selection indices based on index scores for multiple characters of nursery seedlings though reported in other cross pollinated perennials like coconut (Shylaraj, 1982; Thomas Mathew, 1983; Shylaraj and Gopakumar, 1987) and cashew (Susamma et al., 1984) has not been attempted to date in rubber. The performance index computed in the present study takes into account the performance of each progeny along with the extent of environmental variation for each of the traits. This index has made possible the detection of progenies with superior performance in respect of stable juvenile traits i.e. those having a low environmental component of variation.

Plant height, girth, bark thickness, number of leaf flushes retained, number of leaves and rubber yield on test incision emerged as important characters which could be given emphasis in determining the superiority of progenies at the age of one year. Employing these traits simultaneously through the performance index, it was possible to identify nine progenies viz. those of clones AVT 73, RRII 105, PB 86, PB 215, PB 28/83, Ch 32, PB 242, BD 5 and PB 252 as relatively better performers. This also implied the prepotency of the parent clones.

For a more reliable estimate of the yield potential of progenies, traits such as the number of latex vessel rows and rubber yield on consecutive test tappings which are proven early selection criteria (Tan and Subramaniam, 1976; Tan, 1987), were utilized along with vegetative vigour in terms of girth and the number of leaf flushes for computation of performance index at the age of two years. The progenies which ranked superior at the age of two years were those from clones PB 28/83, RRII 105, PB 242, AVT 73, PB 215, Ch 32, Gl 1, Ch 26, PB 252, PB 230, PB 206, PB 217 and PB 5/51.

The percentage recovery of vigorous seedlings as a measure of prepotency has been employed in coconut (Shylaraj, 1982; Thomas Mathew, 1983) and cashew (Susamma et al., 1984). In the present study, the progenies of eleven clones viz., PB 28/83, RRII 105, PB 242, AVT 73, PB 215, PB 252, PB 235, PB 5/51, BD 5, PB 217 and Ch 26 showed a relatively higher recovery of superior seedlings as determined by the index score method utilizing rubber yield on test tapping, girth, number of latex vessel rows and number of leaf flushes at the age of two years. This is another indication of prepotency in the parent clones. Similar studies in cashew (Susamma et al., 1984) revealed a higher percentage recovery of vigorous seedlings from medium yielding trees. The clones included in the present study showed a medium to high yielding trend, but did not differ significantly in the proportion of superior seedlings produced. This result is in conformity with the findings of Bavappa and Ramachander (1967a) based on the study of variability in yield of arecanut within families of mother plams having high, medium and low progeny yields. The high and medium yielding families did not differ significantly in the frequency of high yielding progenies within their families while the low yielding families showed a markedly high frequency of low yielding progenies.

The clones PB 28/83, RRII 105, PB 242, AVT 73, PB 215, Ch 25, PB 252, PB 217 and PB 5/51 which exhibited high performance indices in their progenies and a high percentage recovery of superior seedlings at the age of two years could be considered as likely prepotents.

The coefficient of variation (C.V.) within the twenty progenies in respect of rubber yield on test tapping, girth, number of latex vessel rows and the number of leaf flushes was examined in relation to the mean performance of progenies for these traits. Progenies of eight out of the nine clones identified as likely prepotents exhibited high mean values with a low C.V. in respect of one or more of the four important traits. Progeny of PB 28/83 showed a high mean and low C.V. in respect of three traits viz., rubber yield on test tapping, number of latex vessel rows and number of leaf flushes. Progeny of RRII 105 exhibited high mean and low C.V. in respect of girth and the number of leaf flushes. Progeny of AVT 73 showed high mean and low C.V. in respect of rubber yield under test tapping and girth. Progeny of PB 215 showed a high mean and low C.V. for the number of leaf flushes and that of Ch 26 was in the high mean and low C.V. group for the number of latex vessel rows and the number of leaf flushes. The progeny of PB 252 showed a high mean coupled with low C.V. for rubber yield under test tapping and that of PB 217 showed a high mean and low C.V. with respect to the number of latex vessel rows and number of leaf flushes. The progeny of PB 5/51 was in the high mean and low C.V. group for rubber yield on test tapping.

5.2.4. Early identification of likely prepotents

The possibility of early identification of likely prepotents was examined through simple correlations among seed attributes and seedling attributes at the age of one year and two years. The significant negative relationship between the number of days to seed germination and girth at the age of one year and two years indicates that early germinating seeds produce vigorous seedlings. This is in agreement with the findings of Jayasekera and Senanayake (1971) and Senanayake et al. (1975) that plants grown from early germination seeds had faster growth rates, greater stem girth and larger leaf area upto the age of 18 months than those grown from late germinating seeds. Heavy seeds show early germination as reported by Saraswathyamma and Nair (1976), but the present results showed only a non-significant though negative association of the number of days to germinate with seed weight and germination percentage.

Rubber yield on test incision at the age of one year showed a strong positive association with yield on test tapping at the age of two years, a result which corroborates the findings of Annamma et al. (1989). The strong positive relationship of girth at the age of one year with that at the age of two years is also in agreement with the same report. Bark thickness at the age of one year showed a significant positive association with girth at the age of two years. The number of latex vessel rows at the age of two years showed non-significant but positive associations with traits at the age of one year. These correlations indicate that vigour and yield of one year old seedlings reflect the yield potential and vigour in the subsequent year.

Performance index and rubber yield on test incision at the age of one year showed strong positive correlations with performance index and recovery of superior seedlings at the age of two years. This implies the possibility of identifying likely prepotents at the age of one year thus saving time involved in breeding programmes. A preliminary selection of early germinating seeds could further enhance the effectiveness of the process.

5.3. Inbreeding depression

Inbreeding in cross fertilised species leads to unfavourable biological effects like smaller size, lesser vigour, reduced fertility and an increase in the number of defective types, the intensity of these defects being referred to as inbreeding depression.

Homozygosity resulting from inbreeding leads to the expression of undesirable recessive genes which in turn leads to inbreeding depression. The injurious effects of inbreeding are directly related to the number and kinds of Mendelian characters heterozygous in the original population (Allard, 1960).

As expressed by Simmonds (1985), rubber is an outbreeder highly intolerant of inbreeding. The fact that the inflorescences are self compatible incurs the presence of some selfed plants in the progeny of even an excellent seed garden. The extent of inbreeding in rubber seed gardens and its consequences on the performance of polycross seedlings have not been investigated. The present study was aimed at identifying clones which showed high inbreeding depression in the early stages of development so as to facilitate early culling of inbred seedlings which may occur in the products of polyclonal seed gardens.

Fruit set under selfing was lower than that under open pollination. Clones PB 215, PB 217, PB 5/76 and PB 235 did not set fruit under selfing while a very low percentage of fruit set under selfing was observed for clones AVT 73, PB 86, PB 28/83 and PB 5/51 in comparison with open pollination. It has been reported by Wycherley (1971) and Tan and Subramaniam (1976) that selfing in rubber was ineffective leading to very low fruit set. There is no evidence of self incompatibility in rubber, so the effect must be attributed to zygotic inviability as a consequence of inbreeding (Simmonds, 1986) and the failed seeds might be regarded as very early expressed 'runts' (Simmonds, 1989).

Selfed seeds exhibited late germination and a lower percentage of germination when compared to open pollinated seeds of the clones in general, but the difference was not very marked in many clones. The clones which indicated inbreeding depression with respect to days to seed germination were RRII 105, PB 86, BD 5, Gl 1, PB 5/51, PB 206, PB 230, PB 217 and PB 235. All the clones except PB 206 showed inbreeding depression with respect to germination percentage.

The performance of seedling progeny revealed inbreeding depression for plant height in only four clones viz. AVT 73, PB 252, PB 86 and LCB 1320. Clones RRII 105, BD 5 and PB 206 did not exhibit inbreeding depression for girth. Of the clones evaluated, only PB 252 showed significant inbreeding depression for plant height and girth.

None of the clones exhibited significant inbreeding depression for the number of leaf flushes, number of leaves and juvenile dry rubber yield. However, in terms of numerical differences, selfed progeny were inferior to the open pollinated progeny in the case of PB 242, PB 252, PB 86, LCB 1320, PB 206 and PB 235 for the number of leaf flushes, PB 242, PB 252, BD 5, Gl 1, LCB 1320, PB 206 and PB 235 for the number of leaves and AVT 73, PB 242, PB 252, BD 5, LCB 1320 and PB 235 for juvenile dry rubber yield.

Although inbreeding in rubber was observed by early workers (Sharp, 1940; Ross and Brookson, 1966), biometrical evidence for the phenomenon was put forth only later by Gilbert et al. (1973). Crosses between full sibs showed marked inferiority when compared to outcrossed families. Tan and Subramaniam (1976) reported that selfed progenies were inferior to outcrossed progenies in nursery vigour and yield. They expressed the view that inbreeding effect is evident in rubber, but the degree of inbreeding depression may vary in different clones. Results of the present study revealed no significant inbreeding depression with respect to the five juvenile traits among the clones except in the case of PB 252.

Low fruit set poses a serious hindrance to *Hevea* breeding efforts (Tan, 1987; Kavitha et al., 1990). In the present study , the low fruit set resulted in insufficient size of the progeny for a proper assessment of inbreeding depression for juvenile vegetative traits and rubber yield. It could be inferred that elimination of a significant proportion of inbreds occur at the stage of fruit set and seed germination for which the clones show variation. However a reliable estimation of inbreeding depression for juvenile traits is not possible with the limited data obtained.

5.4. Polyclonal seed garden

The rubber tree is an outbreeding species (Dijkman, 1951; Tan, 1987; Simmonds, 1989). The prevalence of a high degree of outcrossing promotes the production of hybrid seeds of polycross origin. Rubber was propagated entirely by seed until the bud-grafting technique was prefected by Van Helten et al. in 1915. The generation of improved clonal seeds through the establishment of seed gardens was a major development in rubber research in the mid thirties (Subramaniam, 1980). At present all rubber planting involves propagation from seed, whether the seedlings are used as root stock for budding or grown to maturity as seedlings trees. Over the years, the trend has been to replace seedlings with clones but they persist in large areas and are still subject to Class I planting recommendation in Malaysia (Anon., 1990). However, in India, due to the high variability in yield in seedling plantations and the lack of good quality seed gardens for the supply of superior seed materials, seed propagation has been recommended only on a limited scale (Anon., 1991b).

According to Simmonds (1985), the best seedlings well looked after are capable of better yields than ill managed clones. He has further enumerated the reasons for maintaining a steady flow of improved seed gardens as (1) good seedlings have agricultural merits even if they are behind the best clones, (2) large seedling populations constitute a valuable genetic resource of advanced material open to ortet/plus tree selection, (3) outbred seedlings should be used as root stock, and (4) rubber fields could be planted on a dual purpose basis: for tapping and for timber for which good quality seedlings are best suited.

Polycross seed material referred to as 'multiparent first generation synthetic varieties (SYN_1)' by Simmonds (1989) being heterogenous due to the wide array of gene combinations derived from superior parent clones have potential for stability of performance under adverse environments like those encountered in the non-traditional rubber growing areas of India. Polycross breeding programmes involving combining ability test, random mating in isolated seed gardens and application of selection index in the nursery followed by clonal selection are gaining importance in rubber (Naijian and Jingxiang, 1990).

In the early years, mixtures of phenotypically superior clones were planted in seed gardens in the hope of random interpollination and a high G.C.A. component of performance (Simmonds, 1986). The clones were planted in layouts designed to promote random crossing. A low level of selfing in seed gardens was considered desirable not only on account of the inferior performance of selfed progenies but also because most clones set more seed when cross pollinated than when selfed, although a few were equally fertile whether crossed or selfed (Wycherley, 1971).

According to Simmonds (1989) the choice of components of a polyclonal seed garden should be from an array of potential parent clones having high general combining ability. In principle, more parents should enter a seed garden to keep inbreeding down and the choice would be best based on G.C.A. estimates coupled with parental performance. To maximize the production of cross pollinated seed it is desirable that clones in a garden show synchronous flowering. Inbreeding could be reduced by planning the seed garden layout in such a way that the design facilitates crossing in all possible combinations among the component clones.

Salient findings of the present studies on prepotency and genetic divergence summarised in table 46 indicate scope for the selection of a set of clones as polyclonal seed garden components. The study on inbreeding depression, apart from indicating a low fruit set under selfing than under open pollination in most clones, could not provide valid inferences on the expression of inbreeding depression for juvenile traits.

Nine clones viz. PB 215, PB 5/51, PB 28/83, Ch 26, PB 217, RRII 105, PB 252, PB 242 and AVT 73 established as likely pre-potents based on performance index of their progenies and the recovery of superior seedlings were found distributed in three genetically divergent clusters. These clones exhibited promising yield trend and superiority with respect to various yield components. Clone PB 215 was superior with respect to virgin bark thickness, renewed bark thickness, girth and girth increment rate. PB 5/51 was superior for dry rubber content during the three periods. PB 28/83 was superior with respect to yield depression under stress, D.R.C. and plugging indices during the three periods and virgin bark thickness. Of the five likely prepotents in

Table 46. Promising clones in various clusters.

Cluster No.	Clonesassessed for prepotency	Traits of superiority	Dry rubber yield (g tree^{-1} tapping^{-1})
I	Ch 32	P.I.(2)	31.76
	BD 5	R.B.T.	29.94
II	PB 215*	V.B.T., R.B.T., G., G.I.	54.67
	PB 206	--	47.01
	Gl 1	V.B.T., R.B.T.	46.03
	LCB 1320	D.R.C.(1,2)	57.68
	PB 5/51*	D.R.C.(1,2,3), V.B.T.	56.05
	PB 230	V.L.(1,3), F.R.(3), D.R.C.(3), G.I.	57.77
	PB 5/76	D.R.C.(1,2,3), F.R.(2)	63.65
	PB 28/83*	Y.D., D.R.C.(1,2,3), V.B.T., P.I.(1,2,3)	63.36
III	Ch 26*	P.I.(1,2,3), V.L.(1,3)	66.64
	PB 217*	Y.D., F.R.(1,2,3), V.L.(1,2,3), G.I.	71.19
	RRII 105*	F.R.(1,2,3), V.L.(1,3)	68.20
	PB 252*	F.R.(1,2,3), V.B.T., R.B.T., V.L.(1,2,3)	67.13
	PB 242*	V.B.T., R.B.T.	62.94
IV	PB 86	Y.D.	48.16
	Ch 153	R.B.T.	52.95
VI	AVT 73*	G., G.I., Y.D., P.I.(1,2)	43.26
VII	Ch 2	D.R.C.(2), G.I.	46.87
VIII	PB 235	V.L.(1,2), G., G.I., V.B.T., P.I.(1,2), F.R.(2)	77.01

*Likely prepotents.

Figures in parenthesis: 1 - annual; 2 - stress; 3 - peak.

D.R.C. - Dry rubber content; R.B.T. - Renewed bark thickness; F.R. - Latex flow rate; V.B.T. - Virgin bark thickness; G. - Girth; V.L. - Volume of latex; G.I. - Girth increment rate; P.I. - Plugging index; Y.D. - Yield depression under stress.

cluster III, clone Ch 26 was superior for plugging index during the three periods, annual mean volume of latex and peak volume of latex. PB 217 was superior for yield depression under stress, girth increment rate and latex flow rate and volume of latex during the three periods. RRII 105 was superior for latex flow rate during the three periods and annual mean and peak volume of latex. PB 252 was superior for latex flow rate and volume of latex during the three periods, virgin bark thickness and renewed bark thickness. PB 242 was superior for virgin bark thickness and renewed bark thickness. Clone AVT 73 of cluster VI, though only a medium yielder was superior with respect to girth, girth increment rate, yield depression under stress, D.R.C. under stress, annual mean plugging index and plugging index under stress.

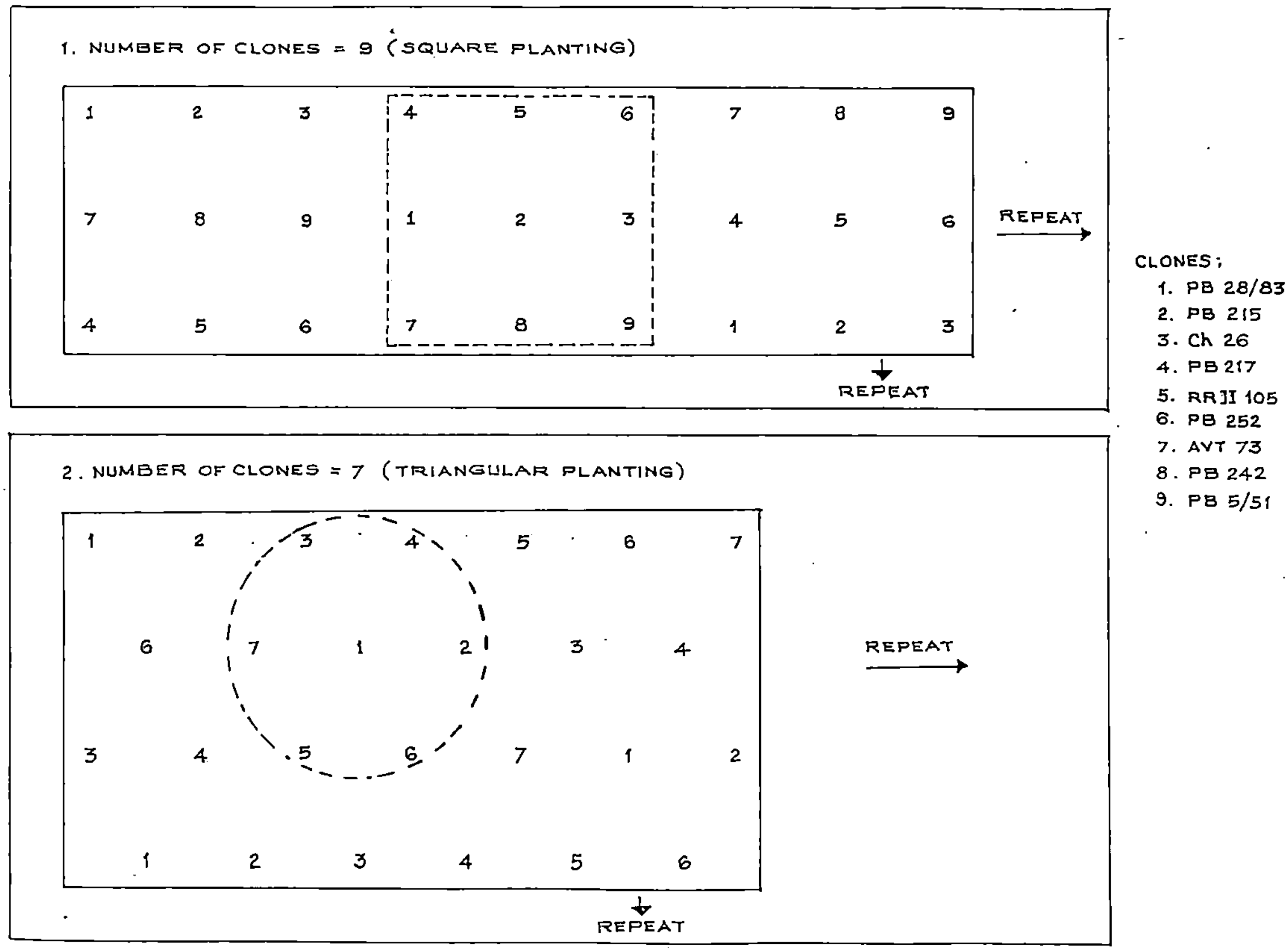
The clone PB 235 though the highest yielder with a mean yield of 77.01 g tree^{-1} tapping^{-1} and superior for a number of traits, showed below average progeny performance. The results indicate that all high yielding clones need not necessarily be prepotent while medium yielders (e.g. AVT 73 and PB 5/51) could possess prepotency.

The nine clones classified as likely prepotents were superior with respect to various yield components and so if used as seed garden components, could produce superior seed material with a wide array of combinations of all the optimum genes for increasing dry rubber production. All the clones except RRII 105, PB 252 and AVT 73 were of the intermediate flowering type and exhibited 50 per cent flowering during the 3rd and 4th weeks of February. The clones RRII 105, PB 252 and AVT 73 though classified as early flowering types exhibiting 50 per cent flowering in the 2nd week of February had a flowering spread of 12 to 14 days. Flowering in these clones could therefore be expected to coincide with the rest.

Seed garden layouts with nine and seven component clones adapted from Simmonds (1986) are represented in figure 33. The clones suggested for inclusion in a nine component polyclonal seed garden are RRII 105, AVT 73, PB 252, PB 215, PB 217, PB 28/83, Ch 26, PB 242 and PB 5/51. As indicated in the figure, each clone is surrounded by every other clone in the garden and this maximises chances of outcrossing. For a seed garden composed of seven parent clones, two among the likely prepotents that could be excluded are PB 5/51 which was a medium yielder with superiority for only one trait and PB 242 though a high yielder, did not figure in the high mean and low C.V. group with respect to any of the important juvenile traits. Hence a seven component seed garden may exclude clones PB 5/51 and PB 242.

Significant clonal variation for twenty two attributes and the estimates of genetic parameters indicated the existence of considerable genetic variability among the clones studied. The relative importance of various components and their contribution

FIG.33. LAY OUT OF POLYCLONAL SEED GARDENS.



Adapted from Simmonds (1986)

towards dry rubber yield were evident from the correlation estimates and the cause and effect relationships. The forty clones were grouped into eight genetically divergent clusters irrespective of their country of origin indicating the absence of any relationship between genetic divergence and geographic diversity. The yield factor was identified as the main factor of divergence. Seedling progeny analysis of twenty promising clones from various clusters revealed nine clones viz. RRII 105, AVT 73, PB 252, PB 215, PB 217, PB 28/83, Ch 26, PB 242 and PB 5/51 to be likely prepotents. No significant inbreeding depression was evident for juvenile vegetative traits and rubber yield in progenies. The nine likely prepotents showed synchronous flowering and possessed superiority for yield and various yield components. These clones are therefore suggested for inclusion in a polyclonal seed garden. Appropriate seed garden layouts are also suggested.

SUMMARY

SUMMARY

This study on genetic divergence, prepotency and inbreeding depression in rubber was undertaken at the Rubber Research Institute of India during 1988 to 1991 with the objective of identifying parent clones as components of polyclonal seed gardens for the generation of superior polycross seed material. Forty clones of Indian, Indonesian, Malaysian and Sri Lankan origin at the fourth year of tapping were assessed for the extent of genetic variability with respect to various physiological, morphological and structural traits. Dry rubber yield and its physiological components were determined separately over three periods viz. as mean for the year, for the stress period and for the peak yield period. The associations among all traits at the genotypic and phenotypic levels were determined. The cause and effect relationships of dry rubber yield and its components during the three periods were determined through path coefficient analysis. Genetic divergence among the forty clones was estimated employing the Mahalanobis' D^2 technique. Principal factor analysis in two genetically divergent clusters helped in identifying the factors of divergence. Twenty promising clones from genetically divergent clusters were assessed for prepotency through seedling progeny analysis. Inbreeding depression of the same clones in respect of fruit set and the performance of seedling progenies was studied.

Significant clonal variation was revealed in respect of all the traits studied. The high values of genotypic coefficients of variation for volume of latex under stress, dry rubber yield during the three periods and plugging index under stress revealed high genetic variability for these traits. Moderate to high heritability coupled with high genetic advance was recorded for traits like dry rubber yield, latex flow rate and volume of latex during the three periods, girth increment rate under tapping, annual mean plugging index and plugging index under stress. This indicates the predominance of additive gene action for these characters and implies that their improvement through selection would be effective. The high heritability with low genetic advance recorded for dry rubber content during the three periods, girth, virgin bark thickness and renewed bark thickness reveal the involvement of non-additive gene action. Improvement of these traits could be achieved through hybridisation.

The assessment of wintering and flowering attributes revealed variation among clones. The clones were classified into early, intermediate and late wintering and flowering types. It was possible to identify clones with synchronous flowering, an attribute desirable for the components of a polyclonal seed garden.

At the genotypic and phenotypic levels, strong positive correlations of annual mean dry rubber yield with dry rubber yield during the stress and peak periods and volume of latex, dry rubber content and latex flow rate during the three periods were recorded. The genotypic and phenotypic correlations of annual mean dry rubber yield with yield depression under stress and plugging indices during the three periods were negative. Girth, length of tapping panel and virgin bark thickness exhibited moderately high positive genotypic and phenotypic correlation with dry rubber yield during the three periods.

Path analysis enabled the partitioning of genotypic correlation coefficients of different components with dry rubber yield into direct and indirect effects. Dry rubber yield during the stress and peak periods differed in their direct effects on annual mean dry rubber yield, the former being more important, with a higher direct effect. Latex flow rate during the peak yield period followed by annual mean volume of latex, dry rubber yield under stress and latex flow rate under stress were the components which exhibited high positive direct effects which accounted for their high positive genotypic correlation with annual mean dry rubber yield. The negative direct effect and negative genotypic correlation of plugging index during the peak period with annual mean dry rubber yield also explains a true relationship. Annual mean latex flow rate, peak volume of latex, volume of latex under stress, girth increment rate and virgin bark thickness though positively correlated with annual mean dry rubber yield had negative direct effects implying the indirect effects to be the cause of the correlation.

The physiological components in general exhibited high magnitudes of genotypic correlations and direct effects on dry rubber yield. A separate analysis of the cause and effect relationships of dry rubber yield and its components during the three periods revealed variation in the magnitude and direction of effects of each component under seasonal variation. This implied the involvement of separate gene systems in the expression of yield and its components under different periods of the year.

The physiological, morphological and structural attributes having high genetic variability were identified along with their relationships with dry rubber yield. The involvement of different genes with additive and non-additive effects in the inheritance of these traits was also indicated. These attributes were therefore utilized for the estimation of genetic divergence among the forty clones.

The clones were grouped into eight genetically divergent clusters. The existence of considerable genetic diversity was revealed by the wide range of D^2 values and inter and intra cluster distances. Clones from different countries were grouped in the same cluster and vice versa indicating the absence of any relationship between geographic diversity and genetic divergence. This could be attributed to the limited geographic area from which the base population of the present day clones originated. Moreover, they are only two or three cycles of selection ahead of the original material. The free exchange of breeding material among rubber growing countries and clonal propagation are factors limiting divergence at the secondary centres. Volume of latex, plugging index, dry rubber content and dry rubber yield contributed more towards genetic divergence. This was supported by the results obtained from factor analysis in clusters I and II. The yield factor comprising dry rubber yield, latex flow rate, volume of latex, length of tapping panel and plugging index as the components common in both the clusters was identified as the main factor of divergence.

Prepotency is particularly relevant in a polycross breeding programme in which superior seed materials have to be generated through open pollination. Seedling progeny analysis of twenty clones from genetically divergent clusters enabled the estimation of prepotency through a performance index and the percentage recovery of superior seedlings in each progeny. At the age of one year, progenies revealed significant variation for foliar traits, bark thickness and rubber yield on test incision but not for plant height and girth. The superiority of the progeny of clones AVT 73, RRII 105, PB 86, PB 215, PB 28/83, Ch 32, PB 242, BD 5 and PB 252 was indicated from their performance indices.

Seedling progeny analysis at the age of two years revealed significant variation among progenies with respect to juvenile traits such as girth, number of latex vessel rows, number of leaf flushes and rubber yield on test tapping. Estimates of genetic parameters revealed relatively high genotypic coefficient of variation for rubber yield on test tapping, number of leaf flushes and number of latex vessel rows. These three traits also exhibited relatively high heritability and genetic advance indicating additive gene effects while girth recorded high heritability with a low genetic advance indicative of non-additive gene effects. Girth, number of latex vessel rows and number of leaf flushes exhibited highly significant positive correlation with dry rubber yield on test tapping which is an important early selection criterion in rubber. These four traits were given simultaneous emphasis in computation of the performance index and determination of the percentage recovery of superior seedlings. Nine clones viz. PB 28/83, PB 215, RRII 105, AVT 73, PB 217, PB 252, Ch 26, PB 242 and PB 5/51 which exhibited relatively high values of performance index coupled with a high percentage recovery of superior seedlings in their progeny, were identified as likely prepotents. Moreover, the progenies of all the clones except PB 242 exhibited high mean values coupled with low coefficients of variation in respect of one or more of the traits, which further indicated prepotency.

The results of the study on inbreeding depression showed fruit set under selfing to be lower than that under open pollination in general. However, no significant inbreeding depression was evident with respect to juvenile traits and rubber yield on test incision in seedlings except for plant height and girth in the progeny of clone PB 252.

Prepotency/general combining ability could provide a sound basis for the identification of seed garden components. The nine clones identified as likely prepotents were included in three genetically divergent clusters and they possessed superiority with respect to dry rubber yield and its various components. Synchrony in flowering among these clones was also recorded from the study of flowering attributes. A suitable seed garden layout to facilitate crossing in all possible combinations of the component clones could minimize the ill effects of inbreeding that may occur. All the nine likely prepotent clones viz. PB 28/83, PB 215, RRII 105, AVT 73, PB 217, PB 252, Ch 26, PB 242 and PB 5/51 are suggested for incorporation in a nine component polyclonal seed garden. For a seven component seed garden, the two clones that could be excluded are PB 5/51 and PB 242. The inclusion of such superior clones in a polyclonal seed garden could help in the pooling of genes governing the various yield components as well as those conferring stability of performance under seasonal variation. This would result in the generation of good quality polycross seed material. Appropriate seed garden layouts for nine and seven clones have been indicated.

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*Originals not seen.

APPENDIX

APPENDIX

D2 VALUES

	1	2	3	4	5	6	7	8	9	10	
1	0.00	46777.07	8024.28	37662.94	4536.91	100724.30	4686.22	31342.70	67770.93	182039.20	1
2	46777.07	0.00	43305.60	5651.05	51852.62	19232.10	25004.88	9204.55	7118.42	52611.33	2
3	8024.28	43305.60	0.00	33735.64	1428.27	77272.70	10157.65	31559.38	51237.11	183054.20	3
4	37662.94	5651.05	33735.64	0.00	38035.04	35957.92	11147.33	5542.32	19510.98	69625.95	4
5	4536.91	51852.62	1428.27	38035.04	0.00	93825.05	9951.88	36905.59	65651.51	199143.80	5
6	100724.30	19232.10	77272.70	35957.92	93825.05	0.00	66791.88	30819.34	8542.35	45421.62	6
7	4686.22	25004.88	10157.65	11147.33	9951.88	66791.88	0.00	12936.10	42020.94	131234.60	7
8	31342.70	9204.55	31559.38	5542.32	36905.59	30819.34	12936.10	0.00	21236.42	71069.63	8
9	67770.93	7118.42	51237.11	19510.98	65651.51	8542.35	42020.94	21236.42	0.00	55927.28	9
10	182039.20	52611.33	183054.20	69625.95	199143.50	45421.62	131234.60	71069.63	55927.28	0.00	10
11	108114.10	21218.24	89777.18	37612.65	106814.90	4975.90	70704.31	31298.60	10984.13	31609.38	11
12	2942.42	30851.38	4602.54	17552.64	4941.22	73605.33	2101.68	20575.78	44715.02	152732.20	12
13	7290.77	32185.62	22294.75	13977.02	19193.73	84342.01	3273.65	16654.10	57280.96	131971.90	13
14	11990.13	18741.51	7267.25	12717.09	11664.79	51571.75	6150.39	16645.25	26412.15	135197.40	14
15	122236.50	21196.55	106538.80	40455.09	124280.40	9506.72	93172.68	49371.01	11094.60	24505.33	15
16	32865.53	64659.20	52635.72	39019.05	43315.49	134143.60	22274.53	41746.45	105035.20	164367.50	16
17	16231.07	35436.91	3305.66	30194.36	7939.37	57546.07	17283.55	22727.33	28671.87	158745.50	17
18	107969.50	15913.98	94274.91	22593.59	109978.50	5996.77	70454.41	22041.91	9947.99	23041.95	18
19	57701.25	4253.10	56439.88	14775.61	69529.51	9046.18	39917.11	16412.61	1464.70	43695.53	19
20	116667.10	20993.09	116257.70	21959.41	129507.40	23350.72	76967.51	35291.33	23790.90	5350.55	20
21	61873.77	34867.04	84086.68	22745.54	83669.16	73584.09	39026.99	21278.61	65512.17	63600.60	21
22	92897.41	16011.32	97468.15	20791.02	107405.40	27204.53	57747.10	22919.91	35720.39	16692.02	22
23	52079.76	7282.22	58312.51	5152.79	64482.64	29510.39	36838.68	7637.44	10782.01	40447.34	23
24	4230.14	66404.22	5710.28	47244.88	2183.36	119619.80	14763.99	49048.67	84219.09	225744.50	24
25	43782.72	44904.73	69952.31	25553.83	65630.24	95430.25	29639.48	73837.61	20097.22	89268.24	25
26	6921.65	25284.94	13635.39	11712.26	12718.87	66030.09	1247.69	13105.62	44633.85	126446.00	26
27	60202.75	7036.54	68457.10	8042.65	74825.65	36320.96	35979.17	19703.07	20141.87	40903.12	27
28	178079.40	47303.59	162940.10	70812.19	183735.10	23009.91	127412.70	67679.87	26761.34	10011.59	28
29	185724.70	50869.49	165547.80	78323.75	187203.40	20658.19	134178.80	73792.36	38055.45	14953.09	29
30	50185.27	4885.64	46565.85	5470.68	54635.21	18124.73	26659.45	12973.26	9375.05	53306.22	30
31	8069.99	22403.04	14097.45	10627.82	14330.49	67838.50	4207.49	30676.35	37304.21	129608.10	31
32	131538.90	29861.19	107657.40	51844.54	127320.10	4271.76	90460.49	46107.15	14445.10	33290.27	32
33	34521.15	16586.94	17619.34	20690.96	26523.93	22961.08	19416.81	12021.09	14972.85	103913.00	33
34	144756.70	46809.29	107578.30	76365.33	130657.40	19329.79	110579.90	77205.54	19619.32	54281.79	34
35	13492.50	49640.64	1554.19	41636.38	4001.05	81030.68	16320.20	41750.89	52669.17	196675.10	35
36	11276.54	20566.00	23164.91	6987.03	22039.55	65458.00	3895.42	12975.51	40976.99	110641.50	36
37	165790.20	54237.08	165982.40	66781.11	179926.20	42559.12	116953.60	56550.15	60987.19	8225.17	37
38	71399.48	5826.32	69750.53	12207.59	79975.56	15763.96	41205.35	14919.04	11178.45	35169.40	38
39	43720.59	12897.23	24810.97	20771.58	36321.88	19755.17	27226.11	13981.58	6274.83	96384.30	39
40	157041.80	72462.50	181491.90	68506.10	185951.40	91335.86	114523.50	68531.55	95464.03	30102.57	40

	11	12	13	14	15	16	17	18	19	20	
1	105114.10	[illegible]	7390.77	[illegible]	[illegible]	[illegible]	16331.07	107563.50	67701.25	116567.10	1
2	21218.34	[illegible]	30187.92	13741.51	[illegible]	54659.27	25436.91	10922.92	4803.10	20993.09	2
3	39777.18	4600.94	20294.75	7367.25	105519.90	50535.72	3205.66	94074.91	50439.55	117257.70	3
4	37515.95	17590.64	10327.02	12717.09	40455.30	36019.99	30194.36	32593.70	14755.61	31959.41	4
5	106014.90	4841.27	12190.73	11054.92	104280.40	43315.49	7939.37	109978.50	69529.51	129537.40	5
6	4975.90	71605.33	54142.01	51571.75	[illegible]	134343.00	57546.07	5595.77	9046.19	33350.72	6
7	70704.91	2101.63	3223.69	6120.35	89172.69	12274.87	10283.75	70454.41	39017.11	76967.51	7
8	31205.60	30575.75	16654.10	19646.24	53371.01	41746.45	22727.33	30041.91	16412.61	25291.30	8
9	10984.17	49715.02	57280.95	26412.12	11094.60	105036.20	38671.27	9947.99	1464.76	13790.90	9
10	91609.25	152732.20	131971.90	125197.40	[illegible]	164367.50	155745.50	23041.55	43635.53	5360.55	10
11	0.00	79428.46	85011.94	58642.25	7755.48	130502.40	67479.20	5328.46	8237.09	14521.93	11
12	79428.46	0.00	5219.06	4319.45	92662.87	32335.72	9125.01	51207.07	45554.30	92251.65	12
13	85011.94	2318.06	0.00	16559.47	97361.49	9775.50	26449.74	83610.99	52011.26	80360.87	13
14	58642.35	4319.45	16559.47	0.00	65303.06	47323.17	7699.14	59274.62	25275.95	72963.96	14
15	7755.48	92662.82	97361.49	65303.06	0.00	145323.30	87077.51	1679.13	8873.71	9677.18	15
16	133502.40	32338.72	9775.53	47323.17	145355.30	0.00	52930.40	126356.60	94708.19	113534.30	16
17	67479.20	2125.01	26449.74	7699.14	87077.51	62920.40	0.00	75716.09	42741.55	98212.14	17
18	5328.46	91207.07	52610.99	59274.62	1679.13	126355.60	75716.09	0.00	6741.93	7381.75	18
19	8237.09	45554.39	52011.86	28275.98	8873.71	94708.19	42741.56	6741.93	0.00	15542.97	19
20	14521.93	92251.65	80360.97	72963.96	9677.19	113534.30	98215.14	7351.78	15542.97	0.00	20
21	65817.32	57534.74	27968.53	60010.04	75307.10	29337.84	78407.41	59307.24	51761.79	41456.01	21
22	20504.32	74239.04	59469.49	58507.04	17425.42	52449.31	97046.11	11571.77	15903.47	3938.16	22
23	25021.95	38738.32	27340.72	30703.01	27627.84	40692.62	49257.35	19503.39	12306.03	14445.25	23
24	130946.70	9240.97	21455.49	17515.30	148757.50	40797.31	16005.03	133785.50	97567.30	151323.90	24
25	90030.04	46311.56	16574.03	54129.76	102817.50	13292.57	52915.28	84237.26	67174.29	65624.95	25
26	70151.95	5100.65	3296.13	9014.60	53569.90	15462.57	15509.35	69527.47	41553.11	74511.32	26
27	33421.43	46128.74	36972.29	35034.52	25626.05	59967.60	63269.14	21190.71	14351.19	14907.78	27
28	14762.25	143610.90	139025.90	117772.70	9553.20	197303.30	135033.90	10917.20	29742.59	11636.09	28
29	13852.09	149178.40	142050.10	112624.60	1406.72	192237.70	177283.80	17423.08	32562.13	17014.50	29
30	20152.61	34247.19	34297.54	23246.57	19920.05	65602.00	79364.91	13842.01	6751.55	10327.32	30
31	72823.96	4260.94	8304.50	5518.22	76610.70	30164.03	19279.46	67608.93	37229.73	74007.66	31
32	3966.32	99726.95	105613.50	72923.97	4411.60	152609.00	53780.01	4157.90	13131.72	19049.37	32
33	31800.83	19553.63	34724.71	11427.07	45782.05	75977.45	8017.84	26958.91	17701.06	57718.42	33
34	27809.11	109393.10	139556.20	75964.55	20151.53	210707.50	97144.03	36470.10	37195.33	55231.46	34
35	95266.99	8752.72	32299.59	9766.93	110262.10	67378.13	5737.31	99771.26	60672.24	125250.40	35
36	68558.74	8683.60	2757.61	12913.66	74516.06	19057.91	25930.37	61957.67	37266.14	52086.04	36
37	29730.00	140203.50	116428.60	121522.50	36309.61	143022.90	139797.20	28232.27	47141.13	15291.66	37
38	12401.40	52355.91	46490.36	38342.63	11965.55	77564.72	57601.95	5937.05	5351.64	6933.50	38
39	27128.11	25262.69	45163.17	11260.62	33760.45	91817.70	16083.61	29949.81	11043.54	51333.09	39
40	76074.75	143566.20	100193.50	135652.30	75419.63	102191.30	166264.40	32817.71	76651.06	33658.07	40

	21	22	23	24	25	26	27	28	29	30	
1	61873.77	91597.41	53079.76	4230.14	43795.72	6911.68	60202.05	175078.40	155226.70	50155.27	1
2	34867.04	15011.30	7282.72	65404.02	41904.73	75264.04	7036.54	47303.58	50869.49	4382.64	2
3	64096.66	97469.15	55512.41	5710.35	69951.31	13335.33	55497.10	162940.10	165547.30	45565.55	3
4	22745.54	70781.03	8168.79	47144.83	28052.87	11711.26	6042.65	70812.19	72383.75	8470.58	4
5	83659.16	107405.40	64490.64	2152.36	55030.24	12711.57	74525.65	193735.10	197203.40	54635.21	5
6	73524.09	37204.43	29510.29	116619.80	95410.35	66060.09	56320.98	23702.91	20558.19	18124.73	6
7	39056.99	57747.10	26523.65	14363.96	29629.46	1247.09	35970.17	127412.70	134175.90	30653.45	7
8	21272.61	21719.91	7637.44	42049.87	23237.61	13105.60	19703.07	67679.27	73799.36	12873.24	8
9	65512.17	25720.39	19752.01	64216.09	50097.22	44633.55	20141.57	36761.34	38055.45	9375.05	9
10	33500.60	16692.02	40447.34	225744.30	95218.24	125440.03	40903.12	10011.69	14853.09	53306.22	10
11	65817.55	23504.32	25021.95	130940.70	90230.54	77151.57	33471.43	14762.25	13855.09	20165.61	11
12	57734.24	74039.04	32732.28	2240.67	45421.76	5105.67	46173.74	143613.90	149178.40	34247.19	12
13	27985.53	55465.49	27340.72	21655.49	10174.07	1091.13	30352.39	139028.60	145050.10	34257.94	13
14	60010.04	58867.04	30709.01	17515.30	64129.76	9814.60	35034.52	113762.70	118094.60	23246.50	14
15	75305.10	17423.42	27627.84	148707.30	102317.50	53649.90	25626.05	9582.20	11496.75	19930.06	15
16	29322.84	83449.31	49698.62	40797.31	15232.67	12461.57	59967.60	127303.30	159237.50	65603.00	16
17	78407.41	93046.11	49267.25	16005.03	68915.85	16509.35	65269.14	135033.90	137293.80	39364.51	17
18	50307.24	11571.77	19503.30	153735.50	34227.26	69517.47	21190.71	10917.20	12483.02	13343.01	18
19	51181.79	15903.47	12305.03	57567.30	67124.36	41551.11	14251.19	29742.59	32568.13	6751.55	19
20	41456.01	3832.16	14445.25	151323.90	56674.25	7811.33	14307.72	11626.09	17014.50	20327.22	20
21	0.00	33774.93	14876.57	93855.65	5304.27	33223.49	26513.72	50792.08	96398.93	35220.24	21
22	33774.93	0.00	6431.05	125724.10	43811.15	55025.34	10055.37	23035.24	30386.48	15067.65	22
23	14876.57	6431.05	0.00	78234.58	24783.96	25271.31	5437.49	45333.87	52636.78	7037.83	23
24	93855.62	125724.10	78234.58	0.00	71204.88	17420.37	88059.01	213173.30	218467.40	70571.76	24
25	5304.27	43811.15	24783.96	71204.88	0.00	25407.67	35062.56	123939.40	135946.40	47016.73	25
26	33223.49	55025.34	25271.31	17420.37	25407.87	0.00	34869.56	125597.20	130673.50	25060.89	26
27	26513.72	10055.37	5437.49	88059.01	35062.56	34869.56	0.00	48411.01	55504.60	8503.02	27
28	86792.08	23035.24	45333.87	213173.30	123939.40	125597.20	48411.01	0.00	2356.43	45931.78	28
29	96355.93	30356.48	52636.78	210461.40	135946.40	130673.50	55504.60	2356.43	0.00	48071.56	29
30	35220.24	15067.65	7037.83	70571.76	47016.73	25060.89	8503.02	45931.72	48071.56	0.00	30
31	49941.55	58576.17	29259.43	19530.55	40659.19	6099.96	28721.03	126022.20	132630.60	23357.69	31
32	86248.92	26595.76	36814.54	154537.60	115163.30	93435.51	42423.29	10491.82	9477.55	26629.00	32
33	62675.42	49397.41	28924.56	41065.37	64677.25	21942.47	40729.13	50605.79	51465.95	15531.93	33
34	149174.10	59178.79	73557.79	157256.50	175431.30	115677.10	68993.06	44110.28	40610.25	47942.00	34
35	102390.70	109176.80	65566.13	8437.08	55262.14	31136.10	75459.50	171439.90	172655.40	51241.64	35
36	27235.37	45130.90	18431.03	27578.49	19930.54	4176.72	23666.17	115377.90	123536.20	21123.09	36
37	47041.50	17453.16	36365.65	205911.00	75040.99	110340.50	49377.55	15545.12	22533.19	52715.45	37
38	29152.52	4441.36	4266.93	97323.02	46671.81	39207.45	6505.95	26481.39	30216.21	4452.61	38
39	75593.55	47678.43	30568.00	50550.58	51679.97	30734.35	34551.67	70927.85	71387.57	15564.42	39
40	26655.52	25507.10	39374.16	204785.00	42799.20	105452.70	48530.31	62744.07	73782.10	65756.25	40

	31	32	33	34	35	36	37	38	39	40	
1	8069.99	131535.90	34521.19	144756.70	13492.50	11370.54	155790.20	71399.49	43720.59	157041.90	1
2	22402.04	29361.19	16526.94	46309.29	49640.64	20566.00	54207.02	9216.32	12297.29	72462.50	2
3	14097.45	107657.40	17619.34	107579.20	1554.19	23164.91	155982.40	59750.53	24510.97	181491.90	3
4	10627.22	51244.54	20690.96	75365.33	41636.32	6927.03	66781.11	12207.59	20771.52	68509.10	4
5	14330.49	127320.10	26503.02	130557.40	4001.05	22035.55	179976.20	79976.56	36321.95	195951.40	5
6	67832.60	4371.76	22961.02	19329.77	81030.62	66452.00	42059.12	15752.96	19755.17	91335.96	6
7	4202.49	90460.49	19416.61	110579.90	16520.20	3596.40	115953.60	41205.29	27226.11	114623.50	7
8	20675.35	46107.15	12021.09	77205.64	41750.28	12975.51	56750.15	14919.04	19981.58	82531.22	8
9	37304.21	14445.10	14972.58	19619.32	53669.12	40976.96	60957.19	11126.45	5574.53	95454.03	9
10	129609.19	33290.27	103913.00	24221.79	196525.10	110641.50	9235.17	28169.40	96324.30	30101.87	10
11	72923.96	3866.22	31900.53	27509.11	95366.99	69555.74	20730.00	12401.40	27129.11	76074.75	11
12	4260.94	99729.95	19552.63	109393.10	8752.71	2623.60	140203.50	52255.91	25262.69	143566.20	12
13	9304.50	108613.50	34724.71	139556.20	32299.59	2757.61	116425.60	46490.36	45163.17	100192.50	13
14	5512.32	72933.97	11487.02	75364.82	9766.92	12913.62	121522.60	38242.63	11260.68	135653.30	14
15	76610.70	4411.69	45782.05	20151.53	110262.10	74916.06	36309.61	11995.55	33766.49	75419.63	15
16	30164.02	162602.00	75372.45	210727.20	67378.12	12057.91	149092.90	77524.72	91817.70	102191.30	16
17	19279.46	93780.01	5017.94	57144.02	5732.31	25972.37	139797.20	57501.95	16063.31	166364.40	17
18	67602.93	4180.90	36952.91	26470.10	99771.26	62957.67	28232.27	6937.05	22949.81	62817.71	18
19	37329.73	13131.73	17701.06	27199.32	60672.24	37366.14	47141.12	5351.64	11042.54	75351.06	19
20	74007.66	18649.37	57718.42	56231.46	126250.40	62022.04	15291.66	6292.50	51333.05	33658.07	20
21	45941.55	86248.92	62675.42	149174.10	102390.70	27235.37	47041.50	29152.62	75853.59	26655.51	21
22	52576.17	26595.76	49297.41	69176.79	109176.80	45130.90	17423.16	4441.36	47672.42	25507.10	22
23	28298.43	36814.64	29924.26	72557.75	65566.12	15431.03	36269.69	4266.93	30569.00	39274.16	23
24	18536.55	154527.60	41065.27	157256.50	8437.02	27572.49	205911.00	97382.08	50500.52	204782.00	24
25	40659.19	115168.30	64677.35	175431.00	99282.14	19930.54	78040.99	46671.91	81675.37	45799.22	25
26	6099.96	90405.62	21842.47	115637.10	21126.10	4176.72	110240.50	29207.48	30794.19	105452.70	26
27	29721.03	42493.29	40729.13	65993.06	76409.50	22666.17	49377.55	6505.95	34551.67	49520.31	27
28	126022.20	10491.82	90602.72	44110.22	171439.90	116377.90	12545.12	26421.39	70927.26	62744.07	28
29	132630.90	9477.53	91465.96	40610.25	172658.40	123536.20	22533.19	30215.21	71297.57	73752.19	29
30	22357.69	36629.00	18231.93	47942.06	51341.24	21123.09	52716.45	4452.62	16564.41	65753.25	30
31	0.00	39803.28	24708.68	99842.06	17691.92	4079.51	126299.80	39833.90	25420.53	121423.20	31
32	39803.28	0.00	41490.24	17766.44	111209.90	87582.86	36277.16	19124.17	33976.27	86075.75	32
33	24708.68	41490.24	0.00	49735.46	20899.77	27793.01	90168.38	29367.86	4833.93	124783.40	33
34	99842.06	17766.44	49735.46	0.00	102478.60	113016.30	100271.10	49304.77	31200.64	169900.70	34
35	17691.92	111209.90	20899.77	102478.60	0.00	31196.20	182875.20	77818.35	24999.99	202630.10	35
36	4079.51	87582.86	27793.01	113016.30	31196.20	0.00	102193.00	32699.92	34111.29	89887.89	36
37	126299.80	36277.16	90168.38	100271.10	182875.20	102193.00	0.00	29646.07	94066.70	22023.02	37
38	39833.90	19124.17	29367.86	49304.77	77818.35	32699.92	29646.07	0.00	26231.17	45740.76	38
39	25420.53	33976.27	4833.93	31200.64	24999.99	34111.29	94066.70	26231.17	0.00	133250.10	39
40	121423.20	86075.75	124783.40	169900.70	202630.10	89887.89	22023.02	45740.76	133250.10	0.00	40

GENETIC DIVERGENCE, PREPOTENCY AND INBREEDING DEPRESSION IN PARA RUBBER

(*Hevea brasiliensis* Muell. Arg.)

By

KAVITHA K. MYDIN

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the
requirement for the degree
DOCTOR OF PHILOSOPHY
Faculty of Agriculture
Kerala Agricultural University

Department of Plant Breeding
COLLEGE OF AGRICULTURE
Vellayani, Trivandrum

1992

ABSTRACT

A study on genetic divergence, prepotency and inbreeding depression in rubber was undertaken in an effort to identify clones for use as components of polyclonal seed gardens. Forty clones of Indian, Indonesian, Malaysian and Sri Lankan origin were evaluated in a replicated trial at the Rubber Research Institute of India. Genetic variability, correlations and the cause and effect relationships of dry rubber yield and its components were worked out. Genetic divergence was estimated employing the Mahalanobis' D^2 technique. The factors of divergence were identified through principal factor analysis. Twenty promising clones from genetically divergent clusters were subjected to seedling progeny analyses for the estimation of prepotency based on performance of their open pollinated seedling progenies and inbreeding depression in the first generation of selfing.

Significant clonal variation was revealed in respect of all the physiological, morphological and structural attributes studied as mean values for the fourth year of tapping for the stress period and for the peak yield period. High genetic variability for volume of latex under stress, plugging index under stress, annual mean dry rubber yield and dry rubber yield during the stress and peak periods was indicated by the high estimates of genotypic coefficient of variation. Additive gene effects offering scope for improvement through selection was indicated for dry rubber yield, latex flow

rate and volume of latex during the three periods, girth increment rate, annual mean plugging index and plugging index under stress, by the moderate to high heritability estimates along with high genetic advance for these traits. Non-additive gene action was indicated by the high heritability and low genetic advance for dry rubber content during the three periods, girth and bark thickness.

At both genotypic and phenotypic levels, annual mean dry rubber yield showed moderate to high positive correlations with dry rubber yield during the stress and peak periods, volume of latex, dry rubber content and latex flow rate during the three periods, girth, girth increment rate, length of the tapping panel and bark thickness and negative correlations with yield depression under stress and plugging index during the three periods.

Dry rubber yield under stress emerged as a more important component than peak dry rubber yield by its higher magnitude of positive direct effect on annual mean dry rubber yield. Latex flow rate during the stress and peak periods and annual mean volume of latex exhibited high positive direct effects on annual mean dry rubber yield while plugging index during the peak yield period, volume of latex under stress and girth increment rate had negative direct effects on annual mean dry rubber yield. The magnitude and direction of the effects of the components on dry rubber yield during the three periods varied indicating these relationships to be under different genetic control. Selection for a high dry rubber yield under stress, annual mean volume of latex and latex flow rate during the stress and peak periods and against a high plugging index during the peak period, volume of latex under stress and girth increment rate would help achieve improvement in annual mean dry rubber yield.

Considerable genetic diversity was revealed by the wide range of D^2 values and intra and inter cluster distances. The forty clones were grouped into eight genetically divergent clusters irrespective of their country of origin indicating the absence of any relationship between geographic diversity and genetic divergence. Volume of latex, plugging index, latex flow rate, dry rubber content and dry rubber yield contributed more towards divergence than the morphological and structural attributes. Supporting evidence was obtained from principal factor analysis which revealed the yield factor to be the main factor of divergence with respect to the clusters studied.

Junveile rubber yield on test tapping, number of latex vessel rows and number of leaf flushes in seedling progenies exhibited high heritability and genetic advance indicating scope for their use as early selection parameters, while girth exhibited high heritability and low genetic advance. These three traits showed significant positive correlations with juvenile rubber yield, of which girth exhibited the strongest association. Juvenile rubber yield, number of latex vessel rows, girth and number of leaf flushes were identified as important traits for being accorded simultaneous emphasis in the computation of performance index and index scores for the determination of recovery of superior seedlings as estimates of prepotency. Nine clones were identified as likely preopotents on the basis of seedling progeny analysis at the age of two years.

Selfing resulted in a lower fruit set than open pollination in the clones in general. No significant inbreeding depression was recorded for juvenile vegetative traits and rubber yield in seedlings.

Clones PB 28/83, PB 215, RRII 105, AVT 73, PB 217, PB 252, Ch 26, PB 242 and PB 5/51 were identified as likely prepotents from three genetically divergent clusters. They recorded superiority for yield and various yield components. These clones exhibited synchrony in flowering and are suggested as components of a nine parent polyclonal seed garden. For a seven parent seed garden the clones suggested to be excluded are PB 5/51 and PB 242. A polyclonal seed garden comprising these nine or seven clones as components could generate good quality polycross seed material. Appropriate seed garden layouts have been suggested.

GENETIC DIVERGENCE, PREPOTENCY AND INBREEDING DEPRESSION IN PARA RUBBER (*Hevea brasiliensis* Muell. Arg.)

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The weekly feed-gain ratios and cumulative feed efficiencies revealed poor conversion rates beyond eighth week of age. The cumulative efficiencies at sixth week were 3.2, 3.3 and 3.4 with protein levels 17, 20 and 23 per cent respectively. The ready-to-cook yield at fifth, eighth and tenth week were 66.39, 68.76 and 69.69 per cent respectively. The processing yields and losses, serum protein and haemoglobin levels; and the moisture, crude protein and ether extractives in liver and thigh meat were not significantly influenced by dietary protein and energy levels, and ages at slaughter.

The marketing age in pekin ducks was found optimum at sixth week on the basis of live body weight, feed conversion efficiencies and economics. Based on the above findings it was concluded that White pekin ducks require 20 per cent protein and 2400 K cal ME/kg diet until sixth week of age. In this study, the highest margin of return over feeding cost recorded with the above diet was Rs.10.11 per duckling, at sixth week. Therefore, age for marketing pekin ducks was found ideal at sixth week on feeding medium level of protein with low energy density diet.

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