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Yield and Related Attributes of Certain New Generation Clones of Hevea brasiliensis *Under Large Scale Evaluation*

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Twenty clones comprising 15 of the RRII 400 series, one introduced Prang Besar clone, one tetraploid and three clones with normal morphotype (derived from the progeny of the compact canopy type variant) were evaluated in large scale evaluation trials over a period of 16 years. The components of variance for yield in two virgin panels, growth and structural attributes, heritabilities of traits and their correlations were studied. Rubber yield which stabilised by the fourth year of tapping and yield per unit girth emerged as highly heritable traits with girth, girth increment at immaturity and the number of latex vessel rows being important clonal characteristics, showing positive correlations with yield in the two virgin panels.

Clones RRII 430, RRII 417, RRII 422 and RRII 414 maintained superiority in rubber yield over the high yielding check, RRII 105 over eight years of tapping, justifying their release for wide scale planting in the traditional rubber growing regions of India. Clones RRII 417, RRII 422 and RRII 430 were distinctly superior to RRII 105 in terms of rubber yield per unit girth. These three clones also exhibited wind fastness. Among the promising yielders, clones RRII 414, RRII 422 and RRII 52 maintained high summer yields. Clone RRII 430 recorded a comparatively low incidence of pink disease . PB 330 proved to be a moderately high yielding clone with a rising yield trend and very high timber yield potential. Clones RRII 429 and RRII 422 were superior for the number of laticifers in the bark.

Keywords: correlations; heritability; large scale evaluation; RRII 400 series; yield stabilisation

Genetic improvement programmes employing hybridisation in natural rubber (*Hevea brasiliensis* Willd. ex A. Juss. Müll. Arg.), produce heterogeneous seedling populations which are evaluated in the nursery, following which selected hybrids are cloned and evaluated in a phased manner in small scale trials, large scale trials and on-farm trials[1–2]. *Hevea* breeding in India was initiated in 1954 with the first hybridisation programme which led to the release of the most popular rubber clone RRII 105[3–5]. In the attempt to further improve yield levels and combine high vigour of growth with yield, hybridisation programmes from 1982 onwards incorporated crosses of RRII 105 with parent clones

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possessing high vigour[6–7]. A number of high yielding hybrids of the RRII 400 series were produced from the cross RRII 105 × RRIC 100[7] and the heterotic response for yield, growth and related attributes in the small scale trial was reported[8]. The precocity of certain clones of the RRII 400 series in the large scale evaluation trial has also been reported[9].

Rubber yield is a complex polygenic trait governed by a number of structural, physiological and biochemical parameters. The relationship of yield with such parameters and the heritability of these traits have been studied in various clonal populations[10–12]. A study of such correlations and the estimation of genetic parameters in a population which includes the new generation hybrids of the RRII 400 series would lend further support for the use of these traits as selection criteria.

The present report pertains to the performance of the RRII 400 series along with a few other clones in the pipeline over 16 years after planting and eight years of tapping in the large scale evaluation trial. Genetic variability and correlations among yield, growth and structural parameters as well as their significance in evolving selection strategies is also discussed in the light of heritabilities of these traits.

MATERIALS AND METHODS

Twenty clones were evaluated in comparison with clone RRII 105 in large scale trials laid out in 1993 at the Central Experiment Station of the Rubber Research Institute of India, situated at Chethackal in Central Kerala, India. The material evaluated (*Table 1*) included 15 clones of the RRII 400 series, one introduced Prang Besar clone, one tetraploid and three clones selected from open pollinated progeny of a parent clone with compact canopy. The clones were planted in two adjacent field trials employing randomised block design with 16 trees per plot. In Trial 1, 12 clones were replicated six times while in Trial 2, 10 clones were replicated thrice.

The girth of trees was recorded annually from the 3rd year after planting up to the 16th year and girth increment per year during the

TABLE 1. PEDIGREE OF CLONES EVALUATED IN TWO LARGE SCALE TRIALS

TRIAL 1		TRIAL 2	
Clone	Pedigree	Clone	Pedigree
RRII 402	RRII 105 × RRIC 100	RRII 410	GT 1 × RRIC 100
RRII 403	”	RRII 422	RRII 105 × RRIC 100
RRII 407	”	RRII 427	”
RRII 414	”	RRII 430	”
RRII 417	”	RRII 434	RRII 105 × PR 107
RRII 429	”	RRII 454	GT 1 × RRIC 100
RRII 446	GT1 × RRIC 100	RRII 52	Normal morphotype progeny from compact canopy type
RRII 449	”	RRII 53	”
RRII 453	”	PB 330	PB 5/51 X PB 32/36
RRII 54	Normal morphotype progeny from compact canopy type	RRII 105 (Check clone in both trials)	Tjir1 × Gl-1
RRII 55	Tetraploid (2n = 72)		

immaturity period and over eight years of tapping was computed. Tapping of the trees was initiated in the eighth year after planting. The tapping system followed was S/2 d3 6d/7. Thereafter, yield was recorded by cup coagulation on a fortnightly basis. Annual mean yield of dry rubber, yield over six years in the first panel of virgin bark *i.e*. panel BO-1, over two years in the second panel of virgin bark *i.e*. panel BO-2 and mean yield over eight years of tapping were worked out. The yield in summer months (February – May) in panel BO-1 over four years from the third to sixth years of tapping was also worked out. Timber yield in the 16th year after planting in terms of clear bole volume per tree was estimated following the quarter girth method[13]. Samples of virgin and renewed bark were collected from two trees per plot and preserved in Formaldehyde Acetic acid Alcohol (F.A.A.) for structural studies. The thickness and number of latex vessel rows in the virgin bark and renewed bark were recorded from 30 – 40 µm thick radial longitudinal sections prepared using a Leica sliding microtome. Secondary attributes like the incidence of pink disease, tapping panel dryness and wind damage were recorded in terms of the percentage of trees affected in each clone.

Analysis of variance and the Duncan's multiple range test (DMRT)[14] were employed to identify clones superior for the various attributes studied. The phenotypic and genotypic coefficients of variation and broad sense heritability for the traits were estimated. The Spearman's coefficient of rank correlations[15] for rubber yield between years was employed to identify the period of stabilisation of yield.

RESULTS AND DISCUSSION

The yield of clones in the virgin panels over eight years of tapping, growth parameters, bole volume and structural features are given in *Tables 2*, *3* and *4*. Significant clonal variation was evident for all the 11 parameters among the clones evaluated in both the trials except for bark thickness in trial 2.

Estimates of Genetic Parameters

The genetic variability in terms of the phenotypic and genotypic coefficients of variation (G.C.V.) and broad sense heritability (H^2) estimates derived from clones evaluated in trials 1 and 2 are given in *Table 5*. Phenotypic Coefficient of Variation (P.C.V.) ranged from 8.16 cm for girth in the 16th year to 48.54 m^3/tree for clear bole volume. Estimates of G.C.V. which were lower than P.C.V. values due to the environmental influence on expression of traits ranged from 0.62 cm for virgin bark thickness to 43.99 m^3/tree for clear bole volume.

Estimates of broad sense heritability in Trial 1 ranged from 0.15 for girth increment at immaturity and virgin bark thickness to 0.89 for rubber yield. In trial 2, heritability estimates ranged from 0.002 for virgin bark thickness to 0.97 for rubber yield. Considering the range in values, traits with H^2 values > 0.70, 0.40 to 0.70 and < 0.40 could be considered as having high, moderately high and low heritability, respectively.

Dry rubber yield in the two virgin panels and mean yield over eight years were highly heritable (H^2 = 0.84 to 0.96) proving that the genotype, more than the environment determines the expression of this trait. Heritability estimates for rubber yield per unit girth were even higher, to the tune of 0.93 cm in trial 1 and 0.97 cm in trial 2. Earlier reports[12,16] have indicated that rubber yield is highly heritable and this is probably a reflection of the youth of the crop which is still at an early stage of selection and genetic variation is still largely additive[16]. Heritability

TABLE 2. YIELD OF CLONES OVER 8 YEARS OF TAPPING IN THE VIRGIN PANELS

	TRIAL 1						TRIAL 2				
Clone	Yield over 6 years Pl.BO-1 (g/t/tap)	Summer yield Pl.BO-1 (g/t/tap)	Yield 2 years Pl.BO-2 (g/t/tap)	Mean Yield 8 years (g/t/tap)	Yield over 8 years per unit girth (gm/cm)	Clone	Yield over 6 years Pl.BO-1 (g/t/tap)	Yield yield Pl. BO-1 (g/t/tap)	Summer 2 years Pl. BO-2 (g/t/tap)	Mean Yield 8 years (g/t/tap)	Yield over 8 years per unit girth (gm/cm)
RRII 402	59.02 ab	34.75 ab	71.18 b	62.06 bc	0.80 d	RRII 410	40.58 d	24.70 cd	65.49 bc	46.81 c	0.63 d
RRII 403	55.56 bc	35.34 ab	75.89 b	60.31bcd	0.90 ab	RRII 422	67.47 a	41.75 a	71.88 b	68.57 a	0.98 a
RRII 407	48.00 d	27.64 c	54.80 c	49.70 e	0.65 e	RRII 427	57.95 bc	31.98 b	58.32 c	58.04 b	0.85 b
RRII 414	63.15 a	37.36 a	67.21 b	64.16 ab	0.86 bcd	RRII 430	67.24 ab	32.23 b	87.49 a	72.30 a	1.03 a
RRII 417	63.19 a	32.37 abc	91.98 a	70.39 a	0.96 a	RRII 434	23.94 f	15.27 ef	31.81 d	25.91 e	0.42 e
RRII 429	58.90 ab	33.87 ab	69.79 b	61.62 bc	0.89 abc	RRII 454	32.87 e	20.81 de	31.26 d	32.47 d	0.48 e
RRII 446	28.80 e	13.89 d	32.12 d	29.61 f	0.45 g	RRII 52	55.20 c	43.67 a	65.95 bc	57.89 b	0.75 c
RRII 449	27.19 e	16.38 d	33.14 d	28.67 f	0.46 g	RRII 53	18.41 f	12.23 f	22.93 d	19.54 f	0.27 f
RRII 453	32.79 e	13.90 d	32.75 d	32.61 f	0.54 f	PB 330	52.96 c	27.09 bcd	82.47 a	60.34 b	0.72 c
RRII 54	17.79 f	13.20 d	22.22 d	18.90 g	0.28 h	RRII 105	54.86 c	29.01 bc	65.39 bc	57.49 b	0.85 b
RRII 55	49.27 cd	31.83 abc	68.62 b	54.11de	0.82 cd	G.Mean	47.15	27.87	58.30	49.93	0.70
RRII 105	50.45 cd	30.11 bc	69.36 b	55.17cde	0.82 cd	V. R.	73.77**	24.13**	40.79**	72.27**	91.80**
G.Mean	46.18	26.72	57.24	48.94	0.70	C.D.(0.05)	5.70	6.19	10.36	6.33	0.077
V. R.	53.82**	24.63**	33.37**	53.55**	77.24**						
C.D.(0.05)	5.89	5.30	10.55	6.43	0.069						

** Significant at $P<0.01$; Values followed by the same letters are on par as per DMRT ;
V.R.: Variance Ratio (MS(T): MS(E)); CD= Critical Difference at $P < 0.05$

TABLE 3. GROWTH AND TIMBER YIELD POTENTIAL OF CLONES

TRIAL 1					TRIAL 2				
Clone	Girth at opening (cm)	Girth 16^{th} year (cm)	Girth increment over 8 years of tapping (cm/yr)	Clear Bole Volume (m^3/tree)	Clone	Girth at opening (cm)	Girth 16^{th} year (cm)	Girth increment over 8 years of tapping (cm/yr)	Clear Bole Volume (m^3/tree)
RRII 402	48.61 ab	77.02 a	3.56 ab	0.112 a	RRII 410	44.38 cde	74.56 bc	3.78 ab	0.107 bc
RRII 403	39.92 cde	66.68 c	3.35 b	0.076 b	RRII 422	51.80 ab	70.16 cde	2.32 cd	0.099 bc
RRII 407	43.23 bcd	75.85 a	4.08 a	0.100 a	RRII 427	47.33 bcd	68.56 de	2.66 cd	0.082 bc
RRII 414	50.76 a	74.77 a	3.01 bc	0.112 a	RRII 430	54.26 a	70.01 cde	1.98 d	0.119 b
RRII 417	47.45 ab	72.89 ab	3.18 bc	0.114 a	RRII 434	38.14 e	62.32 f	3.05 bc	0.070 c
RRII 429	44.23 bc	69.45 bc	3.15 bc	0.081 b	RRII 454	44.04 cde	67.03 e	2.87 bcd	0.085 bc
RRII 446	35.69 e	65.14 cd	3.68 ab	0.083 b	RRII 52	47.81 abcd	76.70 b	3.62 ab	0.119 b
RRII 449	37.88 de	62.02 de	3.02 bc	0.081 b	RRII 53	41.09 de	73.06 bcd	4.00 a	0.097 bc
RRII 453	39.45 cde	60.37 e	2.62 c	0.064 c	PB 330	54.52 a	84.08 a	3.71 ab	0.248 a
RRII 54	41.02 cde	67.13 c	3.35 b	0.011 a	RRII 105	50.12 abc	67.70 e	2.21 cd	0.086 bc
RRII 55	39.17 cde	65.72 cd	3.32 b	0.078 b	G.Mean	47.35	71.42	3.02	0.111
RRII 105	38.35 de	67.61 c	3.67 ab	0.084 b	V. R.	5.70**	16.19**	6.83*	14.82**
G.Mean	42.14	68.72	3.30	0.091	C.D.(0.05)	6.83	4.46	0.83	0.039
V. R.	5.33**	13.78**	3.49*	8.92*					
C.D.(0.05)	5.85	4.10	0.57	0.017					

* Significant at P<0.05; ** Significant at P<0.01; Values followed by the same letters are on par as per DMRT ;
V.R.: Variance Ratio (MS(T): MS(E)); CD= Critical Difference at P < 0.05

TABLE 4. STRUCTURAL FEATURES OF THE VIRGIN AND RENEWED BARK

Clone	TRIAL 1				Clone	TRIAL 2			
	Virgin Bark		Renewed bark			Virgin Bark		Renewed bark	
	Thickness (mm)	No. of LVR	Thickness (mm)	No. of LVR		Thickness (mm)	No. of LVR	Thickness (mm)	No. of LVR
RRII 402	8.55 a	23.31 a	7.80 ab	24.14 a	RRII 410	7.46	19.06 abc	6.90	15.70 cd
RRII 403	7.09 b	16.25 e	6.05 d	13.37 efg	RRII 422	8.34	23.18 a	7.38	23.00 a
RRII 407	8.21 a	14.23 ef	7.71 abc	14.73 defg	RRII 427	9.70	16.57 bc	7.29	14.30 cd
RRII 414	8.78 a	19.06 bcd	7.32 bc	16.20 cdef	RRII 430	7.90	16.26 bc	6.01	15.16 cd
RRII 417	7.99 ab	17.83 bcd	7.31 bc	17.44 cde	RRII 434	9.05	12.40 c	7.26	13.28 cd
RRII 429	7.97 ab	23.17 a	6.65 cd	19.98 bc	RRII 454	9.54	18.69 abc	7.35	13.93 cd
RRII 446	8.68 a	15.65 de	7.41 abc	13.52 efg	RRII 52	7.84	23.50 a	6.87	20.51 ab
RRII 449	8.04 ab	21.82 abc	6.69 cd	21.63 ab	RRII 53	8.19	12.43 c	6.96	12.02 d
RRII 453	8.47 a	14.60 ef	6.10 d	12.55 fg	PB 330	8.16	12.37 c	7.37	16.81 bc
RRII 54	8.51 a	11.17 f	6.79 bcd	11.59 g	RRII 105	8.26	19.30 ab	7.03	17.88 bc
RRII 55	8.65 a	21.97 ab	7.61 abc	17.72 bcd	G.Mean	8.44	17.37	7.04	16.26
RRII 105	8.66 a	17.87 cde	8.38 a	19.81 bc	V. R.	1.00 ns	3.99*	1.42 ns	5.72*
G.Mean	8.30	18.08	7.15	16.89	C.D.(0.05)	-	6.19	-	4.23
V. R.	2.05*	8.62**	4.77*	8.73**					
C.D.(0.05)	0.94	3.76	0.91	3.76					

* Significant at P<0.05; ** Significant at P<0.01; Values followed by the same letters are on par as per DMRT ;
V.R.: Variance Ratio (MS(T): MS(E)); CD= Critical Difference at P < 0.05

TABLE 5. ESTIMATES OF GENETIC PARAMETERS FOR YIELD, GROWTH AND STRUCTURAL TRAITS

Trait	G.C.V.		P.C.V.		Heritability	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Mean yield in Panel BO-1	33.43	36.51	35.28	37.25	0.89	0.96
Mean yield in Panel BO-2	37.74	37.74	41.09	39.14	0.84	0.93
Mean yield over 8 years	34.38	36.06	36.29	36.81	0.89	0.96
Yield over 8 years per unit girth	30.96	35.44	32.16	36.02	0.93	0.97
Girth at opening	10.12	10.52	15.63	13.46	0.42	0.61
Girth 16^{th} year	7.54	8.19	9.14	8.96	0.68	0.84
Girth increment at immaturity	7.81	2.95	20.25	14.31	0.15	0.04
Girth increment under tapping	9.87	22.24	18.21	27.37	0.29	0.66
Clear bole height	10.78	23.18	15.16	29.67	0.51	0.61
Clear bole volume	18.08	43.99	23.98	48.54	0.57	0.82
Virgin bark thickness	4.12	0.62	10.64	15.24	0.15	0.002
Renewed bark thickness	34.38	3.19	36.29	9.14	0.89	0.12
No. of latex vessel rows in virgin bark	20.29	20.72	27.13	29.34	0.56	0.49
No. of latex vessel rows in renewed bark	21.89	18.97	29.18	24.26	0.56	0.61

is the ratio of the fixable genetic variance to the total variance[17] and the high heritability of rubber yield offers promise for the use of high yielding parents in crop improvement programmes. Broad sense heritability is of particular significance in a species like *Hevea brasiliensis* where the selected elite genotypes can be fixed by vegetative propagation.

Girth, clear bole height, clear bole volume and number of latex vessel rows showed moderately high estimates of heritability indicating only moderate levels of environmental influence in their expression. Girth increment at immaturity and bark thickness were the least heritable of the traits studied indicating significant influence of environment in early annual growth rate and bark thickness which showed only a narrow range of variability. This is also reflected in the variation in heritability estimates between girth increment rates in the immature stage and while under tapping. Clones show differential response in growth under tapping, as a consequence of which a wider range of variability in growth rates was observed and this should have influenced the magnitude of the heritability estimates. The variation in heritability between thickness of virgin bark and renewed bark could also be a result of the influence of the process of controlled wounding of the bark through tapping.

The present results suggest that choice of parents for breeding and selection of recombinants based on rubber yield, timber yield, girth and number of laticifers would be effective.

Associations Among Traits

Crop improvement programmes involving selection for a polygenic trait must necessarily take into account the interrelationships among various attributes that might directly or indirectly influence the trait of interest. Correlations among rubber yield and related traits have been reported by several workers[10,12,18,19]. The cause and effect relationships among rubber yield and it's components[20] showed that volume of latex and length of the tapping cut exerted the highest positive direct effects while girth increment rate under tapping exerted a negative direct effect on dry rubber yield.

The present study of the associations among 13 attributes (*Table 6*), revealed rubber yield in the two virgin panels to be positively correlated with girth, girth increment at immaturity and the number of latex vessel rows, the highest positive correlation ($r = 0.92^{**}$ $P < 0.01$) being between yield in the two panels and between annual mean yield and summer yield in panel BO-1. The positive association between yield and girth has been established by many[16,21] though certain reports[22] indicate a negative correlation between the two traits when considered across clones in the first virgin panel of tapping. The strong influence of growth rate in the immature stage and girth at opening on yield in the first eight years of tapping is clearly evident from the present results also. Girth increment rate under tapping clearly differs with clones and had no correlation whatsoever with any of the traits presently studied. Girth increment rate has been reported to show associations varying in magnitude and direction with yield within various clones[5], therefore when considered across clones it does not indicate any relationship with yield and also as reported earlier[22], the correlations obtained from the present study are negative though non-significant.

The number of latex vessel rows in the virgin and renewed bark showed positive correlations with yield during the eight year period, the magnitude of correlations being similar to that between yield and girth. The latex vessel rows in the virgin and renewed

TABLE 6. CORRELATIONS AMONG RUBBER YIELD AND YIELD ATTRIBUTES

	Yield BO-1	Yield BO-2	Yield 8 years	Summer yield	Girth at opening	G.incr. immature	G.incr. tapping	Girth 16 years	Bole volume	LVR virgin	LVR renew	B.T. virgin
Yield BO-2	0.92**											
Yield 8 years	0.81**	0.80**										
Summer yield	0.92**	0.83**	0.74**									
Girth at opening	0.74**	0.70**	0.64**	0.65**								
G.incr. immature	0.48*	0.41	0.44*	0.44*	0.79**							
G.incr. tapping	-0.34	-0.18	-0.32	-0.20	-0.31	-0.25						
Girth 16 years	0.45*	0.53*	0.36	0.47*	0.71**	0.56**	0.45*					
Bole volume	0.25	0.41	0.31	0.19	0.66**	0.50*	0.25	0.80**				
LVR virgin	0.52*	0.40	0.46*	0.65**	0.20	0.10	-0.19	0.06	-0.20			
LVR renewed	0.54*	0.48*	0.57*	0.61**	0.38	0.25	-0.11	0.28	0.14	0.85**		
B.Thickn. virgin	-0.19	-0.41	-0.25	-0.23	-0.06	0.11	-0.26	-0.25	-0.18	-0.12	-0.17	
B.Thickn. renewed	0.10	0.05	0.09	0.13	0.10	0.11	0.34	0.34	0.16	0.16	0.31	0.50*

*significant at P < 0.05 : ** significant at p < 0.01

bark were strongly correlated (r = 0.85** P< 0.01). Bark thickness did not appear to have any bearing on yield, growth or the number of laticifers. However, the virgin and renewed bark thickness were positively associated.

Bole volume was positively associated with girth and girth increment rate but did not show any significant correlation, though positive, with yield. Rubber yield and timber yield being independent characters, selection programmes for evolving latex- timber clones should consider these two attributes separately.

Rubber Yield

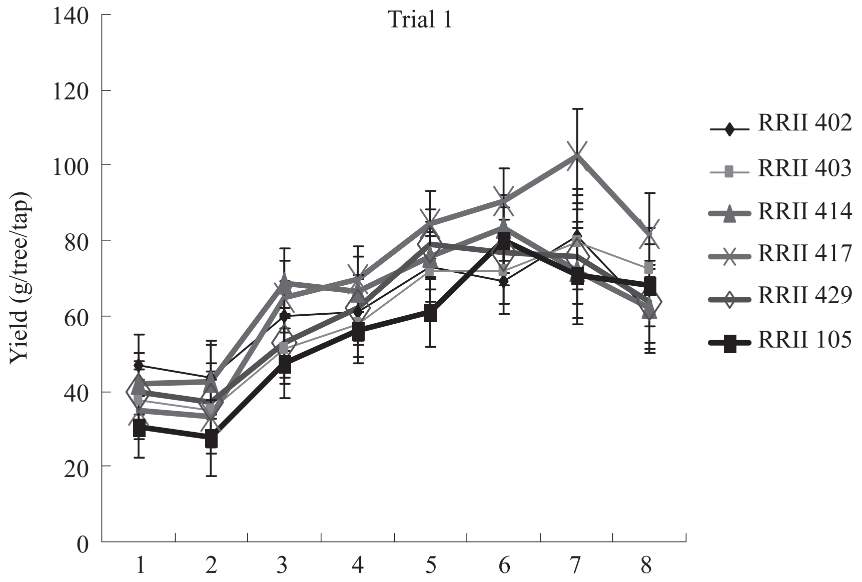
The yield of clone RRII 105 between the two adjacent trials was comparable and ranged from 50.45 to 54.86 g/t/t in panel BO-1, from 69.36 to 65.39 g/t/t in panel BO-2 and from 55.17 to 57.49 g/t/t over eight years of tapping. A comparison of the performance of clones with that of the high yielding check, RRII 105 in the respective trials is attempted here.

The yield of clones in the first virgin panel BO-1 ranged from 17.79 g/t/t to 63.19 g/t/t with a mean of 46.18 g/t/t in trial 1 and from 18.41 g/t/t to 67.47 g/t/t with a mean of 47.15 g/t/t in trial 2 (*Table 2*). Clones RRII 422, RRII 414 and RRII 417 were distinctly superior to the rest while four clones in trial 1, RRII 414, RRII 417, RRII 402 and RRII 429 and two clones in trial 2, RRII 422 and RRII 430 were superior to the check clone RRII 105. Summer yield ranged from 13.20 g/t/t to 37.36 g/t/t with a mean of 26.72 g/t/t in trial 1 and from 12.23 g/t/t to 43.67 g/t/t with a mean of 27.87 g/t/t in trial 2. Clones RRII 414, RRII 422 and RRII 52 were significantly superior to the rest and to clone RRII 105 in terms of summer yield. This indicates the seasonal stability in yield of the high yielding clones, RRII 414 and RRII 422. The low drop in yield of the moderately high yielding clone RRII 52 in summer months has already been reported[9].

In general there was a rise in yield as tapping of clones proceeded from panel BO-1 to BO-2 with the mean yield over two years in the second virgin panel being 57.24 g/t/t in trial 1 and 58.30 g/t/t in trial 2 (*Table 2*). Clones RRII 417, RRII 430 and PB 330 were significantly superior to the rest and to clone RRII 105 in terms of yield in panel BO-2 in the two trials. The mean yield of clones when considered over eight years of tapping was 48.94 g/t/t in trial 1 and 49.93 g/t/t in trial 2. In comparison to the check clone, RRII 105, the long term yield of four clones, RRII 430, RRII 417, RRII 422 and RRII 414 was promising. Clone RRII 403 also exhibited superiority over the check in terms of rubber yield per unit girth. In terms of long term yield in the virgin panels, three clones, *viz*., RRII 417, RRII 422 and RRII 430 were distinctly superior to the rest. The superiority in yield potential of these three clones is more evident in terms of rubber yield per unit girth with the values for RRII 430, RRII 422 and RRII 417 being 1.03, 0.98 and 0.96 g/cm respectively while the high yielding check clone RRII 105 showed 0.82 g/cm in Trial 1 and 0.85 g/cm in Trial 2 (*Table 2*).

The trend in yield of ten clones which showed promising performance is compared with that of RRII 105 in *Figure 1*. Yield levels picked up from the third year onwards in all cases. Five clones in trial 1 and two clones in trial 2, *viz*., RRII 417, RRII 414, RRII 429, RRII 402, RRII 403, RRII 430 and RRII 422 in general maintained higher yield levels compared to RRII 105 over the eight years of tapping. Clones RRII 417 in trial 1 and RRII 430 in trial 2 maintained steady and high yields compared to the rest of the clones.

Spearman's coefficient of rank correlations (*Table 7*) for yield across eight years show



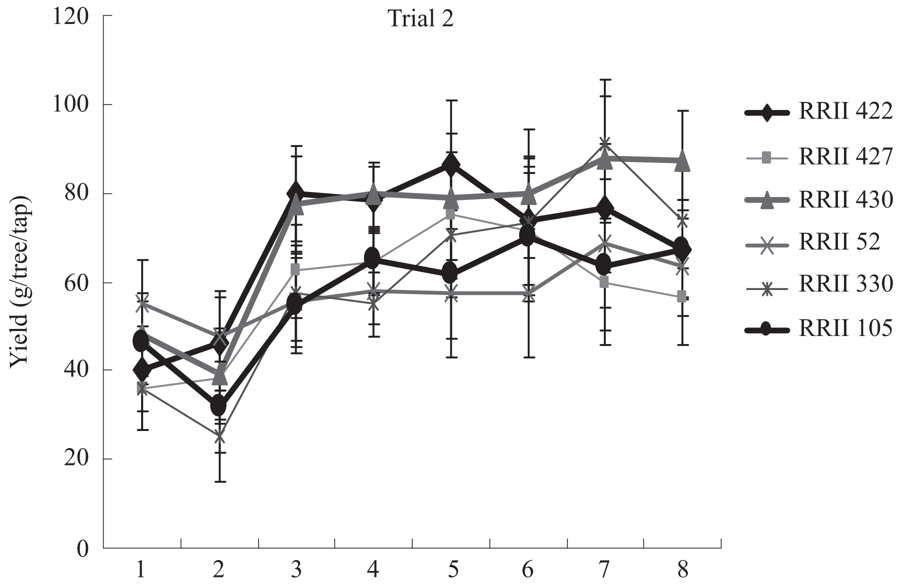


Figure 1. Trend in yield of some of the promising clones over eight years of tapping.

comparable trends in both the trials. Rank correlations between the eighth year and the first two years of tapping were low and non-significant in both the trials. The ranking in yield of clones in the first two years in trial 2 had no significant correlation with yield after the sixth year. The rank correlations from the third year onwards with the subsequent years were high and significant in the two trials indicative of similar trends in all the 22 clones studied. It can thus be inferred that three years of tapping is sufficient for stabilisation of rubber yield and selection for yield could be exercised by the fourth year of tapping. On the other hand, selection based on yield in the initial two years of tapping may lead to erroneous conclusions. This is in conformity with earlier reports[23–24] that yield stabilisation in rubber takes place by the fourth year, though a later report[25] observed that six years of yield recording is required for selection of the top three clones from large scale trials.

Growth and Timber Yield

Significant clonal variation for girth at opening and girth increment rate in the immaturity period among the 22 clones evaluated in the two trials was reported earlier[9]. Clones RRII 430, PB 330, RRII 422, 414, 402, 417 and 52 were superior in terms of vigour at opening with girth ranging from 52.03 to 61.16 cm, while RRII 105 was poor in vigour in both the trials. The present results show that girth and clear bole volume at the age of 16 years and girth increment rate over eight years of tapping varied significantly among clones. Clones RRII 402, RRII 407, RRII 414, RRII 417, PB 330, RRII 52, RRII 410 and RRII 53 were significantly vigorous in terms of girth compared to RRII 105 in the respective trials (*Table 3*). Clones RRII 407, and RRII 53 showed high rate of girth increment under tapping. A good girth increment during tapping is desirable as this contributes to rising yield trends[22]. Contrary to the earlier report of low girth increment rate in clone RRII 105 when planted as single trees in complete randomisation along with clones of varying growth vigour[5], the present results show a comparable growth rate of RRII 105 with RRII 407, the most vigorous clone in trial 1. Clones which were comparable with RRII 105 in terms of girth increment rate under tapping were RRII 403, RRII 414, RRII 417, RRII 429, RRII 446 and RRII 449 in trial 1, while in trial 2 where the growth rate of RRII 105 was below average, clones RRII 422, RRII 427, RRII 434, RRII 454 and RRII 430

TABLE 7. SPEARMAN'S RANK CORRELATIONS OVER EIGHT YEARS WITH RESPECT TO ANNUAL MEAN YIELD IN THE TWO EVALUATION TRIALS[a]

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Year 1	1	0.92**	0.83*	0.80*	0.71*	0.63	0.75*	0.51
Year 2	0.93**	1	0.89**	0.89**	0.83*	0.74*	0.85**	0.55
Year 3	0.73*	0.85**	1	0.96**	0.93**	0.84**	0.90**	0.71*
Year 4	0.85**	0.85**	0.90**	1	0.94**	0.93**	0.92**	0.78*
Year 5	0.71*	0.81*	0.99**	0.93**	1	0.83*	0.90**	0.71*
Year 6	0.62	0.68	0.93**	0.88**	0.95**	1	0.81*	0.87**
Year 7	0.65	0.70	0.79*	0.70	0.77*	0.83*	1	0.78*
Year 8	0.64	0.59	0.72*	0.78*	0.76*	0.84**	0.89**	1

[a]Values above the diagonal pertain to Trial 1 and values below the diagonal pertain to Trial 2
*significant at $P < 0.05$: ** significant at $p < 0.01$

were on par with it. *Figure 2* depicts the girth of some of the promising yielders of the RRII 400 series along with that of RRII 105 up to the 16th year after planting. Clones RRII 414, RRII 417, RRII 429, RRII 422 and RRII 430 maintained better girth compared to RRII 105 though the response in growth of clones under tapping varied.

Timber yield in terms of clear bole volume at the age of 16 years was highest in clone RRII 417 (0.114 m^3/tree) followed by RRII 414, RRII 402, RRII 54 and RRII 407 in trial 1, while clone PB 330 showed the highest bole volume (0.248 m^3/tree) in trial 2 with clones RRII 430 and RRII 52 with 0.119 m^3/tree in the second place, but comparable to the rest of the clones.

Structural Features

The thickness and number of latex vessel rows in the virgin and renewed bark are of significance in determining rubber yield[10]. The present study, however revealed lack of significant variability for bark thickness and all the clones were comparable as evidenced by the DMRT. The number of latex vessel rows, as also reported from a study on a different population[26], showed significant clonal variation (*Table 4*). In the virgin bark, the number of laticifers was highest (> 23 nos.) in clones RRII 402 and RRII 429 in trial 1 and RRII 52 and RRII 422 in trial 2. These clones were superior to RRII 105. Clones RRII 402 (> 24 nos.) and RRII 422 (> 23 nos.) maintained superiority with the highest number of latex vessel rows in the renewed bark also. Clone RRII 422 under small scale evaluation[8] was reported to possess a significantly high number of latex vessel rows in both the virgin and renewed bark, as evidenced from the present results also. This indicates the possibility of sustained high yield in clone RRII 422.

Incidence of Pink Disease, Wind Damage and Tapping Panel Dryness

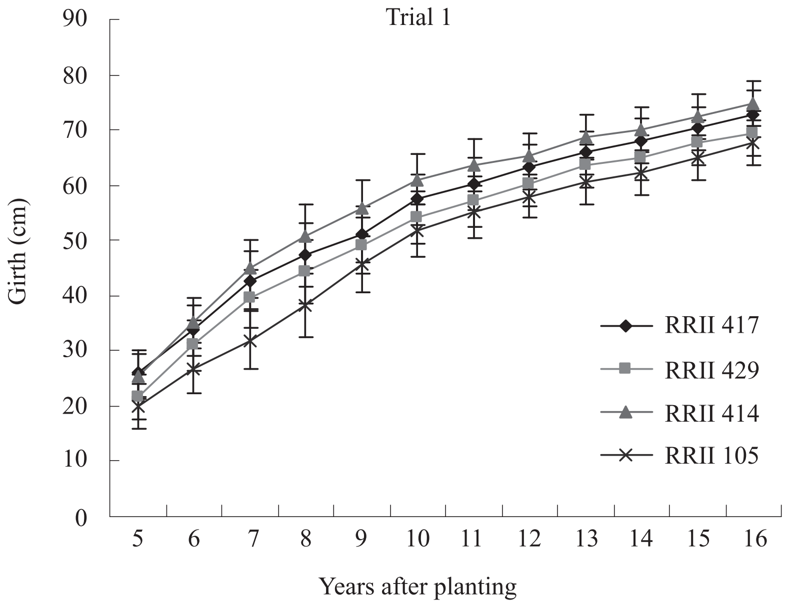
The incidence of pink disease (*Table 8*) in the clones ranged from 22.2 to 88.8 percent in trial 1 and 12.2 to 63.4 percent in trial 2. In the case of clone RRII 105 which is known to be susceptible to the disease, 60 percent trees in trial 1 and 51.2 percent trees in trial 2 were affected. Clones RRII 454, RRII 434, RRII 53, RRII 430, RRII 449 and RRII 54 showed tolerance, with a low incidence of less than 25 percent trees affected. Clone RRII 429 recorded the highest incidence of 88.8 percent of trees affected by the disease.

Wind damage was in general less than 2 percent in the experimental area with none of the trees of clones RRII 430, RRII 422, RRII 417, RRII 52, RRII 454, RRII 434, RRII 403 and RRII 446 affected. Clone RRII 105 showed the highest incidence of wind damage with 5 percent trees in trial 1 and 7.32 percent trees in trial 2 affected.

Tapping panel dryness after eight years of tapping ranged from 2.38 to 21.95 percent among the clones in both the trials. Clone RRII 429 in trial 1 with 20 percent trees affected and clone RRII 52 in trial 2 with 21.95 percent trees affected, recorded the highest incidence.

CONCLUSION

The present study of 20 new generation clones, the majority belonging to the RRII 400 series confirms the superiority of clones RRII 430, RRII 414, RRII 417 and RRII 422 over the high yielding check clone RRII 105 in terms of growth, rubber yield and timber yield . The results lend further support to the upgradation of these clones to category 1 of the planting recommendations for the traditional rubber growing regions of India[27].



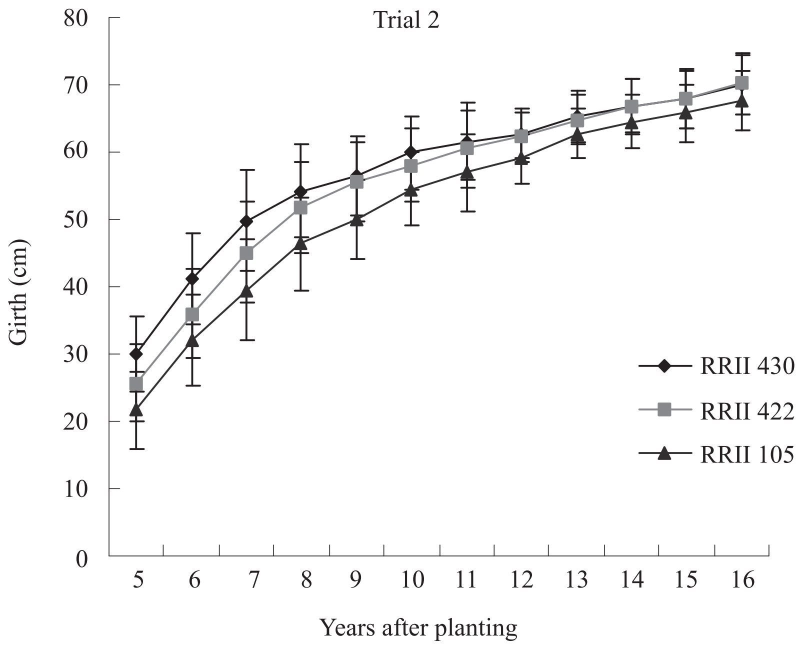


Figure 2. Growth of promising clones over 16 years.

Clones RRII 417 and RRII 430 maintained steady and high yields throughout the eight year period. Clones RRII 414, RRII 422 and RRII 52 maintained high yields in the summer period. Clone RRII 430 recorded a low incidence of pink disease and no wind damage, while RRII 422 and RRII 417 also recorded no wind damage. Clone PB 330 emerged as a moderately high yielding clone with a rising yield trend and very high timber yield potential. Clones RRII 429 and RRII 422 were superior for the number of laticifers in the bark.

The study of the coefficients of rank correlations for yield over eight years, genetic parameters and correlations among traits indicate that evaluation in large scale trial based on yield over the first six years of tapping in panel BO-1, girth at opening, girth increment rate in the immature phase and the number of latex vessel rows would confirm the superiority of a clone in selection programmes for yield improvement. The high heritability estimates for yield indicate maintenance of high yield levels of the clones selected thus even when planted in different environments. Use of such high yielding clones as parents in hybridisation programmes for yield improvement would also yield the desired results. Bole volume could be assessed when timber yield is an additional selection objective. Heritability of bole volume also being moderately high, clones with large boles could be selected as parents for crossing if improvement in timber yield is the objective. Bole volume in the 16th year of growth, however did not show any negative relationship with rubber yield as per the theory of competition for assimilates and a partitioning favouring latex yield affecting tree growth. Hence it appears that increase in bole volume would not be at the expense of rubber yield. However the association of rubber and timber yields needs to be confirmed from studies on more varying populations.

TABLE 8. INCIDENCE OF PINK DISEASE, TAPPING PANEL DRYNESS AND WIND DAMAGE IN THE CLONES

TRIAL 1				TRIAL 2			
	% incidence of				% incidence of		
Clone	Pink disease	Wind damage	Tapping panel dryness	Clone	Pink disease	Wind damage	Tapping panel dryness
RRII 402	51.2	1.20	14.29	RRII 410	63.4	2.44	2.38
RRII 403	60.8	0.00	7.69	RRII 422	47.5	0.00	12.82
RRII 407	55.8	2.90	16.42	RRII 427	25.6	5.13	5.41
RRII 414	36.4	1.13	10.58	RRII 430	20.0	0.00	6.25
RRII 417	47.7	0.00	9.63	RRII 434	12.5	0.00	13.16
RRII 429	88.8	3.70	20.00	RRII 454	12.2	0.00	2.56
RRII 446	30.0	0.00	2.99	RRII 52	31.0	0.00	21.95
RRII 449	22.2	4.20	4.82	RRII 53	16.6	2.80	2.70
RRII 453	41.7	1.20	9.76	PB 330	30.2	2.33	11.90
RRII 54	22.4	1.20	7.14	RRII 105	51.2	7.32	2.56
RRII 55	47.5	1.30	9.21	G.Mean	31.52	2.00	8.17
RRII 105	60.0	5.00	8.82				
G.Mean	47.04	1.82	10.12				

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