GROWTH AND YIELD ANALYSIS OF TOP WORKED COCOA PLANTS

By
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THESIS

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DECLARATION

I hereby declare that this thesis entitled **"GROWTH AND YIELD ANALYSIS OF TOP WORKED COCOA PLANTS"** 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 title, from any other University or Society.

NIMMY JOSE

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24.8.1996

CERTIFICATE

Certified that this thesis, entitled **"GROWTH AND YIELD ANALYSIS OF TOP WORKED COCOA PLANTS"** is a record of research work done independently by **Kum. Nimmy Jose**, 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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CERTIFICATE

We, the undersigned members of the Advisory Committee of **Kum. Nimmy Jose**, a candidate for the degree of Master of Science in Agriculture, agree that the thesis entitled **"GROWTH AND YIELD ANALYSIS OF TOP WORKED COCOA PLANTS"** may be submitted by Kum. Nimmy Jose, in partial fulfilment of the requirement for the degree.

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To My Beloved Parents

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Introduction

INTRODUCTION

Cocoa (*Theobroma cacao* L.) which is one of the most important beverage crops in the world belongs to the family Sterculiaceae. It is believed to have originated from the basins of river Amazon in South America. It is a crop of yesteryears, the earliest of its cultivation having been recorded in sixteenth century in Mexico. It spread from Mexico to the Carribean islands from where it was taken across the Pacific to Philippines about the year 1600 (Wood and Lass, 1985). It was introduced to India from Ambon in the Moluccas in 1798 (Ratnam, 1961).

Commercial cultivation of cocoa in India started in the early 1960s but area expansion gained momentum only from 1970. Cocoa is largely grown as a homestead crop in Kerala in the coconut and arecanut gardens and as a mixed crop in the arecanut gardens. It is grown in an area of 15,287 ha with a production of 8,329 T (1991-'93 estimates). Kerala stands first in area and production, followed by Karnataka and Tamil Nadu.

According to the 1989-90 estimates, the internal requirement of cocoa beans will be 20,000 tonnes per annum by the year 2000 AD (Velappan, 1991) as against the estimated production potential of 7000 tonnes of the existing cocoa plantations in the country. Besides this, cocoa beans and its derivatives are now projected as an important export item. Thus, there is a need to increase cocoa production in India in order to prevent foreign exchange drain in future. For increasing production, crop improvement for raising productivity forms an important step.

One of the major reasons for low productivity and returns from the existing cocoa plantations in the country is that most of these plantations have been established from seedling progenies which are genetically poor and highly erratic in bearing. The extent of variation in yield is so high that often about 75 per cent of the yield is recovered from about 25 per cent of the plants. Genetic differences are attributable to most of these differences in yielding ability. One of the methods of improving the genetic potential of an existing population is top working, a procedure which has been standardised (KAU, 1990). Top worked plants grew faster than budded plants and were of significantly higher yield. There are, however, large differences in yield of top worked clones both between clones and within plants of the same clone (Nair *et al.*, 1994). While the interclonal differences are explainable as due to genetic factors, the intraclonal differences were difficult to explain excepting of stock effect. Attempts were also made in a study (Nair *et al.*, 1994) to separate out the stock effect measured in terms of girth of stock and pre-experimental yielding ability. While it was found that part of these differences are attributable to stock effect, there are still large differences between plants of the same clone.

The present study was taken up primarily to locate other factors and to assess their effect on the differences between plants of the same clone. Assessment of the extent of advantage arising from top working and identifying clones that are superior as scions for top working were the other objectives of the study.

Among the other factors that were considered to be responsible, the advantage of early vigour of some plants in crop community was taken as the important factor. This was assessed using leaf area index of the plants as the criterion. As in the case of the previous study (Nair *et al.*, 1994), the pre-experimental girth of stem and pre-experimental yielding ability were taken as the indices of stock effect.

The objectives of the present study are summarised below.

1. To study the variability between different top worked clones.

2. To study the variability within the top worked clones.

3. To assess the extent of stock effect as judged by pre-experimental girth and pre-experimental yielding ability on the yield of top worked clones.

4. To study differences in leaf area index as a factor affecting yield of top worked plants.

5. To quantity the extent of yield advantage from top working.

6. To identify clones that are superior as scions for top working.

Review of Literature

REVIEW OF LITERATURE

Crop improvement is an integral part of crop cultivation. Cocoa (*Theobroma cacao* L.) is no exception to this. Adoption of better management practices like manuring, irrigation and timely plant protection, no doubt, would increase the yields marginally, but boosting cocoa production from existing old plantation would perhaps be possible only if the existing seedling populations can be genetically transformed into high yielding varieties by *in situ* grafting or top working. Unfortunately, the information on rejuvenation of old cocoa plants by top working and its performance is very scanty. Some of the important pieces of work relating to the advantages of top working in tree crops, growth and yield performance of top worked plants, stock-scion influence in vegetative propagation, influence of leaf area index (LAI) and other growth parameters on the yielding ability of tree crops are given below.

2.1 Methods of top working

2.1.1 Cocoa

Based on a field trial conducted for the standardization of conditions for top working cocoa, a procedure for top working cocoa was successfully developed experimentally.

Snapping the stem back at jorquette height was found successful in inducing growth of chupons. Budding on these chupons was also successful (KAU, 1991). Nair *et al.* (1994) reported that this method of top working cocoa was fully successful and these top worked plants continued to make better growth than freshly budded plants. Top worked plants came to bearing earlier than freshly budded plants eventhough a minimum lapse of about one and a half years is to be expected (KAU, 1994). Top working trials were carried out by budding on hard trunk but success rate was very low (KAU, 1989).

2.1.2 Other crops

Khan *et al.* (1986) and Sathpathy (1990) have reported that top working of cashew trees can be done by grafting in the beheaded crown by splitting the bark called crown grafting or by grafting on the new shoots from below the beheaded region with shoots of high yielding varieties of cashew. Similar reports were made by Guruprasad *et al.* (1988), Pugalendhi and Shah (1991) and Lenka *et al.* (1991).

Mango seedling trees below 20 years can be conveniently top worked with scion woods of commercial varieties (Singh, 1978; Kanwar and Jawanda, 1983).

Top working was found useful in the case of dioecious perennial trees like nutmeg, since it permits the transformation of unproductive males to desired females with precocious bearing (Beena, 1994). Studies conducted by Beena (1994) revealed that top working of nutmeg trees by *in situ* budding on hard trunk could be successfully done.

Successful top working was also reported in crops like pomegranate (Kar *et al.*, 1989), walnut (Xi and Diang, 1990), wild jujube (Yadav, 1991) and coffee (Ramachandran *et al.*, 1993).

2.2 Growth and yield performance of top worked plants

Kurian and Beena (1995) observed faster growth of *in situ* budded nutmeg plants compared to other vegetative propagation methods due to the well established and extensive root system. The stumped buddings made up the cut down growth in one or one and a half years and they were comparable to the seedlings of the same age.

Studies carried out at Agricultural Research Station, Ullal over a period of seven years revealed the viability and profitability of top working cashew. Fourteen year old cashew trees which were top worked during April 1984 put forth a canopy of 5-6 m height and 3-4 m width in a period of six years. Old cashew trees which yielded less than 3 kg per tree per year gave an average yield 7.21 kg per tree (yield per tree was 3.57 kg during 1986; 4.65 kg during 1987; 5.92 kg during 1988; 9.58 kg during 1989 and 12.32 kg during 1990) in a period of six years after top working (Khan *et al.*, 1994).

Evaluation of the growth and yield performance of top worked cashew trees was done by Kumar *et al.* (1990) over a period of five years after rejuvenation. It was observed that top worked trees on an average with less than five successful grafts per tree attained a height of 6.3 m and a spread of 31.8 m^2 in a period of five years. This was on par with the growth of seventeen year old cashew trees in the plot which were not subjected to rejuvenation, indicating that top worked trees attained the original growth and canopy within a period of five years. The top worked trees gave nearly four-fold increase in yield within five years. The increased yield was mainly due to genetic transformation of trees into high yielding types. The technology not only helped in getting higher yields but also nuts of desired quality (Guruprasad *et al.*, 1988).

Nair *et al.* (1994) assessed the extent of advantage from top working cocoa. Statistical comparison of the difference in yield of the plants before and after top working was made by working out variance ratio. It was found to be significant confirming the superiority of top worked clonal population. It was observed that a gain of 113 per cent could be obtained from top worked cocoa plants 31 to 42 months after top working.

2.3 Tree vigour as a criterion of yield

Nayar *et al.* (1981) reported positive significant (P=0.01) correlation of spread on yield of cashew trees derived from seedlings. The 'r' values were 0.318 and 0.497 for 1977-'78 and 1978-'79, respectively. They got a correlation coefficient of 0.235 between yield and girth during 1977-'78 and it was found to be significant at P=0.05 while the same relation in 1978-'79 was 0.303 which was significant at P=0.01.

A positive correlation between yield and height was also noticed in 1978-'79 and it was significant at P=0.01 and 'r' value was 0.417. The results indicated that relationship of spread was much more closer to yield than with other parameters.

A significant relationship between yield and tree growth in seedling-derived mango was reported by Khan (1960) and Oppenheimer (1960). Rogers and Booth (1964) worked out the relationship of crop yield and shoot growth in apple.

Investigation undertaken by Manoj (1992) to know the degree of association existing among nut yield and different biometrical characters in cashew revealed that there was maximum positive correlation of mean canopy spread with yield (0.57). Yield was also found to possess significant positive correlation with girth of tree (0.54), leaf area (0.27) and height of tree (0.26). Path coefficient analysis indicated that girth and mean canopy spread had positive direct effect on yield and positive association of yield with the former was having a slightly higher indirect effect on yield through canopy spread than its direct effect on yield.

Investigation undertaken by Manoj *et al.* (1994) to study the degree of association existing among nut yield and different biometric characters in cashew had shown that maximum positive correlation was noted in the character, mean canopy spread with yield (0.57). Yield was found to possess statistically significant positive correlation also with leaf area (0.27). It was observed that height of the tree was positively correlated with girth and mean canopy spread while mean canopy spread which had the highest positive correlation with yield in turn was highly correlated with girth of the tree (0.74). The studies also revealed that leaf area had positive correlation with all these characters.

In a study to find the relationship between trunk cross-sectional area and weight of apple trees, Westwood and Roberts (1970) observed a linear relationship between trunk cross-sectional area and above ground weight of apple trees. They suggested that trunk measurements can be used to estimate the potential bearing surface of any orchard tree as long as it has not been pruned heavily to prevent crowding. This relationship permitted the calculation of yield efficiency as fruit weight per cm^2 trunk cross-section.

Fallahi *et al.* (1990) made an attempt to compare the growth, yield and fruit quality of eight lemon cultivars (*Citrus limon* (L.) Burm.f.) on macrophylla (*Citrus macrophylla* Webster) rootstock. Yield, trunk circumference (15 cm above the bud union) and canopy volume were measured. Trunk cross-sectional area was calculated annually and cumulative yield was calculated from five to twelve years after planting. The canopy volume was measured twelve years after planting. The results showed that trunk cross-sectional area was not necessarily proportional to canopy volume in all cultivars. Therefore, reporting yield efficiency as yield per canopy volume is a better approach than using yield per trunk cross-sectional area.

A study conducted by George *et al.* (1984) for three years to standardize a technique for forecasting cashew yield based on seven biometrical characters recorded at weekly intervals revealed that yield could be forecasted with reasonable precision (R^2 = 0.64) by a single spot observation made during peak flowering period. The number of variables could be brought down to three viz., the number of nuts on the tree, condition of flowering and canopy area without substantially affecting the accuracy of the estimate (R^2 = 0.61).

An assessment of various vegetative and fruit characters was made in 42 cultivars of mango (Iyer *et al.*, 1989). Plant height was found to have positive correlation with first extension growth, number of internodes and yield.

Trial conducted by Robinson *et al.* (1991) on canopy development, yield and fruit quality of apple trees grown for ten years showed that yield was highly correlated with trunk cross-sectional area per hectare.

Growth and fruiting in eight apple varieties differing in growth vigour when grafted on common rootstock were studied by Filippov and Shcherbatko (1989). In six year old trees, the highest annual shoot growth increment was seen in varieties with higher trunk circumference, height and crown width.

2.4 Influence of stock on the performance of scion in vegetative propagation

Teaotia *et al.* (1970) investigated the relationship between yield and the major characteristics of vigour viz., trunk diameter, spread and height in mango variety Dashehari grafted on five different rootstocks. Linear regression equations revealed that spread, height and circumference of stock were all significantly related with yield. Out of these three components of vigour, spread had higher significant relationship with yield (P=0.01) than other variable (P=0.05). Multiple regression equations showed that yield was significantly related with spread along with either the height or the circumference of stock when included in the equation. But no significant relationship was found when the spread was excluded and only the height and circumference of the stock were included. On the basis of the above findings, spread was suggested to be used to predict the yield of mango in different types of experiments.

Nair *et al.* (1994) attributed part of the intraclonal yield differences in the top worked cocoa plants to the stock effect. Correlation coefficient values showed that the association of pod yield of clones both with stem girth of stock plants prior to top working (r = 0.247) and with pre-experimental yield by stock plants (r = 0.261) were significant thus indicating the possibility of an appreciable stock effect. The association between stem girth and pre-experimental yield (r = 0.501) was highly significant, thus, confirming also the expected relation between vegetative vigour and yielding ability of plants derived from seedlings.

The effect of five rootstocks on the growth and yield of two different cultivars of mango was studied by Samaddar and Chakrabarti (1989). It was observed that height, yield and yield per tree volume varied in the cultivars with different rootstocks.

Kohli and Reddy (1989) studied the influence of rootstock on growth and yield of Alphonso mango. Among the different rootstocks, none of the vegetative parameters was found to be statistically significant except scion girth.

Studies conducted by Schechter *et al.* (1991) on the influence of rootstock on vegetative growth characteristics and productivity of 'Delicious' apple revealed that rootstocks strongly influenced the number, area, dry weight and percentage of leaves in shoot and spur.

Lehman *et al.* (1990) observed the growth dynamics of young apple trees as influenced by scion and rootstock vigour. The study revealed few scion - rootstock interactions. Studies conducted by Tukey (1990) on the effect of rootstock on apple tree growth and fruiting revealed that cultivars performed differently with difference in rootstock. Similar rootstock effects on apple tree growth and fruiting were observed by Tukey (1991).

The effect of strain and rootstock on spur characteristics and yield of 'Delicious' apple strains was studied by Warrington *et al.* (1990). A significant positive correlation was observed between spur density and yield efficiency. In a related study Warrington *et al.* (1990) observed that spur leaf number and spur leaf area were both high with vigorous rootstocks, whereas spur density was low.

Poniedzialek *et al.* (1995) studied the effect of rootstocks on growth and fruiting of apple trees and observed no differences in vigour of trees on different rootstocks. Only the number of shoots and height of trees were lower on certain rootstocks. No significant difference in cumulative yield and crop efficiency was found.

2.5 Leaf area index as a factor affecting yield

Watson (1952) established that leaf area gave a simple and an approximate measure of plants' photosynthetic potential. He found it to be a more common determinant of plant growth and yield than photosynthetic capacity of individual leaves in a crop community. Hence, measurement of leaf area was often necessary for agronomic and physiological studies and several methods have been developed for measuring leaf area.

Assessment of the differences in several physiological parameters of green house grown cocoa hybrids at fifteen days interval after emergence upto eight months was made by Almeida and Valle (1988). It was observed that leaf area was the most important factor influencing total dry matter production rate with intergeneric variation being noted for these two parameters. However, significant intergenotypic differences in relative growth rate, net assimilation rate and leaf area ratio were not found.

Koike *et al.* (1988) found that apple trees with reduced vigour had lower leaf area index when observed five years after planting.

In a field trial conducted with softwood grafts of cashew at the Regional Agricultural Research Station, Pilicode, leaf area index was taken as a measure of vigour (Rajagopalan *et al.*, 1992). among the three parameters, plant height, number of branches and leaf area index, there was significant differences among the varieties with respect to leaf area. This study indicated that leaf area index was a better measure of crop growth vigour when compared to that of plant height and number of branches. This was in agreement with the observations made by Bhagavan and Subhaiah (1979).

Factors influencing yield in cashew seedlings were studied by Parameswaran *et al.* (1984). A strong correlation was observed between tree yield and percentage of flowering shoots per unit area of tree canopy and total canopy area.

Among the three characters studied, Nayar *et al.* (1981) reported that canopy spread had maximum positive correlation with yield followed by trunk girth and height of the cashew trees.

Tailliez and Ballokoffi (1992) suggested that knowledge of leaf area provides some indication of crown bulk but not of its architecture on which photosynthetic efficiency can depend. Morghan *et al*. (1991) defined architecture of a plant as a set of features which defines the shape, size and geometry of the plant. The position, size and orientation of leaves played significant roles in the interaction of crop with the incident radiation. Grant and Ryugo (1984), Morghan *et al*. (1985) and Laing (1985) showed that radiation regime within a canopy influenced flowering, leaf photosynthetic rates and fruit growth.

Investigation undertaken by Manoj *et al*. (1994) revealed a positive correlation of leaf area with yield of cashew trees.

Materials and Methods

MATERIALS AND METHODS

The present study on the growth and yield analysis of top worked cocoa (*Theobroma cacao* L.) plants maintained at the farm attached to the College of Horticulture, Vellanikkara was undertaken during 1994-'96. A brief description of the materials used and methods followed is given below.

3.1 Materials

Two sets of plants available under the Cadbury-KAU Co-operative Cocoa Research Project (CCRP) were utilised for the study. An account of the crop history is given below.

3.1.1 Set I

This set consisted of 26 rows of plants originally planted in 1979 with a maximum of eight plants per row. Experiments on top working these plants were taken up since November 1988 when they were nine to thirteen years old. A procedure for top working cocoa was developed which consisted of snapping the stem back at 30 cm height to induce growth of chupons. Budding on these chupons was done and the original snapped stem was retained till the buds differentiated and grew to the stage of at least two hardened leaves. Top working using this procedure was done with a row of plants snapped back every month. Each row was top worked with a different clone and top working was completed by September 1991. All the top worked plants started yielding by 1993-'94 though the first few rows started yielding by 1992-'93. Observations of these top worked trees were taken for a period of two years, 36 to 66 months after top working. Total number of plants used for the study was 143. Details are given in Table 1.

3.1.2 Set II

This included the top worked plants of Germplasm I to IV available in the farm. Germplasm I was a group of plants arising from pods of fifteen selected trees introduced from Cocoa Research Institute of Ghana in 1978 and field-planted in 1979. Germplasm II to IV included seedling populations of 80 types collected from promising plants of various plantations of Kerala and established in 1980. These thirteen year old plants were snapped down at jorquette height during October 1993 and top working was completed by March 1994 using fifteen selected high yielding clones. The total number of top worked plants in this set used for the study was 447. Observations of these plants were taken one year after top working. Details are given in Table 2.

Table 1. Clones used for top working plants in Set I

Sl.No.	Clone	No. of plants
1.	GVI-51	2
2.	GVI-54	4
3.	GVI-55	4
4.	GVI-56	4
5.	GVI-59	6
6.	GVI-60	4
7.	GVI-61	6
8.	GVI-64	6
9.	GVI-68	5
10.	M-9.16	7
11.	M-16.9	6
12.	GI-4.8	8
13.	GI-5.9	8
14.	GI-10.3	6
15.	GI-15.5	6
16.	GII-12.3	7
17.	GII-19.5	2
18.	GII-20.4	6
19.	GIII-1.2	7
20.	GIII-4.1	8
21.	GIV-2.5	6
22.	GIV-18.5	6
23.	GIV-32.5	8
24.	S-44.1	5
25.	S-50.12	4
26.	S-51.1	2
	Total	143

Table 2. Clones used for top working plants in Set II

Sl.No.	Clone	No. of plants
1.	M-9.16	23
2.	M-16.9	31
3.	GI-5.9	30
4.	GI-10.3	30
5.	GI-15.5	32
6.	GII-19.5	29
7.	GII-20.4	27
8.	GIV-18.5	32
9.	GIV-35.7	28
10.	S-44.1	29
11.	GVI-51	35
12.	GVI-54	38
13.	GVI-55	32
14.	GVI-64	22
15.	GVI-68	29
	Total	447

3.2 Methods

In order to study the variability within and between different top worked clones, to separate out the stock effect and to assess the effect of early vigour as a factor influencing the differences between top worked plants, data on the yield of plants, leaf area index, pre-experimental yield and girth of stock plants were collected. In the case of Set I, data on yield for the period from April 1994 to March 1996 were collected. The period of start of data collection corresponds to a lapse of 36 to 66 months after snapping for top working. It was assumed that these plants had come to steady bearing and that the period after top working was not a critical factor affecting the yield.

In the case of Set II, yield data for the early period of bearing seventeen months after snapping for top working were collected. The actual period of data collection was from April 1995 to March 1996. Details of the observations taken are given below.

3.2.1 Yield of top worked plants

Yield was estimated in terms of total wet bean weight produced per tree and was calculated using the formula.

Yield per tree in kg = Total number of pods/tree x Mean wet bean weight/pod

Data on wet bean weight per pod of the different clones were collected from earlier records which gave mean values of the different clones from pods collected during the period from December to March. Data on these are given in Table 3.

3.2.2 Girth of the tree prior to top working

The data available at CCRP on the girth of the trees a year prior to top working were used. Stem girth at 15 cm was used as standard. Data on these are given in Tables 4 and 5.

3.2.3 Yield of the tree prior to top working

To determine the influence of stock plant on the yield of top worked plants, data on yield prior to top working were compiled from the earlier recorded data from CCRP. The yield prior to top working for a two year period was recorded for both the sets of plants. The number of pods per plant was taken as yield parameter of stock plants. Data on these are given in Tables 4 and 5.

3.2.4 Leaf area index

Leaf area index was reckoned as the total plane area of leaves in a canopy to the area of the ground beneath. As the leaves of a cocoa tree were highly variable in their size and shape, they were divided into three groups viz., large, medium

Table 3. Wet bean weight per pod of different clones used for top working

Sl.No.	Clone	Wet bean weight per pod, g
1.	M-9.16	62.2
2.	M-13.12	113.3
3.	M-16.9	152.5
4.	GI-4.8	107.5
5.	GI-5.9	140.0
6.	GI-10.3	122.0
7.	GI-15.5	108.3
8.	GII-12.3	132.5
9.	GII-19.5	165.0
10.	GII-20.4	135.0
11.	GIII-1.2	108.0
12.	GIII-4.1	105.0
13.	GIV-2.5	116.6
14.	GIV-18.5	137.1
15.	GIV-32.5	150.6
16.	GIV-35.7	100.6
17.	GVI-50	149.5
18.	GVI-51	205.0
19.	GVI-54	115.8
20.	GVI-55	197.9
21.	GVI-56	138.9
22.	GVI-59	77.1
23.	GVI-60	142.3
24.	GVI-61	147.1
25.	GVI-64	129.0
26.	GVI-68	115.0
27.	S-44.1	126.3
28.	S-50.12	105.1
29.	S-51.1	45.0

Table 4. Mean girth and yield of stock plants of Set I before top working

Sl. No.	Clone used	No.of plants	Pre-experimental	
			Girth, cm (1987)	Mean yield, pods $plant^{-1}$ $year^{-1}$ (1985-87)
1.	GVI-51	2	33.0	3.0
2.	GVI-54	4	31.8	9.3
3.	GVI-55	4	28.0	6.3
4.	GVI-56	4	37.3	14.2
5.	GVI-59	6	29.2	17.5
6.	GVI-60	4	29.3	11.4
7.	GVI-61	6	33.8	20.0
8.	GVI-64	6	32.2	6.1
9.	GVI-68	5	32.8	23.5
10.	M-9.16	7	30.9	11.2
11.	M-16.9	6	33.3	12.8
12.	GI-4.8	8	32.8	14.9
13.	GI-5.9	8	29.4	14.5
14.	GI-10.3	6	30.7	14.6
15.	GI-15.5	6	30.8	11.3
16.	GII-12.3	7	31.9	11.8
17.	GII-19.5	2	44.5	24.3
18.	GII-20.4	6	32.3	17.1
19.	GIII-1.2	7	38.1	10.5
20.	GIII-4.1	8	30.4	14.4
21.	GIV-2.5	6	37.2	24.1
22.	GIV-18.5	6	26.5	10.5
23.	GIV-32.5	8	37.6	15.1
24.	S-44.1	5	36.8	30.7
25.	S-50.12	4	33.0	7.2
26.	S-51.1	2	32.0	6.3

Table 5. Mean girth and yield of stock plants of Set II before top working

Sl. No.	Clone used	No.of plants	Pre-experimental	
			Girth, cm (1992)	Mean yield, pods $plant^{-1}$ $year^{-1}$ (1990-92)
1.	M-9.16	23	41.8	39.0
2.	M-16.9	31	42.3	31.5
3.	GI-5.9	30	43.2	40.0
4.	GI-10.3	30	44.6	37.0
5.	GI-15.5	32	38.0	34.9
6.	GII-19.5	29	40.8	34.4
7.	GII-20.4	27	42.1	43.3
8.	GIV-18.5	32	41.0	35.9
9.	GIV-35.7	28	45.5	45.5
10.	S-44.1	29	43.6	40.0
11.	GVI-51	35	37.1	31.3
12.	GVI-54	38	40.3	40.2
13.	GVI-55	32	43.6	33.5
14.	GVI-64	22	40.3	46.2
15.	GVI-68	29	44.5	28.8

and small based on the size. The number of leaves belonging to each group of a tree was counted and data recorded. A sample of 100 leaves of each size group was taken in such a way that there was high variability within each size group. The total leaf area of 100 leaves of each group was then recorded separately using Leaf Area Meter. From the calculated mean leaf area of each size group and the total number of leaves of each group of each tree, total leaf area per plant was calculated. Leaf area index was then worked out assuming 3 m x 3 m as the land area.

Statistical analysis

Observations on wet bean yield and leaf area index (LAI) were taken for top worked plants of both the sets separately for comparing their performance after top working. The data were statistically analysed using analysis of variance technique (Panse and Sukhatme, 1978). For analysis, clones were taken as treatments, number of plants per clone as replications and the design as CRD (completely randomised design) with variable replications.

For the top worked plants of Set I, total wet bean yield per tree was recorded during 1994-'96 and that for Set II during 1995-'96. For both the sets, yield was expressed as wet bean weight per tree per year. Girth of the stock plants a year prior to top working was used as pre-experimental girth. Yield of this stock plants prior to top working for a two year period expressed as number of pods per tree per year was taken as the pre-experimental yield.

In order to assess the extent of stock effect, simple correlations were worked out between pre-experimental girth and yield after top working as per the technique suggested by Cochran and Cox (1957). Similar correlations were worked out between yields of experimental and pre-experimental periods. Multiple correlation was determined to find the association of girth and yielding ability of stock plant on the performance of top worked plants.

Assessment of the influence of LAI of the top worked plants on its yielding ability was done by correlating it with yield after top working. Mean yield of top worked clones after separating out the stock effect and influence of LAI was compared by performing analysis of covariance taking pre-experimental yield, pre-experimental girth and LAI as covariates separately. Data were subjected to square root transformation for statistical analysis.

Results

RESULTS

The data collected for various characters of the crop were tabulated and subjected to statistical analysis. The results are presented in this chapter.

4.1 Variability studies

Analysis of variance was done separately for the two sets of plants for wet bean yield and leaf area index (LAI). Since the estimates of the coefficient of variation were relatively high for the characters, the data were subjected to square root transformation and further analysis was carried out using transformed data. Results obtained for the various characters of both the sets studied are presented separately.

4.1.1 Set I

4.1.1.1 Yield after top working

The plants of this set were top worked 36 to 66 months before collection of data and the yield relates to a period of 24 months. Yield expressed as wet bean weight per tree per year was recorded for the 143 top worked plants belonging to 26 different clones. The data given in Table 6 showed that the yield per tree varied widely among the clones. Clone GII-19.5 recorded the highest mean yield of 10.1 kg/tree.

Table 6. Mean wet bean yield and leaf area index (LAI) of top worked clones of Set I

Sl. No.	Clone used	No.of plants	*Mean yield, kg $plant^{-1}$ $year^{-1}$	*Mean LAI
1.	GVI-51	2	4.1 (7.9)	1.9 (3.5)
2.	GVI-54	4	1.9 (1.4)	1.6 (2.7)
3.	GVI-55	4	2.3 (2.4)	1.4 (2.0)
4.	GVI-56	4	2.6 (2.9)	1.3 (1.9)
5.	GVI-59	6	2.6 (2.9)	1.4 (1.9)
6.	GVI-60	4	2.9 (3.8)	1.7 (3.4)
7.	GVI-61	6	2.8 (3.7)	1.6 (2.6)
8.	GVI-64	6	2.2 (2.3)	1.2 (1.6)
9.	GVI-68	5	3.2 (4.9)	1.3 (1.7)
10.	M-9.16	7	2.1 (1.9)	1.2 (1.6)
11.	M-16.9	6	3.4 (5.8)	1.6 (3.1)
12.	GI-4.8	8	2.8 (3.7)	1.6 (3.1)
13.	GI-5.9	8	3.6 (6.2)	1.2 (1.6)
14.	GI-10.3	6	1.6 (0.8)	1.2 (1.9)
15.	GI-15.5	6	3.1 (4.4)	1.6 (2.5)
16.	GII-12.3	7	2.2 (2.3)	1.6 (3.0)
17.	GII-19.5	2	4.5(10.1)	2.5 (6.2)
18.	GII-20.4	6	3.1 (4.5)	1.7 (2.6)
19.	GIII-1.2	7	1.8 (1.2)	1.3 (2.0)
20.	GIII-4.1	8	2.3 (2.2)	1.3 (1.8)
21.	GIV-2.5	6	2.1 (1.7)	1.3 (2.0)
22.	GIV-18.5	6	2.4 (2.3)	1.6 (2.8)
23.	GIV-32.5	8	2.2 (2.2)	1.1 (1.1)
24.	S-44.1	5	2.2 (2.2)	1.8 (3.6)
25.	S-50.12	4	3.1 (4.8)	1.6 (2.7)
26.	S-51.1	2	1.4 (0.5)	1.8 (3.2)
F			S (P=0.01)	NS (P=0.05)
C.V.			(62.2%) 26.5% *	(66.4%) 32.4% *

* Transormed data. The figures in parenthesis are in orginal scale

This was followed by clone GVI-51 and GI-5.9 with mean yields of 7.9 kg and 6.2 kg, respectively. The mean yield was lowest for clone S-51.1 with a value of 0.5 kg. The coefficient of variation was very high with a value of 62.2 per cent which came down to 26.5 per cent on square root transformation. Analysis of variance done using the transformed data showed that clones differed significantly among themselves, the F value being significant at P=0.01. The yield of clone M-16.9 was on par with clone GI-5.9. Of the 26 clones studied, only four clones yielded more than 5 kg/tree on average basis. These four clones in the decreasing order of the mean yield were GII-19.5, GVI-51, GI-5.9 and M-16.9. Clones which were ranked as medium were GVI-68, S-50.12, GII-20.4 and GI-15.5. These had an yield range from 4.4 to 4.9 kg per tree.

4.1.1.2 Leaf area index of top worked clones

Data on the LAI of 26 clones showed wide variation among themselves (table 6). Clone GII-19.5 recorded a very high LAI of 6.2 followed by clone S-44.1 and GVI-51 with average value of 3.6 each. Clone GIV-32.5 recorded the minimum leaf area index. Of the 26 clones studied, clones GII-19.5, S-44.1, GVI-51, GVI-60, S-51.1, M-16.9, GI-4.8 and GII-12.3 had average LAI values of more than three. The coefficient of variation was found to be 32.4 per cent on transformation. Analysis of variance done using the transformed values showed that clones do not vary significantly among themselves for LAI.

4.1.2 Set II

4.1.2.1 Yield after top working

These plants were top worked seventeen months before collection of data and the yield relates to a period of twelve months. Yield expressed as wet bean weight per tree per year was recorded for the 447 top worked plants belonging to fifteen different clones (Table 7). The mean yield per tree showed wide variation among clones. Clone GI-5.9 recorded the highest mean yield of 5.3 kg followed by the clone GVI-55 with mean yield of 4.7 kg. The lowest value of 0.6 kg was recorded for clone M-9.16. The coefficient of variation which was 99.9 per cent on transformation came down to 32.8 per cent. Analysis of variance done using transformed data showed that the clones differed significantly among themselves, the F value being significant at P=0.01. Except clone GI-5.9 and GVI-55 all other clones yielded less than 4 kg/tree.

4.1.2.2 Leaf area index of top worked plants

The mean values recorded for LAI showed wide variation as revealed by the data given in Table 7. It ranged from 1.1 for clone M-9.16 to 2.7 for clone S-44.1. Out of the fifteen

Table 7. Mean wet bean yield and leaf area index (LAI) of top worked clones of Set II

Sl. No.	Clone used	No.of plants	*Mean yield, kg plant^{-1} year^{-1}	*Mean LAI
1.	M-9.16	23	1.2 (0.6)	1.0 (1.1)
2.	M-16.9	31	1.7 (2.2)	1.2 (1.6)
3.	GI-5.9	30	2.4 (5.3)	1.3 (1.8)
4.	GI-10.3	30	1.8 (2.7)	1.2 (1.5)
5.	GI-15.5	32	1.3 (1.0)	1.5 (2.6)
6.	GII-19.5	29	1.9 (3.0)	1.5 (2.5)
7.	GII-20.4	27	2.4 (3.5)	1.2 (1.6)
8.	GIV-18.5	32	1.9 (3.0)	1.4 (1.9)
9.	GIV-35.7	28	1.5 (1.4)	1.3 (2.0)
10.	S-44.1	29	1.3 (1.0)	1.6 (2.7)
11.	GVI-51	35	1.4 (0.9)	1.5 (2.3)
12.	GVI-54	38	1.6 (1.9)	1.0 (1.1)
13.	GVI-55	32	2.3 (4.7)	1.1 (1.3)
14.	GVI-64	22	1.7 (2.4)	1.3 (1.7)
15.	GVI-68	29	1.3 (0.8)	1.1 (1.4)
F (P=0.01)			S	S
C.V.			(99.9%) 32.8% *	(53.2%) 27.4% *

* Transormed data. The figures in parenthesis are in orginal scale

clones, clones S-44.1, GI-15.5, GII-19.5 and GVI-51 recorded LAI values of more than two. Coefficient of variation for the transformed data was 27.4 per cent. Analysis of variance done using transformed values showed that clones varied significantly in LAI, the F value being significant at P=0.01.

4.2 Stock effect on the performance of top worked plants

4.2.1 Set I

Simple correlation studies conducted to determine the association of yield of top worked plants with the stem girth of stock plants prior to top working showed that it was not significant (r=0.059). Similar correlation studies made between pre-experimental yield of top worked plants and the yield after top working also showed no significant correlation (r=0.139). Multiple correlation of pre-experimental girth and yielding ability of stock plant with the yield of top worked plants also showed no significant relationship (R^2=0.020).

4.2.2 Set II

Simple correlation between stem girth of stock plants and yield of top worked plants showed significant correlation (r=0.156). The association of pre-experimental yield of top worked plants on the yield of top worked plants also showed significant correlation (r=0.128). Multiple correlation between pre-experimental girth and yield of top worked plants also showed significant relationship (R^2=0.028).

4.3 Leaf area index (LAI) as a factor affecting yield

4.3.1 Set I

Correlation of yield of top worked plants with LAI of these plants was found to be significant (r=0.38). To separate out the clone-related differences in growth vigour, further statistical treatment of data was done by determining correlation coefficient of residual effects of yield (after eliminating the clonal differences in yield and LAI). The correlation coefficient of the yield of top worked plants with LAI after eliminating the clonal effect was 0.378.

4.3.2 Set II

The association of yield of top worked plants on LAI of these plants was also found to be significant (r=0.20). After separating out the clonal effect, correlation of yield of top worked plants with LAI was 0.198.

4.4 Comparison of the yield of top worked plants after separating out the stock effect and influence of leaf area index

4.4.1 Set I

Analysis of variance carried out to compare the yield of top worked clones without making adjustment for the variation in pre-experimental girth, pre-experimental yield and LAI showed significant variation among the clones. In order to separate out the stock effect and differences in LAI on the yielding ability of top worked plants, analysis of covariance was carried out taking pre-experimental girth, pre-experimental yield and LAI as ancillary variables. Simple regression analysis showed that dependence of yield of top worked plants on pre-experimental girth and pre-experimental yield was not significant. Similar regression analysis of yield on LAI of top worked plants showed significant dependence of yield on LAI. Analysis of covariance worked out after making adjustment for the variability in LAI of clones also showed significant difference between clones in yield (P=0.01). For the comparison of the yield of top worked clones, the mean clonal yield was adjusted for the regression of yield on LAI. It was observed that clone GII-19.5 gave the maximum yield of 8.2 kg wet beans per tree. Other clones which were found superior were GVI-51, GI-5.9, M-16.9, GVI-68 and S-50.12. The yield ranged from 4.7 to 7.3 kg wet beans per tree (Table 8). The coefficient of variation in the

Table 8. Mean wet bean yield of top worked clones of Set I adjusted for leaf area index

Sl. No.	Clone used	No.of plants	Mean yield adjusted for LAI, kg $plant^{-1}$ $year^{-1}$
1.	GVI-51	2	7.3
2.	GVI-54	4	1.2
3.	GVI-55	4	2.6
4.	GVI-56	4	3.1
5.	GVI-59	6	3.2
6.	GVI-60	4	3.2
7.	GVI-61	6	3.5
8.	GVI-64	6	2.6
9.	GVI-68	5	5.2
10.	M-9.16	7	2.2
11.	M-16.9	6	5.4
12.	GI-4.8	8	3.3
13.	GI-5.9	8	6.6
14.	GI-10.3	6	1.0
15.	GI-15.5	6	4.3
16.	GII-12.3	7	2.0
17.	GII-19.5	2	8.2
18.	GII-20.4	6	4.3
19.	GIII-1.2	7	1.4
20.	GIII-4.1	8	2.5
21.	GIV-2.5	6	1.9
22.	GIV-18.5	6	2.3
23.	GIV-32.5	8	2.7
24.	S-44.1	5	1.6
25.	S-50.12	4	4.7
26.	S-51.1	2	0.0

C.V. 55.5%

Table 9. Ranking of clones of Set I and their comparison using yield adjusted for LAI

Clones used			Non homogenous clones (No.)	
Rank No.	Clone	Clone No.	Superior	Interior
1.	GVI-51	17	-	16,21,24,19,2,14,26
2.	GVI-54	1	-	19,14,26
3.	GVI-55	13	-	23,8,20,22,10,16,21, 24,19,2,14,26
4.	GVI-56	11	-	14
5.	GVI-59	9	-	-
6.	GVI-60	25	-	-
7.	GVI-61	18	-	-
8.	GVI-64	15	-	-
9.	GVI-68	7	-	-
10.	M-9.16	12	-	-
11.	M-16.9	6	-	-
12.	GI-4.8	5	-	-
13.	GI-5.9	4	-	-
14.	GI-10.3	23	13	-
15.	GI-15.5	8	13	-
16.	GII-12.3	3	-	-
17.	GII-19.5	20	13	-
18.	GII-20.4	22	13	-
19.	GIII-1.2	10	13	-
20.	GIII-4.1	16	17,13	-
21.	GIV-2.5	21	13	-
22.	GIV-18.5	24	17,13	
23.	GIV-32.5	19	13	-
24.	S-44.1	2	17,13	-
25.	S-50.12	14	-	-
26.	S-51.1	26	1,13	-

adjusted yield data was also high (55.5%). Statement on statistical homogeneity of the clones is given in Table 9.

4.4.2 Set II

Analysis of variance carried out to compare the yield of top worked clones without making adjustment for variation in pre-experimental girth, pre-experimental yield and LAI showed significant variation among clones. Analysis of covariance was carried out using pre-experimental girth, pre-experimental yield and LAI as ancillary variables so as to separate out the stock effect and differences in LAI on the yielding ability of top worked plants. Simple regression analysis revealed significant dependence of the yield of top worked plants on pre-experimental yield, pre-experimental girth and LAI. Analysis of covariance was carried out separately for each of these ancillary characters. Clones showed significant difference in yield even after separating the variability due to each of the ancillary characters (P=0.01).

Comparison of the mean yield of top worked clones after making adjustment for the regression of yield on pre-experimental girth showed that clone GI-5.9 was superior to others with a mean value of 5.26 kg wet beans per tree. Other clones found to be superior were GVI-55, GII-20.4, GII-19.5 and GIV-18.5. The yield ranged from 3.03 to 4.67 kg wet beans adjusted yield data was also high (55.5%). Statement on statistical homogeneity of the clones is given in Table 9.

4.4.2 Set II

Analysis of variance carried out to compare the yield of top worked clones without making adjustment for variation in pre-experimental girth, pre-experimental yield and LAI showed significant variation among clones. Analysis of covariance was carried out using pre-experimental girth, pre-experimental yield and LAI as ancillary variables so as to separate out the stock effect and differences in LAI on the yielding ability of top worked plants. Simple regression analysis revealed significant dependence of the yield of top worked plants on pre-experimental yield, pre-experimental girth and LAI. Analysis of covariance was carried out separately for each of these ancillary characters. Clones showed significant difference in yield even after separating the variability due to each of the ancillary characters (P=0.01).

Comparison of the mean yield of top worked clones after making adjustment for the regression of yield on pre-experimental girth showed that clone GI-5.9 was superior to others with a mean value of 5.26 kg wet beans per tree. Other clones found to be superior were GVI-55, GII-20.4, GII-19.5 and GIV-18.5. The yield ranged from 3.03 to 4.67 kg wet beans per tree. Clones rated as poor yielders were S-44.1, GVI-68 and M-9.16 whose yield ranged from 0.59 to 0.88 kg wet beans per tree (Table 10). Coefficient of variation in the adjusted yield data was 62.06 per cent.

Comparison of the mean yield of top worked clones after making adjustment for regression of yield on pre-experimental yield showed that clone GI-5.9 yielded better than others with a mean value of 5.29 kg wet beans per tree (Table 10). Other clones that were found to be superior were clone GVI-55, GII-20.4, GII-19.5 and GIV-18.5. Coefficient of variation of the adjusted yield data was 62.67 per cent.

Clone that was found superior after separating out the influence of LAI was GI-5.9 with a mean value of 5.31 kg wet bean weight per tree. Clones GVI-55, GII-20.4, GIV-18.5, GI-10.3 and GII-19.5 were also found to be superior with an yield range 2.42 kg to 5.14 kg wet bean weight per tree (Table 10). Coefficient of variation in the adjusted yield data was 68.53 per cent. Statement on statistical homogeneity is given in Table 11.

4.5 Extent of advantage from top working

Comparing the overall mean yield of plants before top working and yield of clones after top working, the extent of yield advantage from top working cocoa was calculated.

Table 10. Mean wet bean yield of top worked clones of Set II adjusted for different covariate characters

Sl. No.	Clone used	No.of plants	Yield adjusted for different covariates, kg plant^{-1} year^{-1}		
			Girth	Pre-experimentl yield	LAI
1.	M-9.16	23	0.59	0.57	1.17
2.	M-16.9	31	2.20	2.28	2.36
3.	GI-5.9	30	5.26	5.29	5.31
4.	GI-10.3	30	2.63	2.75	3.04
5.	GI-15.5	32	1.11	0.98	0.34
6.	GII-19.5	29	3.04	3.02	2.42
7.	GII-20.4	27	4.54	3.40	3.67
8.	GIV-18.5	32	3.03	3.01	2.90
9.	GIV-35.7	28	1.22	1.29	1.25
10.	S-44.1	29	0.88	0.92	1.26
11.	GVI-51	35	1.14	1.00	0.53
12.	GVI-54	38	2.01	1.91	2.53
13.	GVI-55	32	4.67	4.78	5.14
14.	GVI-64	22	2.49	2.33	2.53
15.	GVI-68	29	0.70	0.91	1.13
	C.V.		62.06%	62.67%	68.53%

Table 11. Ranking of clones of Set II and their comparison using yield adjusted for LAI

Clones used			Non homogenous clones (No.)
Rank No.	Clone	Clone No.	
1.	M-9.16	3	13
2.	M-16.9	13	3
3.	GI-5.9	7	4,8,14
4.	GI-10.3	4	7,8,14,12,6,2
5.	GI-15.5	8	7,4,14,12,6,2
6.	GII-19.5	14	7,4,8,12,6,2
7.	GII-20.4	12	4,8,14,6,2
8.	GIV-18.5	6	4,8,14,12,2
9.	GIV-35.7	2	4,8,14,12,6,9
10.	S-44.1	9	2,1,15,11,5,10
11.	GVI-51	1	9,15,11,5,10
12.	GVI-54	15	9,1,11,5,10
13.	GVI-55	11	9,1,15,5,10
14.	GVI-64	5	9,1,15,11,10
15.	GVI-68	10	9,1,15,11,5

Table 12. Mean yield of stock plants and top worked clones of Set I

Sl. No.	Clone used	No.of plants	Yield, pods plant^{-1} year^{-1} Pre-experimental (1986-88)	Experimental (1994-96)
1.	GVI-51	2	3.0	38.3
2.	GVI-54	4	9.3	11.5
3.	GVI-55	4	6.3	12.2
4.	GVI-56	4	14.2	20.9
5.	GVI-59	6	17.5	37.4
6.	GVI-60	4	11.4	26.3
7.	GVI-61	6	20.0	24.9
8.	GVI-64	6	6.1	17.4
9.	GVI-68	5	23.5	42.1
10.	M-9.16	7	11.2	30.4
11.	M-16.9	6	12.8	37.7
12.	GI-4.8	8	14.9	34.1
13.	GI-5.9	8	14.5	44.5
14.	GI-10.3	6	14.6	6.8
15.	GI-15.5	6	11.3	40.4
16.	GII-12.3	7	11.8	17.2
17.	GII-19.5	2	24.3	61.0
18.	GII-20.4	6	17.1	33.1
19.	GIII-1.2	7	10.5	11.2
20.	GIII-4.1	8	9.4	21.2
21.	GIV-2.5	6	24.1	14.8
22.	GIV-18.5	6	10.5	18.1
23.	GIV-32.5	8	15.2	14.2
24.	S-44.1	5	30.7	17.0
25.	S-50.12	4	7.2	45.9
26.	S-51.1	2	6.3	9.5
	Total		357.9	688.1
	Mean		13.8	26.5

Table 13. Mean yield of stock plants and top worked clones of Set II

Sl. No.	Clone used	No.of plants	Yield, pods $plant^{-1}$ $year^{-1}$	
			Pre-experimental (1991-93)	Experimental (1995-96)
1.	M-9.16	23	39.0	9.5
2.	M-16.9	31	31.5	14.5
3.	GI-5.9	30	40.0	38.0
4.	GI-10.3	30	37.0	22.5
5.	GI-15.5	32	34.8	8.8
6.	GII-19.5	29	34.4	18.1
7.	GII-20.4	27	43.3	25.7
8.	GIV-18.5	32	35.9	21.9
9.	GIV-35.7	28	45.4	13.7
10.	S-44.1	29	40.0	7.6
11.	GVI-51	35	31.3	5.3
12.	GVI-54	38	40.2	16.8
13.	GVI-55	32	33.5	17.3
14.	GVI-64	22	46.2	18.8
15.	GVI-68	29	28.8	7.1
	Total		561.3	245.6
	Mean		37.4	16.3

4.5.1 Set I

Overall mean number of pods per plant for a two year period prior to top working was 13.8 pods per year and comparable value for the clones 36 to 66 months after top working was 26.5 pods per year, a gain of 92 per cent (Table 12.

4.5.2 Set II

Overall mean number of pods per plant for two year period prior to top working was 37.4 pods per year and comparable value for the clones seventeen months after top working was 16.3 pods per year. It was observed that 44 per cent of the pre-experimental yield was made up within seventeen months after top working (Table 13).

Discussion

DISCUSSION

Cocoa populations arising from seedlings show a lot of variation in yield. The extent of such variation is high that often about 75 per cent of the yield is recovered from about 25 per cent of the plants. This is one of the reasons for low productivity and returns from thousands of existing cocoa plantations in the country. One of the methods of improving the genetic potential of an existing population is top working.

Establishment of top worked plants is faster than newly budded plants. There are, however, large differences in yield of top worked plants. Attempts were made in an earlier study (Nair *et al.*, 1994) to explain the intraclonal variation and a part of it was attributed to the stock effect. The present study on top worked cocoa plants carried out in order to study the growth and yield performance of top worked cocoa plants should be viewed with this background.

In this study, attempts were made to determine the stock effect measured in terms of pre-experimental girth and pre-experimental yield of top worked cocoa plants of two age groups. Assessment of the effect of other factors deciding intraclonal differences, quantifying the extent of yield advantage from top working and identifying clones that are superior as scions for top working were the other objectives.

5.1 Variability in the yield of top worked cocoa clones

Studies on variability of biometric characters in cocoa have been reported as early as 1923-'33 by Pound in Trinidad. This, as well as studies carried out in subsequent years revealed that yield of cocoa expressed as wet bean weight is a highly variable character. High variability in weight of seed was observed even within a single pod (Enriquez and Soria, 1966).

In the present study, high degree of variability was observed for yield of top worked clones of both the age groups (Tables 6 and 7). Yield expressed as wet bean weight per tree per year ranged from 0.5 kg to 10.1 kg with a mean of 3.2 kg for the clones of Set I (36 to 66 months after top working). In Set II (seventeen months after top working), it ranged from 0.8 kg to 5.3 kg with a mean 2.3 kg. For both the sets, between - clone variability was more than within - clone variability. This is in confirmity with the results observed by Nair *et al.* (1994).

An assessment of intraclonal variation of top worked clones was made using coefficient of variation. It was very high in both the sets, the values being 62.2 per cent for Set I and 99.9 per cent for Set II. Comparing between the two age groups, the variability was much larger in younger plants. A decline with advancing age is attributable to stabilization of yield in older plants. As was observed in an earlier study, part of the variation is attributable to stock effect. It is, however, to be noted that further statistical treatment of data led to the conclusion that significant effect of this factor disappeared in older plants and that it was operational only in the early years. Further discussion on the factors responsible for this will be made in due course.

5.2 Stock effect on the performance of top worked plants

In the top worked plants of Set I, simple and multiple correlation studies of pre-experimental girth and pre-experimental yield with yield of top worked plants showed no significant association of yield with these parameters. It is to be noted that in an earlier study using a set of plants drawn from the same population had shown significant correlation with both the parameters of stock effect included in this study. The disappearance of such a significant association is clearly indicative of the fact that some other factors dominate after a few years of top working. A comparison with such correlation values of Set II also leads to the same conclusion. Correlation coefficient values with both the parameters viz., pre-experimental girth and pre-experimental yield were both significant in this set. In order to find out the combined effect of both these factors on yield, multiple correlation coefficient was worked out. This was also statistically significant. Such a consistent statistically significant association cannot be neglected and the necessary conclusion is to be that the condition of the stock plants affects the performance of top worked clones in terms of yield. As mentioned earlier, there is disappearance of this significant stock effect with further growth of plants. There are reports of association of stock vigour on performance of grafted fruit trees like mango (Teaotia *et al.*, 1970) and apple (Kohli and Reddy, 1989).

In an attempt to separate out the stock effect and to quantify the extent of involvement of this factor, data relating to Set II were subjected to analysis of covariance. Such an exercise on Set I was not attempted as the relation with these stock characters was not statistically significant. In Set II, pre-experimental girth and pre-experimental yield were separately used as covariates and interclonal differences were assessed using analysis of covariance. This adjustment for pre-experimental vigour is expected to eliminate part of the variation and lead to decrease in coefficient of variation. The data collected, however, showed that though coefficient of variation came down to an extent, there was still a lot of residual variability resulting in coefficient of variation values as high as 62.1 per cent and 62.8 per cent, respectively, when girth and previous yield were separately used as covariates (Table 10). It is concluded that even in young plants, stock effect only partially accounts for the differences between the plants of the same clone.

It is also noted from the data, even after eliminating the effects of pre-experimental vigour using analysis of covariance that differences continued to be highly significant indicating that such residual variation is the major factor deciding the performance of vegetatively modified plants.

5.3 Leaf area index (LAI) as a factor influencing yield of top worked cocoa plants

It was observed that plants of Set I showed higher variation in LAI (CV = 66.4 per cent) compared to the plants of Set II (CV = 53.3 per cent). Mean LAI values ranged from 1.1 to 6.2 for top worked clones of Set I (Table 6) and 1.1 to 2.7 for those of Set II (Table 7). The overall mean values of LAI for Set I and Set II were 2.4 and 1.8, respectively. In an attempt to find out the extent of relationship of this vegetative character with yield, simple correlation coefficients were worked out between wet bean yield and LAI. The correlation coefficient values were highly significant in

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both Set I and II. Significant relation between LAI and yielding ability has been reported by Almeida and Valle (1988) in cocoa.

Significant association between LAI and yield can arise out of clonal differences in LAI which are reflected in yield or through the association of these two characters between plants of the same clone. In Set I, the differences between clones in LAI assessed through analysis of variance was not found to be statistically significant (Table 6). In Set II, on the contrary, this character showed significant differences between clones (Table 7) indicating thereby that the top worked clone can decide vigour of top worked canopy for some time after the operation but not after about three years. As evidenced by the lack of significant difference in LAI between clones, it is to be concluded that the major factor deciding significant correlation between LAI and yield should be arising out of intraclonal differences. In Set II, on the contrary, clonal differences in LAI were significant. Correlation with yield was also significant. In this set, therefore, the relationship between LAI and yield can at least partly arise out of clonal differences in vigour affecting the yield. To separate out such clone-related differences in growth vigour, further statistical treatment of data was done by determining correlation coefficient of residual effects of yield and LAI (after eliminating clonal differences in yield).

This step would eliminate the clonal effect on yield through the influence of LAI. The estimated correlation coefficient values were nearly comparable indicating, thus, that even in Set II, the clonal difference did not influence yield through this character of LAI. In an attempt to separate out the influence of LAI on yield and to quantify the extent of involvement of this factor, the data relating to both the sets were subjected to analysis of covariance. But there were still large variability noted in the adjusted yield data (Table 8 and 10) as indicated by very high coefficient of variation values of 55.5 per cent and 68.5 per cent for Set I and II, respectively. It is concluded that apart from LAI there are certain other factors influencing the yield in the initial and later years after top working.

Conclusions out of this discussion may be summarised as follows:

1. Clones influence early growth vigour of top worked canopy.

2. Clonal differences in LAI are significant only in the early stages.

3. Clone-induced differences in LAI do not influence the yield of clones.

4. There are large intraclone, plant to plant differences in canopy development which directly and significantly influence the yield.

5. All grown-up clones which are included in the trial produced nearly comparable canopy.

6. Significant plant to plant difference in canopy development may arise out of stock effect in the early years. But these disappear after about three years.

7. Factors other than stock effect and clonal differences are responsible for the large plant to plant intraclonal differences in vigour which is strongly related with yield. One of the probable factors responsible for these plant to plant differences in LAI is the early advantage in growth that a few plants get which enable them to grow out and smother the neighbouring plants. The smothered plants continue to be of poor canopy development and therefore of poor yielding ability.

5.4 Extent of advantage from top working

Comparison of the overall mean yield of plants before and after top working revealed that a gain of 92 per cent per year could be obtained by top working with superior clones within a period of three to four years (Table 12).

Performance of the top worked plants of Set II indicates that about 44 per cent of the pre-experimental yield could be obtained in a year following a period of seventeen months after top working (Table 13). In an earlier study using a set of plants drawn from the same population as Set I, Nair *et al*. (1994) observed a gain of 113 per cent per year during a period from 31 to 42 months after top working.

5.5 Identification of superior clones for top working

As the top worked plants of Set I only had attained full canopy development and probable stabilization of yield, identification of the superior clones was possible only from this set. Of the 26 clones used for top working, clones GII-19.5, GVI-51, GI-5.9, M-16.9 and GVI-68 were found to be superior (Table 6) with respect to yield. Mean yield values ranged from 4.9 to 10.1 kg wet beans per year in these clones.

The important conclusions from this study may be summarised as follows:

1. There are large differences in the yield of top worked clones both between and within plants of the same clone. The interclonal differences explainable as due to genetic factors are more than the intraclonal differences.

2. There are also large intraclonal, plant to plant differences in yield.

3. Part of this intraclonal variation is attributed to stock effect. However, this stock effect persists only in the early years.

4. One of the important factors responsible for the intraclonal difference in yielding ability is the difference in growth vigour as judged by the leaf area index.

5. The clones that were found superior as scions for top working are GII-19.5, GVI-51, GI-5.9, M-16.9 and GVI-68.

Summary

SUMMARY

A study was conducted at the College of Horticulture, Vellanikkara, Trichur from October 1994 to March 1996 to assess the growth and yield of top worked cocoa (*Theobroma cacao* L.) plants and to determine the stock effect measured in terms of pre-experimental girth and pre-experimental yield of these plants of two age groups. Assessment of the factors other than stock effect deciding the intraclonal differences, quantifying the extent of yield advantage from top working and identifying clones that are superior as scions for top working were the other objectives.

A total of 590 top worked cocoa plants of two age groups were utilised for this study. The first set of plants consisted of 143 plants originally planted in 1979 and top worked in November 1988 to September 1991 using 26 high yielding clones. Observations of these top worked plants were taken for a period from April 1994 to March 1996 which corresponds to a lapse of 36 to 66 months after top working. It was assumed that these plants had come to steady bearing and that the period after top working was not a critical factor affecting the yield. The second set included 447 plants originally planted in 1979 and top worked during October 1993 using fifteen selected high yielding clones. Yield data for the early period of bearing, seventeen months

after snapping for top working were collected from April 1995 to March 1996 for these top worked plants. In order to assess the extent of stock effect, data on pre-experimental girth (a year prior to top working) and pre-experimental yield (two year period prior to top working) of both sets of plants available at Cadbury-KAU Co-operative Cocoa Research Project, Vellanikkara were utilised for the study. In order to determine the influence of canopy development on yield of top worked plants, leaf area index of these top worked plants was measured during 1996. Statistical analysis of the data led to the following conclusions.

1. There were large differences in the yield of top worked clones both between clones and within plants of the same clone. The interclonal differences explainable as due to genetic factors were much larger than instraclonal differences.

2. Part of the intraclonal variation was attributed to stock effect. However, this stock effect persisted only in the early years.

3. Clones influence early growth vigour of top worked canopy.

4. Clonal differences in LAI were significant only in the early stages.

5. Clone - induced differences in LAI do not influence the yield of clones.

6. There were large intraclone, plant to plant differences in canopy development which directly and significantly influenced the yield.

7. All the grown-up clones which were included in the trial produced nearly comparable canopy.

8. Significant plant to plant differences in canopy development may arise out of stock effect in the early years. But these disappeared after about three years.

9. Factors other than stock effect and clonal differences were responsible for the large plant to plant intraclonal differences in vigour which were strongly related with yield.

10. One of the probable factors responsible for these plant to plant differences in LAI was the early advantage that a few plants got which enabled them to grow out and smother the neighbouring plants. The smothered plants continued to be of poor canopy development and therefore of poor yielding ability.

11. One of the important factors responsible for the intraclonal differences in yielding ability was the difference in growth vigour as judged by leaf area index.

12. The clones GII-19.5, GVI-51, GI-5.9, M-16.9 and GVI-68 were superior as scions for top working.

13. The yield gain from top working was found to be 92 per cent after about three years. This practice was found to result in harvestable yield in about a year after top working and as much as 44 per cent of the pre-experimental yield of stock plants could be recovered after seventeen months.

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GROWTH AND YIELD ANALYSIS OF TOP WORKED COCOA PLANTS

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ABSTRACT OF A THESIS

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ABSTRACT

The present study 'growth and yield analysis of top worked cocoa (*Theobroma cacao* L.) plants' was conducted during October 1994 to March 1996 at the College of Horticulture, Vellanikkara, Trichur. A total of 590 top worked cocoa plants of two age groups, top worked with 29 high yielding clones were utilised for the study. Observations of 143 top worked plants of first set were taken for a period from April 1994 to March 1996 which corresponds to a lapse of 36 to 66 months after top working. Those of second set were taken for the early period of bearing, from April 1995 to March 1996 which corresponds to a lapse of seventeen months after top working. Stock effect on the performance of top worked plants was measured in terms of pre-experimental girth (a year prior to top working) and pre-experimental yield (two year period prior to top working) of these plants prior to top working. Differences in growth vigour as a factor influencing yield was judged by assessing leaf area index. There were large differences in the yield of top worked clones both between and within plants of the same clone. The interclonal differences explainable as due to genetic factors were more than intraclonal differences. There were also large intraclonal, plant to plant differences in yield. Part of this intraclonal

variation was attributed to stock effect. However, this stock effect persisted only in the early years. One of the important factors responsible for the intraclonal differences in yielding ability was the differences in growth vigour as judged by leaf area index. Clones that were identified as scions superior for top working were GII-19.5, GVI-51, GI-5.9, M-16.9 and GVI-68. Top worked plants come to bearing in about a year after the operation and as much as 44 per cent of the pre-experimental yield was recovered after seventeen months. The extent of yield advantage after yield stabilisation was 92 per cent.