Yield Prediction in Cocoa (*Theobroma cacao* L.)

By

JAYASREE K.

THESIS

submitted in partial fulfillment of the
requirement for the degree of

Master of Science in Agricultural Statistics

Faculty of Agriculture
Kerala Agricultural University

Department of Agricultural Statistics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR-680 656
KERALA, INDIA
2009

DECLARATION

I hereby declare that this thesis entitled **"Yield Prediction in Cocoa (*Theobroma cacao* L.) "** is a bonafide record of research work done by me during the course of research and that this thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title of any other University or Society.

Vellanikkara **Jayasree K.**

CERTIFICATE

Certified that this thesis entitled **"Yield Prediction in Cocoa (*Theobroma cacao* L.)"** is a record of research work done independently by Ms. Jayasree K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associate ship to her.

Vellanikkara

Dr. Laly John C.
(Chairperson, Advisory Committee)
Associate Professor,
Department of Agricultural Statistics,
College of Horticulture,
Vellanikkara

CERTIFICATE

We, the undersigned members of the advisory committee of Ms.Jayasree K, a candidate for the degree of Master of Science in Agricultural Statistics, agree that the thesis entitled "**Yield Prediction in Cocoa (*Theobroma cacao* L.)**" may be submitted by Jayasree K. in partial fulfillment of the requirement for the degree.

Dr. C. Laly John
(Chair Person)
Associate Professor (Agricultural Statistics),
College of Horticulture,
Vellanikkara.

Sri. P.Gangadharan,
(Member)
Associate Professor & Head ,
Dept. of Agricultural Statistics,
College of Horticulture,
Vellanikkara

Sri. S.Krishnan,
(Member)
Assistant Professor (Sel. Gr.),
Dept. of Agricultural Statistics,
College of Horticulture,
Vellanikkara

Dr.S. Prasannakumari Amma,
(Member)
Professor & Head,
Cadbury – KAU Cooperative Cocoa Research
Project, College of Horticulture,
Vellanikkara

Dr. Sathianandan T.V
(External Examiner)
Senior Scientist
Fishery Resources Assessment Division
Central Marine Fisheries Research Institute
Kochi - 18

ACKNOWLEDGEMENT

First and foremost I bow my head before the Almighty God who enabled me to successfully complete the thesis work in time.

I express my deepest sense of respect, gratitude and indebtedness to Dr. Laly John C, Chairman of Advisory Committee, Associate Professor, Department of Agricultural Statistics, College of Horticulture, Vellanikkara for her critical comments, constant encouragement, ever willing help, well timed advice and extreme patience throughout the course of my study period and in the preparation of this thesis. I am very fortunate to be her student and without her cooperation and advice, I would not have been able to complete this work.

I consider it as my privilege to express my deep-felt gratitude to Sri. Gangadharan P, Associate Professor and Head, Department of Agricultural Statistics, College of Horticulture, Vellanikkara, for his sustained interest and scholarly suggestions throughout the course of my work.

I would like to utilize this opportunity to extend my profound sense of gratitude and sincere thanks to Sri. Krishnan S, Assistant Professor (Sel. Gr.), Department of Agricultural Statistics, College of Horticulture, Vellanikkara , a member of my advisory committee, for his ever willing help and scholarly suggestions.

I am deeply obliged to Dr. Prasannakumari Amma S, Professor and Head of Cadbury – KAU Co-operative Cocoa Research Project, Vellanikkara, a member of my advisory committee, for her kind help and encouragement given at various stages of this study and also for providing proper data for the study. Her advice had always been in a constructive manner, which I always remember.

My heartfelt thanks to Smt. Ajita T.K., Assistant Professor (Sel. Gr.), Department of Agricultural Statistics, College of Horticulture, Vellanikkara , for her support, friendly approach, constant encouragement and caring rendered to me.

My sincere thanks to Dr. E.K. Lalitha bai, Professor and Dr. V.K. Mallika (Retd. Professor) of Cadbury – KAU Co-operative Cocoa Research Project, Vellanikkara, for their cooperation and valuable suggestions during the study.

I express my sincere thanks to Dr. P. K. Rajeevan, Associate Dean, College of Horticulture, Vellanikkara, for providing the necessary facilities for the study.

I have no words to express my sense of gratitude to my class mate Unnikrishnan T, for his constant help and co-operation during the time of research work.

I duly acknowledge whole heartedly the personal sacrifice, moral support and encouragement extended by my husband for the completion of this work.

Special thanks to Smt. Rukhia, permanent labourer in the Department of Agricultural Statistics, College of Horticulture, for her kind help.

I take this opportunity to express my sincere thanks to all my friends and teachers in the College of Horticulture.

My diction seems to be poor to express my heartfelt gratitude to my family members for their unbounded support and encouragement.

I gratefully acknowledge the Kerala Agricultural University for awarding me the Junior Research Fellowship during the course of study.

Jayasree K.

Dedicated to My Husband and My Guide

CONTENTS

List of Tables

List of Figures

List of plates

List of Abbreviations

YAP	-	Year After Planting
SE	-	Standard Error
CV	-	Coefficient of Variation
MS	-	Mean Square
ANOVA	-	Analysis of Variance
df	-	degrees of freedom

Introduction

1. INTRODUCTION

Cocoa (*Theobroma cacao* L.*)* belongs to the family Malvaceae. A native of Amazon base of South America, cocoa got its entry into India in the early half of the 20th century. It is conferred plantation status like coffee, tea and rubber, but is seldom recognized as a plantation crop under the Indian Agrarian Administrative Sector. Cocoa ranks third as a beverage crop in the world preceded by tea and coffee. As a most sturdy ever green crop, the Indian conditions provide immense scope for cocoa to develop as one of the pioneering commercial produce of the country. Also, cocoa is one of the supporter of agro-based industry in India. The commercial cultivation of cocoa commenced in India from 1960's only and is mainly grown in Kerala, Andhra Pradesh, Karnataka and Tamilnadu. Kerala accounts for about 60 per cent of the area and production of cocoa in the country. Forastero and Criollo are the two important varieties of cocoa. Forastero provides the bulk of commercial cocoa of the world. Experiments have shown that Forastero variety has better adaptability and productivity under Kerala conditions. Research on cocoa was initiated at Kerala Agricultural University in 1979.

Eventhough cocoa comes under the definition of plantation crops, pure plantation of cocoa is absent in India. Its imminent capacity to share the alley spaces of tall growing coconut and arecanut palms and its combining ability with the microclimatic conditions available in such perennial gardens helps its cultivation in utilizing such areas without exacting for an independent growing climate of its own. Now cocoa is cultivated in rubber plantations also.

Kerala is the leading State in promoting cocoa cultivation. The soil and climatic conditions prevailing in Kerala are suited for the cultivation of cocoa except that irrigation is required in areas prone to prolonged drought. There was an attractive price for cocoa pods and beans prevalent till 1980's. This favourable situation, coupled with large scale distribution of planting materials could bring about an enviable area coverage recording 29,000 ha under cocoa by 1980-81.

The fall in price in 1981-82 and 1982-83 led to considerable reduction in area of cocoa cultivation. During 1990's, there was considerable increase in price and consequently there was a boost in area under cocoa cultivation. Later, the rising demand for chocolates led to the increase in production of cocoa and now cocoa cultivation is getting momentum.

Chocolate consumption is gaining popularity in the country due to increasing prosperity coupled with a shift in food habits, pushing up the country's cocoa imports. Demand for cocoa from international and domestic markets has increased tremendously over the past few years outstripping supply. In response to rising demand in the chocolate industry and reduce dependency on imports, domestic cocoa production is to be increased by 60 per cent in the next four years.

The country's annual cocoa demand is thought to be around 18,000 tonnes. Cocoa requirement is growing around 15 percent annually and will reach about 30,000 tonnes in the next 5 years (Cadbury India). Cocoa bean is the primary raw material for confectioneries, beverages, chocolates and other edible products. To enhance cocoa cultivation, large scale availability of planting materials is to be ensured. Seedlings are to be selected such that the plant will give high yield in its life span.

Cocoa exhibits high variability with respect to yield and related characters like girth, height and canopy spread. Of these, height and canopy spread are controlled in the early stages of plant growth. Yield being influenced by the above traits, its relation ship with these attributes will have to be studied. A sound knowledge about yield and yield attributes is essential for checking out a well-orchestrated crop improvement programme. Cocoa is no exception to this.

The available literature shows the existence of high variability for yield of cocoa (Pound, 1932, 1933, Soria, 1975, Subramonian and Balasimha, 1982). High variability has been reported even among clones which are genetically similar and supposed to be uniform (Cherian 1993). Due to the high variability in yield among cocoa plants, individual tree is to be given importance.

For cocoa, selection of seedling is very important. Usually, the seedlings are selected based on high value for HD^2 (Height x Diameter^2). But reports show that seedlings with low value of HD^2 also give high yield. Thus, if the seedlings are selected for planting based on high value for HD^2 alone, there is every chance of losing plants with high yield potential. Hence, some optimum values for the initial plant growth characters girth, height and spread of the plant which will result in high yield is to be estimated. By providing such an optimum, the best yielding plants can be identified in the early years of planting itself. Also, girth at any age of a plant is an important determining factor of its yield. By fixing an optimum value for girth at different ages of the plant, proper management can be provided to attain the optimum girth for maximizing yield. It helps the agriculturalists to estimate yield of a cocoa tree well ahead of harvest and best trees can be identified for further propagation. In the light of the above, the present study was taken up with the following objectives:

1. To determine the age at yield stabilization
2. To predict the yield of cocoa based on the growth characters viz; height, girth, spread and early yield.
3. To derive optimum combination of the four characters viz; height, girth, spread and early yield for maximum yield

Review of Literature

2. REVIEW OF LITERATURE

Published work on yield prediction in cocoa is limited. An attempt has been made to collect all relevant literature on related crops as well and are presented in the following pages.

2.1 Correlation Studies

2.1.1 Cocoa

Glendinning (1960) noted that growth and yield in cocoa was positively correlated with the rate of trunk diameter during early stages of growth. An increase of 1.2 c.m per annum in the pre bearing rate of trunk diameter seemed to be roughly equivalent to a difference in yielding capacity of 1,600 ibs. of dry cocoa.

Glendinning (1963) found a significant positive correlation between number of fruits produced and total wet weight of cocoa seeds showing that in some populations number of fruits was a good estimate of yield. It was reported that size of seeds was relatively constant for a tree.

Longworth and Freeman (1963) reported that in cocoa, correlation between trunk girth and yield tended to decrease with age, while it was not so for correlation between yields in successive periods.

Glendinning (1966) reported significant correlation between the rate of growth before bearing and the total yield up to 5 years of cocoa plants. After bearing, vegetative growth slowed down and high correlation was observed between the reduction in growth rate and total yield.

Atanda (1972) found that correlation between girth and yield altered with age.

Esker *et al.* (1977) reported that dry bean production per cocoa pod was closely related to bean number than to average bean weight. It was also observed that in fruits with a relatively higher number of beans, the average bean weight is of major importance.

Rajamony *et al*. (1984) found that seed weight of cocoa was positively correlated with number of leaves and height of seedling.

Nair *et al.* (1990) reported a direct relation for height and canopy spread of cocoa plants with number of pods per plant and bean yield.

Francies (1998) found that plant height (two years after planting) and girth (three years after planting) had significant correlation with yield.

Sridevi (1999) found that the total wet bean weight of a cocoa tree was positively correlated with number of pods, height and girth. From path analysis, it was found that the number of pods per tree had the highest direct effect on yield followed by wet bean weight per pod.

The study conducted by Bhat *et al*. (2000) on cocoa hybrids indicated that the stem girth had significant positive correlation with the plants over all height. The canopy height also had strong positive association with the stem girth of the plant indicating that the vigour and total plant maturity are decided by the stem girth at the collar region.

Prasannakumari *et al.* (2002) worked out the correlation between height, girth and HD^2 of cocoa seedlings at different growth intervals with final vigour after 375 days and found that most of the correlations were non significant. When seedlings were classified into different groups based on speed of germination, height at an early period showed significant correlation with final vigour in one of the groups.

2.1.2 Other crops

Pankajakshan and Minnie (1961) observed that girth at collar was positively correlated with height and number of leaves in coconut.

Dhaliwal (1968) observed that yield was positively and significantly correlated with the circumference of the main stem at ground level in *Coffea arabica*. Yield also showed positive and significant correlation with height of tree.

Nayar *et al.* (1979) found that girth, height and spread were positively correlated with yield in cashew.

George (1982) found significant positive correlation between canopy size and girth of trunk in two selected cashew varieties.

Significant correlation was observed between cashew yield and percentage of flowering shoots per unit area of tree canopy followed by total canopy area (Parameswaran *et al.*1984).

Correlation coefficient worked out in cashew for eight characters with yield suggested that selection could be based on nut weight per tree since this was highly correlated with yield (Mohan *et al.*1987).

Iyer *et al*. (1989) made an assessment of various vegetative and fruit characters in 42 cultivars of mango and found that plant height had positive correlation with first extension growth, number of internodes and yield.

Using path analysis, Alphi and Prabhakaran (1991) found that among the various biometric characters of sugar cane, the major contributors towards cane yield in all stages of plant growth were height and girth of the cane.

Investigation undertaken by Manoj (1992) to know the degree of association among nut yield and different biometrical characters in cashew revealed that there was maximum positive correlation between mean canopy spread and yield (0.57). Yield was also found to posses significant positive correlation with girth of tree (0.54), leaf area (0.27) and height of tree (0.20). Path 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.

Correlation studies in cashew conducted by Reddy *et al.* (1996) showed that out of 19 characters studied nut yield had positive correlation with number of nuts per panicle, height, canopy spread, panicle length and stem girth.

Nalini (1997) got positive correlation between height and yield in cashew. The spread and total canopy surface area had negative correlation with yield.

Rao *et al*. (2002) found high significant positive correlation between nut yield and stem girth (r = 0.686), mean canopy spread (r = .667) in cashew. It was also found that greater the canopy spread, greater would be the nut yield.

Sreekanth *et al.* (2004) reported significant positive correlation between ground coverage by canopy and plant age in cashew.

Akinyele and Osekita (2006) calculated correlation and path coefficients for seed yield per plant and its components from data amassed over two years in okra. The components of seed yield considered were days to flowering, days to maturity, number of branches per plant, number of pods per plant, height at flowering, final height, pod length, pod width, number of seeds per pod and weight of hundred seeds. Seed yield per plant showed significant positive correlation with number of pods per plant, height at flowering, pod width and weight of hundred seeds. Path coefficient analysis revealed that number of pods per plant and height at flowering had the highest direct effect on seed yield indicating that the two attributes have strong influence on seed yield in okra.

Togay *et al.* (2008) found significant positive correlation between pea yield and number of branches (r =0.291*), number of pods per plant (r = 0.621*). Significantly negative correlation was obtained between seed yield and first pod height. Path analysis showed that number of pods per plant had maximum direct effect on seed yield.

2.2 Yield Prediction Models

2.2.1 Cocoa

Adenikinju (1975) fitted seven types of regression equations for three cocoa varieties in an attempt to find an adequate relationship for estimating leaf area per seedling. Close relation was recorded between leaf area per seedling and any of the three growth parameters, viz., leaf number, seedling height and age in all three cocoa varieties. The equation which gave the smallest deviation from the actual leaf area was considered as accurate for estimating total leaf area per seedling.

2.2.2 Other crops

Mohan and Prakash (1971) predicted the yield of jute using a multiple linear regression equation with plant height, basal diameter and fibre content as explanatory variables. Partial correlation analysis revealed that basal diameter had the greatest influence on jute yield.

George and Vijayakumar (1979) fitted a multiple regression model for forecasting the yield of cashew trees (Y) based on biometrical characters (X_i). Taking single spot observations on the characters at the first pea nut stage, forecasts were made one to two months in advance of the first harvest. Another forecast model was fitted by taking the mean of the three observations starting from the first pea nut stage at an interval of one month. Total numbers of nut alone was found to contribute substantially to yield.

Chaube and Ratnalikar (1982) conducted a study to forecast production of cotton using picking wise data before the completion of harvest. Yields of cotton from first picking to fifth picking were used as regressors in a forecasting model. It was found that data up to third picking was sufficient for forecasting the total yield.

Krishnakumar (1983) used linear regression models to predict the yield of coconut palm on the basis of different leaf nutrients.

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).

A model was developed by Jain *et al*. (1985) for forecasting crop yields in which growth indices of biometrical characters based on two or more periods simultaneously have been utilized. The growth indices were obtained as weighted accumulations of observations on biometrical characters in different periods, weights being respective correlation coefficients between yield and biometrical characters.

Step wise regression analysis of ten seed/seedling characters on the nut yield of cashew made by Bhagavan and Kumaran (1990) highlighted the prominence of six characters namely seed length, days taken for germination, seedling height, length and breadth of first leaf and number of opened leaves.

Alphi and Prabhakaran (1991) found that sugarcane yield could be predicted with sufficiently high degree of accuracy as early as the sixth month after planting with the aid of biometrical characters. The prediction equations were evolved by the method of multiple linear regression using plant wise and plot wise observations.

Using step wise regression analysis, Latha (1992) got an R^2 of 55 percent for predicting cashew yield based on N content of leaf at flushing, flowering, fruiting and N/P ratio at flushing.

Manoj (1992) got an R^2 of 57 percent for predicting cashew yield based on mean canopy spread, leaf area, number of nuts per panicle, shelling percentage and total soluble solid content using step wise regression analysis.

Sreekanth *et al.* (2004) tested the appropriateness of linear, logarithmic, power and exponential models to predict cashew yield using ground coverage and plant age under different density of planting. When ground coverage by canopy was used, yield could be predicted by linear regression and R^2 was 80 per cent for normal density and 83 percent for medium density. With plant age as explanatory variable also, linear model was obtained and R^2 was 85 percent for normal density and 87 percent for medium density.

2.3 Growth and Yield Characters

2.3.1 Cocoa

Cocoa trees differ widely in their ability to produce flowers and to set fruits. Hewison and Ababio (1929) found that only 0.2 to 1.5 percent of the opened flowers developed into mature fruits and majority of pods in cocoa attained maximum size in seventeen to eighteen weeks after fertilization.

Greenwood and Posnette (1950) observed that overhead shade influences the growth of flushes of cocoa in Ghana. It was found that unshaded mature cocoa flushed more frequently and with greater intensity than shaded cocoa and that this difference was more marked during periods of low temperature.

Glendinning (1966) proposed a high yielding variety of cocoa as one making vigorous early growth which is later relatively greatly reduced.

Bartely (1970) found that cocoa clones and hybrid seedlings exhibited very high variability in yield during the first three years of production. From the fourth year onwards the variation gradually decreased.

Toxopeus and Jacob (1970) reported that inadequate fertilization of the ovule of the cocoa flowers seemed to be the main cause of variability in the number of beans per pod.

Atanda (1972) reported that seedling height, leaf number, canopy development, precocity and magnitude of pod production, wet and dry bean weight were all reliable indices for evaluation of potential performance of a cocoa cultivar. It was also inferred that the cumulative pod yield for the first two to five years of general fruiting was sufficient to predict yield potential.

Adenikinju (1974) reported that seedlings of cocoa produced by beans from 21-week-old pods were the most vigorous, where, vigour is based on the integral of all measured growth parameters (leaf number, leaf area, seedling height, girth and root weight). It was also found that there exist close correlations between these growth parameters on the one hand and bean maturity and seedling age on the other, the relations with the former being curvilinear and with the latter linear. Seedling age and bean maturity accounted for between 87–99 and 42–96 per cent respectively of the variations in growth parameters.

Kesavachandran (1979) found that the volume and weight of the pods of cocoa varied within the three classes of pods namely large, medium and small.

According to Alvim (1981), variation in yield of cocoa from year to year was more affected by rainfall distribution than by any other climatic factor.

As per Rajamony (1981), the development of cocoa pods was found to be a very gradual process. The pods took 127-141 days (mean 138.17 days) for reaching the ripening stage.

George (1982) reported that seedling height of cocoa during the third and ninth month of growth can be considered as an indicator of seedling vigour in the nursery and on the basis of this character the tallest 50 percent seedlings can be considered as superior planting material.

Nair (1983) reported that the yield (number of pods) and size of seeds were the two important criteria for selection of mother plant for collection of seeds in cocoa.

In a study by Bhat *et al*. (1990) on cocoa planted along with arecanut reported that majority of the plants are low yielders and only minority are high yielders. Based on 10 years' yield, mean pods/tree was 10-159 pods with coefficient of variation 16.53 to 16.53-109.1%.

Cherian (1993) reported that the number of pods was the major contributing character of cocoa yield followed by wet bean weight per pod.

Cherian *et al.* (1996) reported that selection based on number of pods will be effective in identifying good yielding genotypes in cocoa.

Jose (1996) reported that in addition to the seasonal variation and trend, the random deviation in production for the previous two quarters also influence the cocoa yield of the present quarter.

Mallika *et al.* (1996) conducted a study to evaluate the pod and bean characters of cocoa hybrids during the initial years of bearing and observed that selection based on number of pods and wet bean weight per pod will be most effective in improving the yield of cocoa. However, selection for these traits should be practiced only after attaining steady bearing. It was also found that length and thickness of beans showed a stabilization of values during the initial years and hence these can be taken as indicators of their later performance.

Mallika *et al*. (2000) found that the stable yield in cocoa was reached five to six years after planting. Also a biennial bearing tendency in cocoa hybrids and clones was observed by them.

Balasimha (2002) reported that the increments in growth parameters at pre bearing age influence yield of cocoa. So it is very important to plant, vigorous seedlings for better establishment and yield potential at maturity. It was also found that yield depends on number of fruit bearing branches.

Prasannakumari *et al*. (2005) observed that there was a lag period of four to five months between the occurrence of adverse weather and monthly pod yield of cocoa. No significant difference was observed between mean pod yield in alternate years suggesting that cocoa is a regular yielder with no biennial tendency.

2.3.2 Other crops

Murthy and Bavappa (1960) recorded considerable variation in girth of arecanut palms.

Anand and Torrie (1963) reported that the number of pods per plant and seeds per pod were more important than seed weight for predicting the yield in soyabean.

Senanayake and Samaranayake (1976) suggested that in rubber either the plant height or diameter could be used as a measurable parameter of yield because of their high positive correlation. It was also shown that seedlings which germinated earlier continued to have a higher growth rate in the nursery.

Profound influence of plant vigour on yield was noted by Nayar *et al.* (1979) in cashew. Also, it was found that girth, height and spread contributed independently and jointly in enhancing the yield.

Parameswaran (1979) conducted a study to identify different vegetative, flowering and fruiting characters influencing yield in cashew and found that most important vegetative character contributing towards yield was percentage of flowered shoots per unit area.

Materials and Methods

3. MATERIALS AND METHODS

3.1 Collection of data

The data for the present study entitled "Yield prediction in Cocoa (*Theobroma cacao* L.)" were collected from a progeny trial of the Cadbury-KAU Co-operative Cocoa Research Project, Vellanikkara. The data pertain to a popular variety of cocoa named 'Forastero'. The hybrid seedlings of cocoa were derived from controlled hand pollination during 1988. The plants were observed in the nursery for a period of 14 months for screening for resistance to vascular streak die back. The resistant seedlings (14 months old) were transplanted to the main field in the year 1989 under the shade of rubber. The individual plant data on the growth characters viz., girth, height and spread and pod yield of 1558 plants were collected for this study. The details of the collected data are depicted in Table 1.

Table 1: Details of the data collected

Character	Period of observation	No. of years
Girth	From 1989-90 to 2001-02	13
Height	From 1989-90 to 1991-92	3
Spread	1991-92	1
Pod yield	From 1991-92 to 2002-03	12

Cocoa grows in tiers. Under intercropping situation prevalent in India, growth is restricted to one to two tiers by pruning. In the present study, height was measured only up to 1991-92, till the plants were pruned. Canopy spread was measured only during 1991-92 after which the canopy overlapped.

Plate 1. A Forastero tree in full bearing

Plate 2. A view of experimental plants

Growth observations

3.2.1 Plant height (cm)

The height of the tree trunk was measured from the ground level to the tip of the main chupon or the top most node which had just unfurled its leaves and expressed in centimeters. The following notations were used for the height measurements:

Height in the year of planting (1989-90) - initial year	:	H_0
Height – 1 year after planting (1990-91)	:	H_1
Height – 2 years after planting (1991-92)	:	H_2

3.2.2 Girth (cm)

Observations on girth of the tree trunk were taken by 15 cm above ground level. The notations for the girth measurements are given below:

Girth in the year of planting (1989-90) –initial year	:	G_0
Girth – 1 year after planting (1990-91)	:	G_1
Girth – 2 years after planting (1991-92)	:	G_2
Girth – 3 years after planting (1992-93)	:	G_3
Girth – 4 years after planting (1993-94)	:	G_4
Girth – 5 years after planting (1994-95)	:	G_5
Girth – 6 years after planting (1995-96)	:	G_6
Girth – 7 years after planting (1996-97)	:	G_7
Girth – 8 years after planting (1997-98)	:	G_8
Girth – 9 years after planting (1998-99)	:	G_9
Girth – 10 years after planting (1999-00)	:	G_{10}
Girth – 11 years after planting (2000-01)	:	G_{11}
Girth – 12 years after planting (2001-02)	:	G_{12}

(a) Girth

(b) Height

(c) Spread (E-W)

(d) Spread (N-S)

Plate 3. Recording observations

3.2.3 HD^2 (cm^3)

HD^2 was computed as the product of height (H) and square of diameter (D^2). This is the accepted criterion for seedling selection in the nursery. In Kerala Agricultural University, the seedlings with high HD^2 values are selected for conducting progeny trials (Mallika *et al*, 2002). The notations used for HD^2 are given below.

HD^2 in the year of planting (1989-90) – initial year	:	$(HD^2)_0$
HD^2 one year after planting (1990-91)	:	$(HD^2)_1$
HD^2 two years after planting (1991-92)	:	$(HD^2)_2$

HD^2 for a plant is computed from its height and girth as follows:
Let G_i and H_i be the girth and height of a plant in the i^{th} year. Then,

$$G_i = 2\Pi\, r_i$$

$$r_i = G_i / 2\Pi$$

$$D_i = 2r_i$$

HD^2 of a plant in the i^{th} year, $(HD^2)_i = H_i D_i^2$ where i = 0, 1, 2.

3.2.4 Mean canopy spread (cm)

Mean spread of the tree canopy was worked out by measuring the spread in North-South and East-West direction and then averaging these two. The spread measurement was available only for one year during 1991-92 and the notation used is given below:

Canopy spread – 2 years after planting (1991-92) : S_2

3.3 Yield

Yield refers to pod number. Annual yield is the total number of mature pods including damaged pods (due to pest and disease attack) harvested from each tree throughout the year.

The seedlings were transplanted in the year 1989-90 and that year is designated as year of planting. Plants started yielding in the second year after planting. Notations used for annual yield and total yield for 12 years are given below:

Yield – 2 years after planting	:	Y_2
Yield – 3 years after planting	:	Y_3
Yield – 4 years after planting	:	Y_4
Yield – 5 years after planting	:	Y_5
Yield – 6 years after planting	:	Y_6
Yield – 7 years after planting	:	Y_7
Yield – 8 years after planting	:	Y_8
Yield – 9 years after planting	:	Y_9
Yield – 10 years after planting	:	Y_{10}
Yield – 11 years after planting	:	Y_{11}
Yield – 12 years after planting	:	Y_{12}
Yield – 13 years after planting	:	Y_{13}
Total yield from 1991 to 2002	:	Y where $Y = \sum_{i=2}^{13} Y_i$

3.3.1 Precocity

The tendency of precocious bearing was quantified on the basis of total pods produced within a period of five years of field planting. Precocity of a plant (P) was obtained as

$$P = \sum_{i=2}^{5} Y_i \text{, where } Y_i \text{ is the yield in the } i^{th} \text{ year.}$$

Precocity is a measure of early yield in cocoa and a minimum precocity of 100 pods is expected for a cocoa plant.

3.4 Methodology

The average yield of cocoa plant/year in Kerala is 30 pods and at this yield level, it is expected that a plant yields 360 pods in 12 years. As the shade level was very high in the experimental plot, the average number of pods for 12 years for the 1558 plants was 249.5 with a mean of 20.79 pods per year. Hence, the low yielding plants, having total yield below 250 pods were excluded from the study. The number of plants thus got reduced to 660.

Statistical methods used for the study are detailed in the following sections:

3.4.1 Biennial yield

Biennial yield was worked out to check for any biennial bearing tendency for the plants under study. Biennial yield of the plants was denoted as B_1, B_2, B_3, B_4, B_5 and B_6

where,

$B_1 = Y_2 + Y_3$

$B_2 = Y_4 + Y_5$

$B_3 = Y_6 + Y_7$

$B_4 = Y_8 + Y_9$

$B_5 = Y_{10} + Y_{11}$

$B_6 = Y_{12} + Y_{13}$

3.4.2 Determination of age at yield stabilization

Graphical method was used for determining the age at yield stabilization of the cocoa plants under study. The mean pod yield per year was computed as follows:

Let Y_{ij} denote the pod yield of j^{th} plant in the i^{th} year. Then, Mean pod yield in the i^{th} year, $\bar{Y}_i = \frac{\sum_{j=1}^{n} Y_{ij}}{n}$ where n = 660

$\bar{Y}_i$ was plotted against year i, where i varied from 1991-92 to 2002-03 (12 years). Median number of pods was obtained in each year and plotted as a check.

The plants were classified into different groups based on the total pod yield (Y). Total pod yield/tree ranged from 250 to 1168. Classifications with different ranges of total yield were made and for each classification, analysis of variance (ANOVA) for one way classification was performed. The classification with width 50 had minimum within group MS and the plants could be classified into 10 groups. The range for total yield (Y) for this grouping and the corresponding frequency are provided in Table 2.

Table 2: Classification of plants based on total yield Y

Group	Range for total yield Y	No. of plants
1	250-300	160
2	300-350	126
3	350-400	109
4	400-450	74
5	450-500	65
6	500-550	46
7	550-600	31
8	600-650	18
9	650-700	13
10	≥ 700	18

For each group, the mean pod yield was worked out for the 12 years from 1991-92 to 2002-03, as follows:

Let Y_{ijk} denote the pod yield of k^{th} plant in the j^{th} group for i^{th} year.

Mean pod yield for the i^{th} year in the j^{th} group, $\bar{Y}_{ij} = \frac{\sum_{k=1}^{n_j} Y_{ijk}}{n_j}$

where, $i = 2$ to 13, $j = 1$ to 10, n_j = number of plants in the j^{th} group. For all the 10 groups, the mean yield was plotted for the different years. From the graph, the age at yield stabilization was found out.

3.4.3 Correlation studies

Yield is a highly complex character which is very much influenced by other related characters. Hence correlation studies were carried out for assessing the extent of association among various growth characters and yield (annual and total). The following correlations were worked out.

3.4.3 (a) Correlation Between

i. Girth and Yield
ii. Height and Yield
iii. Spread and Yield
iv. Girth, height and spread
v. HD^2 and Yield
vi. Annual yield and total yield
vii. Precocity and Girth
viii. Precocity and height
ix. Precocity and spread
x. Precocity and HD^2

3.4.4 Models for predicting yield

Known models were fitted for predicting total yield Y and tested for goodness of fit, based on girth G_i, $i = 1$ to 9, height H_i, $i = 1$ to 2, spread S_2, precocity P and $(HD^2)_i$, i = 0 to 2 as explanatory variables. Models were also tried with two independent variables as precocity in combination with G_i, i= 0 to 5 and also with $(HD^2)_i$, i = 0 to 2.

Precocity is an important determining factor for yield potential of a cocoa plant. Hence, yield prediction models were tried by categorizing the plants into different groups based on precocity. Different classifications were tried and the classification with minimum within group MS for total yield Y was selected based on ANOVA. Models were tried within each group and checked for predictability. Also, based on precocity the plants were classified into two groups one having precocity greater than mean precocity and the other having precocity less than mean precocity. Models were tried in the two groups for predicting total yield.

Known models were fitted and tested for goodness of fit for predicting annual yield Y_i after yield stabilization year. Variables having significant correlation with annual yield were used for fitting models.

3.4.5 Determination of optimum of different growth characters for maximum yield

Different classifications of plants based on girth, height, spread, HD^2 and precocity were tried for finding the optimum of the individual characters and also their combinations for getting maximum total yield (Y).

3.4.5.1 Based on single character

Analysis of variance for one-way classification with unequal observations was performed for different classifications based on G_i, i = 0 to 12, H_i, i = 0 to 2, S_2, P and $(HD^2)_i$, i = 0 to 2 and the classification with minimum within group MS and high significant difference between groups for total yield Y was selected. The means for total yield were grouped into homogeneous subgroups based on

Duncan's Multiple Range Test (DMRT). 95% confidence limits (upper and lower) and confidence interval of the means of total yield Y in each group based on the different classifications were computed.

3.4.5.2 Criteria for selecting optimum range for the different characters

The optimum range for the different characters for maximum total yield Y was determined based on frequency percentage, mean values of total yield, 95% confidence intervals and population means for each character.

3.4.5.3 Based on two characters

The analysis of variance for the following combinations of the growth characters were performed. This is same as the analysis of variance of two way classification with unequal number of observations per cell.

G_i and H_i , i = 0, 1 and 2.

For finding the optimum combination of the two characters, different ranges of the two characters were tried and the classification for which the interaction between the two factors was highly significant was selected.

3.4.5.4 Based on three characters

Only practically useful combination of the growth characters was selected for doing the three way classification. In Kerala Agricultural University, the seedling for planting are selected based on HD^2 value which is a measure involving initial height H_0 and initial girth G_0. Also, precocity is an important determining factor for yield potential of cocoa. Hence, the plants were classified based on the three characters G_0, H_0 and P, to identify the combination which give maximum total yield Y. Different classifications were tried by considering different ranges for the three characters and the classification for which the three factor interaction was significant was selected. The analysis is similar to the analysis of three way classification with unequal number of observations.

Canopy spread is a character which is obtained after establishment of the plant and it was measured only in the second YAP after which it was overlapped. Hence, optimum combination for four characters including spread is not tried here.

All the above analyses were done by using MS Excel and SPSS packages.

Results and Discussion

4. RESULTS AND DISCUSSION

The results of the study "Yield prediction in cocoa (*Theobroma cacao* L.)" conducted at Department of Agricultural Statistics, College of Horticulture, Vellanikkara are given below under different sub heads.

4.1. Determination of yield stabilization age

To determine the yield stabilization age, the pattern of yield (annual and biennial) were studied first.

4.1 (a) Pattern of annual yield

The cocoa plants under investigation were grown under the dense shade of rubber. To understand the pattern of yield of the cocoa plants over 12 years from 1991-92 (Y_2) to 2002-03 (Y_{13}), mean annual pod yield was estimated and is provided in Table 3. The SE of mean and CV of annual yield are also provided. From the table and graph, it could be observed that the mean pod yield / tree increased from 2nd to 10th year after planting. But, a reduction in yield was noticed from 11th to 13th year after planting. The SE of mean yield is very low in all the years. But the CV values are very high which indicates the variability in the yield of cocoa. High variability for number of pods was reported by Bhat *et al*. (1990) and Cherian *et al.* (1996).

To observe for any change in pattern of yield, median yield was computed for different years and is provided in Table 3 and plotted along with mean in Figure 1. From the graph, it could be observed that the yield pattern remained the same based on mean and median.

Table 3: Mean annual yield, SE, CV and median of cocoa plants

Year	i^{th} year after planting (Y_i)	Mean pod yield/tree	SE	CV	Median
1991-92	Y_2	10.02	0.52	88.55	7
1992-93	Y_3	14.67	0.56	89.67	11
1993-94	Y_4	27.50	0.80	72.37	24
1994-95	Y_5	33.55	0.80	60.54	31
1995-96	Y_6	35.65	0.82	58.89	33
1996-97	Y_7	36.48	0.91	64.00	32
1997-98	Y_8	44.67	1.08	61.69	40
1998-99	Y_9	46.46	1.06	58.32	42
1999-00	Y_{10}	60.81	1.30	55.05	55
2000-01	Y_{11}	39.40	0.92	59.65	36
2001-02	Y_{12}	34.94	0.96	69.31	30
2002-03	Y_{13}	28.96	0.86	75.33	25

4.1 (b) Pattern of biennial yield

To know whether cocoa exhibits any biennial bearing tendency, the biennial yields of cocoa plants were computed and are presented in Table 4. The graph of the same is shown in Figure 2. From the graph, it could be observed that the cocoa plants under study did not show any biennial yielding tendency. Hence, the age at yield stabilization could be determined from Figure 1.

Prasannakumary *et al.* (2005) also reported absence of biennial bearing tendency for cocoa. But biennial bearing tendency was reported by Mallika *et al.* (2000) in a study on cocoa hybrids.

Table 4: Biennial yield of cocoa plant

Biennial	Period	B_1	B_2	B_3	B_4	B_5	B_6
	Yield	16.58	58.34	71.75	90.58	99.82	62.03

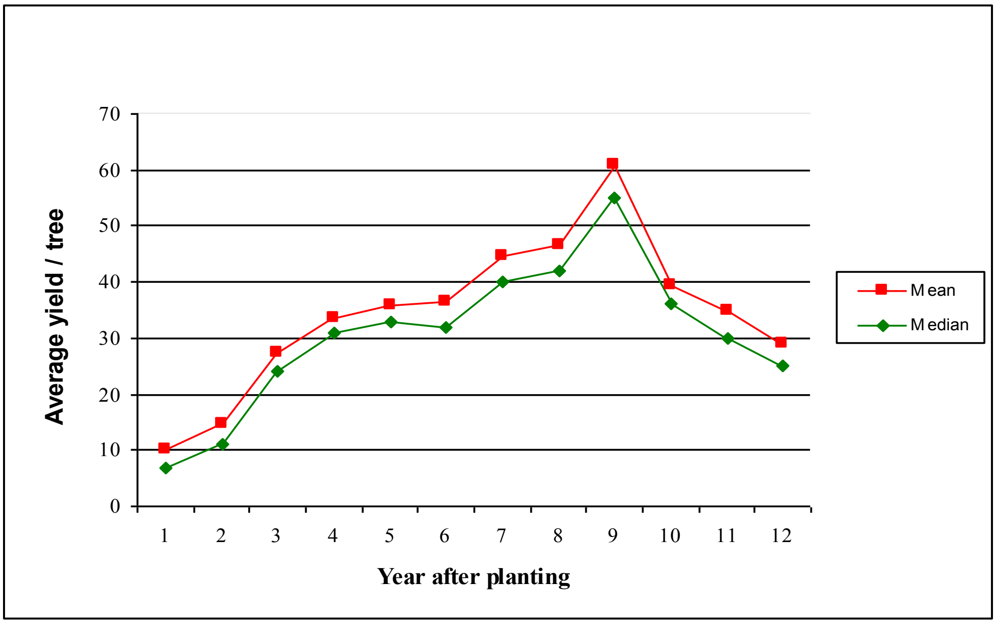


Figure1: Mean and median annual pod yield over years

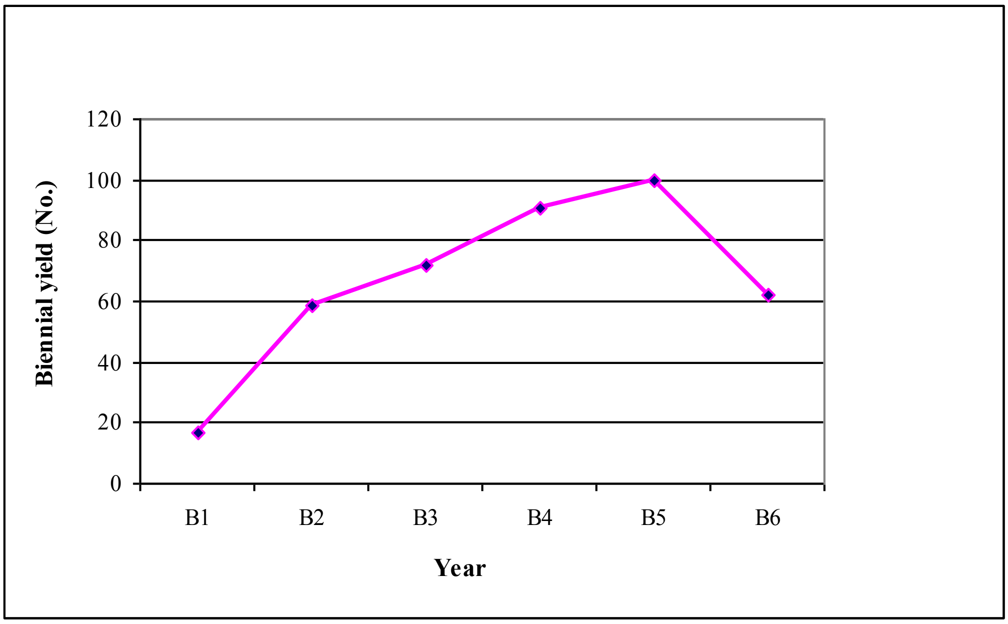


Figure 2: Biennial yield pattern of cocoa plants

4.1 (c) Yield pattern after grouping of plants

For determining the age at yield stabilization, the plants were classified into ten groups based on total yield (Y). The criteria for grouping are provided in section 3.4.2. The mean annual yield in the different groups is depicted in Table 5 and the graph of the same is provided in Figure 3.

The pattern of mean annual yield in the different groups as given in Figure 3 was similar to that in Figure 1. Based on the yield pattern, it could be observed that the age at stabilized yield for the population of cocoa plants under study was sixth YAP. This result is in agreement with the findings of Mallika *et al*. (2000) that the stable yield in cocoa was reached five to six YAP. From Figure 3 also, it could be observed that the yield increased up to tenth YAP (Y_{10}). There was a declining trend in annual yield after that. The yield reduction can be due to unfavorable growing conditions such as too high shade intensity, high temperature, inadequate rainfall, incidence of disease etc.

Table 5: Mean annual yield in the different groups

Year	Group									
	1	2	3	4	5	6	7	8	9	10
1991-92	9.18	11.08	9.62	9.74	9.16	10.67	9.21	12.64	7.67	13.90
1992-93	10.84	12.99	14.98	15.66	16.44	18.23	13.71	18.13	22.75	21.89
1993-94	20.19	23.21	25.92	28.96	33.95	38.57	24.55	37.59	42.23	47.94
1994-95	24.73	28.02	31.72	32.41	39.54	47.85	37.35	46.72	59.62	62.17
1995-96	25.29	30.80	31.71	34.73	43.08	41.63	46.84	63.11	66.15	77.56
1996-97	25.28	30.10	33.49	38.58	40.49	45.65	58.16	57.72	57.15	77.06
1997-98	29.08	36.24	39.64	47.77	57.03	62.02	64.29	67.50	71.08	92.61
1998-99	32.30	36.97	43.01	48.14	53.46	56.59	72.32	81.00	82.69	95.00
1999-00	42.23	48.57	57.12	59.81	70.89	79.70	99.81	97.94	96.54	122.39
2000-01	27.71	31.94	36.58	44.47	43.43	50.87	63.74	56.29	68.31	66.89
2001-02	24.36	26.50	33.22	39.79	36.32	44.84	50.48	54.44	53.54	86.71
2002-03	19.86	23.44	28.23	31.79	32.84	35.64	39.71	43.33	45.00	66.38

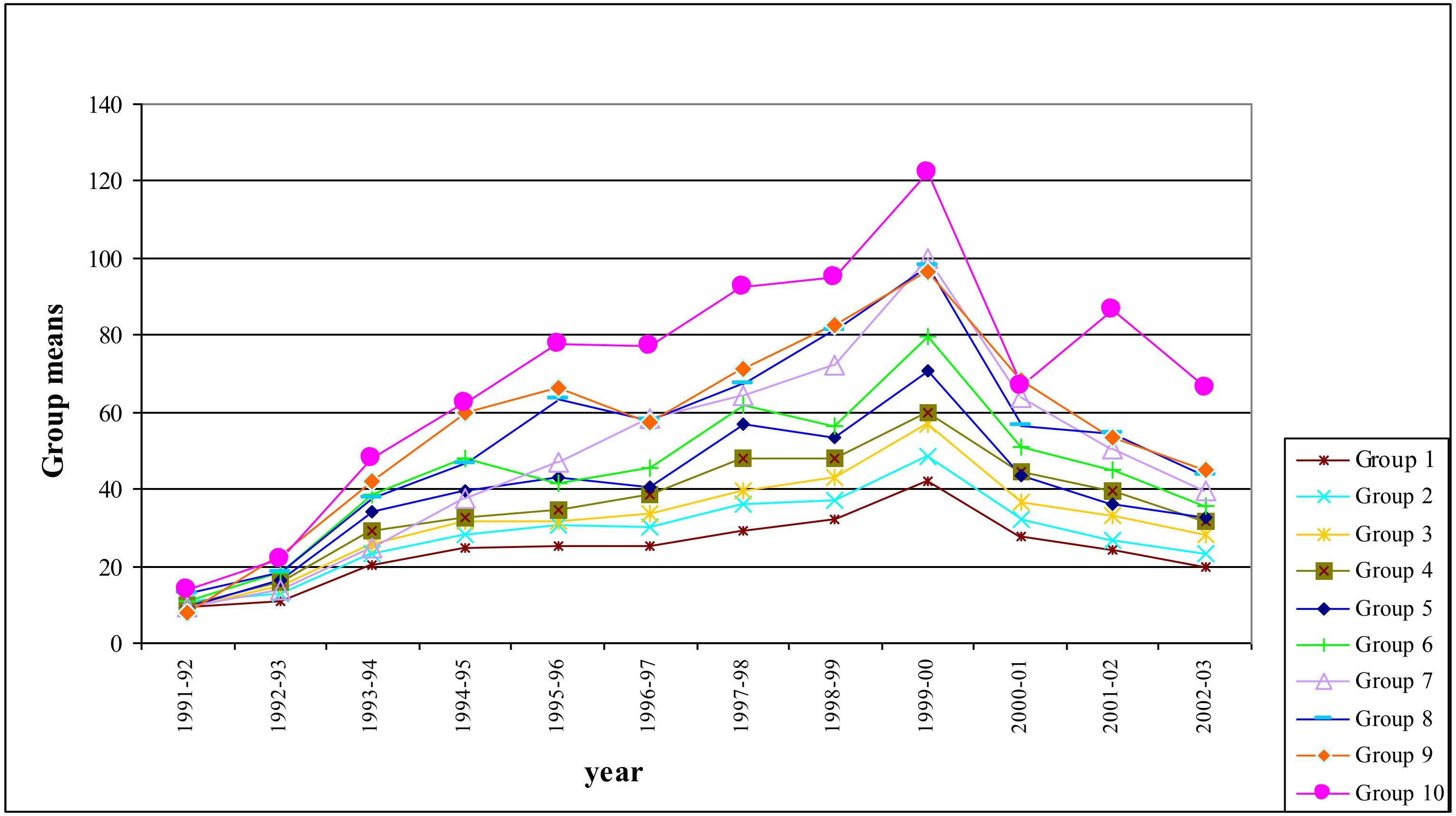


Figure 3: Annual mean yield per tree in the different groups

4.2 Correlation studies

Correlation between different growth characters and yield were estimated to examine the extent of their association and are presented in Tables 6 to 12.

4.2.1 Correlation between girth and yield

Correlation between girth measurements (G_0, G_1,…G_{12}) and annual yield (Y_2, Y_3, …Y_{12}) as well as total yield Y is provided in Table 6. It could be observed from the table that girth and yield were highly related. Girth in a particular year has significant influence on yield in the same year as well as subsequent four to five years. Generally, the correlations were high in the same and next year and magnitude got reduced further. In cocoa, the plants attain optimum girth at fifth YAP and height is restricted by pruning. So with advancing age, the plants put on more growth by way of girth, but increase in yield may not be proportionate.

Initial girth (G_0) had high significant correlation with first five years yield (Y_2 to Y_6). But its correlation with total yield Y was non significant.

Girth in the first YAP (G_1) had high significant correlation with yield in the second to sixth YAP (Y_2, Y_3, Y_4, Y_5 and Y_6). Highest correlation is with yield in the subsequent year (Y_2). Also, G_1 had high significant correlation with total yield Y.

Correlations between girth in the second YAP (G_2) and annual yield during second to sixth YAP (Y_2, Y_3, Y_4, Y_5 and Y_6) were significant. G_2 also had high significant correlation of 0.256 with total yield Y.

Girth in the fourth YAP (G_4) had significant correlation with yield in the same year (Y_4) and also upto eighth YAP (Y_8). Also G_4 had significant correlation with total yieldY (0.319).

Table 6: Correlation between girth and yield

	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y
G_0	.249**	.348**	.249**	.121**	.138**	-0.06	0.03	-0.114	-0.16	-0.089	-0.071	-0.09	0.045
G_1	.593**	.490**	.352**	.236**	.191**	-0.088	.232**	-0.118	-0.142	-0.108	-0.046	-0.026	.18**
G_2	.423**	.622**	.481**	.366**	.241**	-0.003	.202**	-0.08	-0.154	-0.067	-0.047	-0.047	.256**
G_3		.521**	.486**	.412**	.260**	0.044	.192**	-0.043	-0.077	-0.031	-0.034	-0.03	.303**
G_4			.348**	.389**	.277**	.111**	.174**	0.021	-0.002	0.015	-0.001	0.012	.319**
G_5				.367**	.345**	.225**	.194**	.127**	.079*	.087*	0.053	0.063	.396**
G_6					.342**	.272**	.224**	.164**	.147**	.134**	.097*	.107**	.431**
G_7						.292**	.212**	.170**	.162**	.155**	.103**	.123**	.408**
G_8							.225**	.192**	.197**	.160**	.117**	.146**	.387**
G_9								.256**	.309**	.261**	.179**	.190**	.408**
G_{10}									.306**	.227**	.134**	.171**	.377**
G_{11}										0.065	-0.002	0.026	.111**
G_{12}											.178**	.179**	.337**

** Significant at 1% level
* Significant at 5% level

Girth in the third YAP (G_3) had significant correlation with yield in the same year (Y_3) and subsequent three years yield (Y_4, Y_5 and Y_6). The correlation between G_3 and total yield Y was also highly significant (0.303).

From Table 6, it could be observed that the correlations between girth in the fifth YAP (G_5) and yield from fifth to ninth YAP (Y_5, Y_6, Y_7, Y_8 and Y_9) were highly significant ($p<.01$). The correlation between G_5 and total yield Y was also significant (0.396).

Girth in the year of yield stabilization (G_6) had significant correlation with Y_6, Y_7, Y_8, Y_9, Y_{10}, Y_{11}, Y_{12} and Y_{13}. G_6 also showed high significant correlation with total yield Y (0.431).

Similar to G_6, girths in the 7^{th} to 12^{th} YAP except G_{11} had significant correlation with yield in the same year and all subsequent years. Also, G_7 to G_{12} had high significant correlation with total yield.

From the correlation studies on girth and yield of cocoa, it could be observed that girth in a particular year had high correlation with yield in the same and subsequent years. Total yield for 12 years is also influenced by girth of the plants at all stages of its growth. Similar observations were made by Longworth and Freeman (1963) and Atanda (1972).Thus girth is a determining factor of yield.

4.2.2 Correlations between height, girth and spread

The correlations between height (H_0, H_1 and H_2), girth (G_0, G_1,…,G_{12}) and spread (S_2) are given in Table 7. From the table, it could be noted that height and girth of cocoa plants were highly correlated. Seedling height (H_0) and girth up to eighth YAP (G_0 to G_8) had high significant correlation. Correlations of H_0 with girths G_9 to G_{12} and also S_2 were non significant. H_1 had significant correlation with girths up to seven YAP (G_0 to G_7) and also with spread (S_2). H_2 had significant correlation with girths in all years from G_0 to G_{12}. Significant positive correlation between plant height and girth in cocoa was reported by Bhat *et al*. (2000).

The correlation between girth from the year of planting (G_0) to 12th YAP (G_{12}) and spread (S_2) was non significant.

Close association between girths of the plants in the different years and heights in the early years after planting is established. Among these, height in the year just before pruning (H_2) had clear influence on girth. In cocoa, height is restricted by pruning to one tier (150-200 cm). Further increase in growth is reflected in girth and production of a dense canopy. The canopy volume was not recorded in the present study. In the progeny trial I, pruning was not very systematic. So the plants recorded increase in some height up to third YAP. Accordingly, the magnitude of correlation between girth and height got reduced gradually.

4.2.3 Correlation between height, spread and yield

To know the influence of plant height in the early years on pod yield, the correlation of plant height with annual yield from Y_2 to Y_{13} as well as total yield (Y) was estimated and is presented in Table 8. From Table 8, it could be observed that the initial height (H_0) had high significant correlation with yield in the first five years viz., Y_2, Y_3, Y_4, Y_5 and Y_6. H_1 had significant correlation with yield in the subsequent three years viz., Y_2, Y_3 and Y_4. The height H_0 and H_1 had no significant correlation with total yield Y. Height, H_2 had high significant correlation with yield in the same year (Y_2) and subsequent four years (Y_3, Y_4, Y_5 and Y_6). H_2 had significant correlation with total yield Y also.

The correlations with height and yield indicate that height of the plant in the early years of plant growth influences yield in the subsequent years. Also, the height before pruning (H_2) has influence on the total yield for 12 years.

Table 7: Correlation between girth, height and spread

	G_0	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8	G_9	G_{10}	G_{11}	G_{12}	S_2
H_0	.543**	.537**	.525**	.438**	.312**	.212**	.179**	.142**	.104**	0.05	0.07	0.05	0.04	0.048
H_1	.310**	.313**	.342**	.305**	.224**	.154**	.129**	.104**	0.07	0.02	0.03	0.03	0.01	0.154**
H_2	.479**	.623**	.745**	.701**	.573**	.467**	.410**	.337**	.287**	.168**	.170**	.145**	.131**	-0.02
S_2	0.02	0.01	0.01	0.01	0.02	0.03	0.04	0.04	0.05	0.07	0.07	0.07	0.07	1

Table 8: Correlation between height and yield, spread and yield

	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y
H_0	.272**	.308**	.224**	.127**	.105**	-0.01	.081*	-0.11	-0.16	-0.07	-0.06	-0.08	0.063
H_1	.159**	.187**	.152**	0.075	0.076	-0.03	0.043	-0.01	-0.07	-0.01	-0.03	-0.01	0.075
H_2	.243**	.492**	.386**	.341**	.232**	0.028	.098*	-0.02	-0.15	-0.07	-0.1	-0.09	.197**
S_2	0.061	0.002	0.017	0.074	-0.021	0.016	0.027	0.053	0.088*	.120**	0.071	0.089*	0.103*

Table 9: Correlation between HD^2 and yield

	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y
$(HD^2)_0$	.161**	.288**	.198**	.094*	.130**	-0.04	0.068	-0.07	-0.11	-0.08	-0.05	-0.07	0.068
$(HD^2)_1$	-0.01	-0.07	-0.06	0.025	0.069	.154**	.259**	.550**	.453**	.298**	.420**	.789**	.598**
$(HD^2)_2$	-0.03	-0.05	0.007	0.067	.126**	.180**	.277**	.506**	.636**	.271**	.418**	.661**	.644**

** Significant at 1% level

* Significant at 5% level

To study the influence of canopy spread on yield of cocoa, correlation coefficients were worked out with annual yield for all the 12 years (Y_2 to Y_{13}) and also with total yield Y and is given in Table 8. Positive correlation was observed between canopy spread and yield except with Y_6. But correlation was found significant with yield in the later years (Y_{10}, Y_{11} and Y_{13}) and total yield Y.

From the correlation studies, it could be established that girth and height have significant influence on the yield of cocoa whereas spread does not show much influence on yield.

4.2.4 Correlation between HD^2 and yield

In cocoa, seedlings are selected for planting based on the value of HD^2. Usually, seedlings with high values of HD^2 are selected for planting. Hence, to understand the nature of association of HD^2 with yield, correlations were worked out and are presented in Table 9. Initial HD^2, $(HD^2)_0$ had significant correlation with first five years' yield (Y_2, Y_3, Y_4, Y_5 and Y_6). But the correlation was negative with yield in the later years. The correlation between $(HD^2)_0$ and total yield Y was non significant. Sridevi (1999) got non significant correlation with $(HD^2)_0$ and yield in the fourth YAP.

The correlation between HD^2 one YAP, $(HD^2)_1$ and yield Y_7, Y_8, Y_9, Y_{10} , Y_{11} ,Y_{12} and Y_{13} was significant. It had high significant correlation with total yield Y (0.598). HD^2 in the second YAP, $(HD^2)_2$ had high significant correlation with yield from sixth to 13th YAP (Y_6, Y_7, Y_8 … Y_{13}). Also high significant correlation of 0.644 was observed with total yield Y.

From the correlations, it could be inferred that initial HD^2, $(HD^2)_0$ had significant influence on yield of the plant upto age at yield stabilization. HD^2 in the first and second YAP have clear influence on the yield after yield stabilization year.

4.2.5 Correlation between precocity and growth parameters and total yield

It is of immense use for a cocoa breeder to know the association of precocity with other characters. The correlation between precocity and girth, height, spread, and HD^2 were worked out and is provided in Table 10. Girths from the first to fifth YAP had high significant correlation with precocity (P). Initial height H_0 and heights in the first and second YAP (H_1 and H_2) also had high significant correlation with P. The correlation between spread and precocity was non significant.

The correlation between initial HD^2 and precocity was non significant, but it got significant correlation with $(HD^2)_1$ and $(HD^2)_2$ (0.249 and 0.356). The correlation between precocity and total yield Y was also highly significant (0.397). Atanda (1972) also reported influence of precocity on the yield potential of cocoa.

4.2.6 Correlation between annual yield and total yield

The correlation among annual yield (Y_2, Y_3,…Y_{12}, Y_{13}) and total yield (Y) are depicted in Table 11. From the table, it could be observed that annual yield in any particular year influences subsequent years' yield. Annual yield from third YAP to 13 YAP (Y_3 to Y_{13}) had significant correlation with total yield Y. The reduction in magnitude of correlation of yield in 11^{th}, 12^{th} and 13^{th} YAP (Y_{11}, Y_{12} and Y_{13}) with total yield Y might be due to the reduction in yield after tenth year. Yield in early years had significant correlation with yield in the subsequent two to three years, but after yield stabilization year, the correlation was significant with subsequent five to six years' yield. From third year onwards, annual yield showed significant correlation with total yield Y.

Table 10: Correlation between precocity and growth parameters and total yield

	G_0	G_1	G_2	G_3	G_4	G_5	H_0	H_1	H_2	S_2	HD_0^2	HD_1^2	HD_2^2	Y
P	0.05	.181**	.255**	.298**	.130**	.418**	.312**	.213**	.560**	.050	0.06	.249*	.356**	.397**

Table 11: Correlation between annual yield and total yield

	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_{10}	Y_{11}	Y_{12}	Y_{13}	Y
Y_2	1												
Y_3	.268**	1											
Y_4	.127*	.525**	1										
Y_5	0.02	.317**	.477**	1									
Y_6	0.09	.172**	.273**	.282**	1								
Y_7	-0.05	0.03	.135**	.257**	.353**	1							
Y_8	0.05	0	0.05	.084*	.250**	.157**	1						
Y_9	-0.1	-0.07	0.03	.122**	.180**	.261**	.177**	1					
Y_{10}	-0.09	-0.12	-0.07	-0.02	.151**	.199**	.260**	.417**	1				
Y_{11}	-0.11	-0.1	-0.04	0.05	.170**	.143**	.199**	.260**	.264**	1			
Y_{12}	-0.05	-0.15	-0.07	0	.131**	.137**	.269**	.180**	.349**	.329**	1		
Y_{13}	-0.04	-0.09	-0.18	-0.06	0.01	0.04	.202**	.155**	.330**	.293**	.389**	1	
Y	0.06	.187**	.320**	.414**	.543**	.499**	.560**	.553**	.594**	.491**	.519**	.422**	1

** Significance at 1% level
* Significance at 5% level

4.3 Fitting of models for prediction of yield

Correlation studies showed that girth, height, spread, HD^2 and precocity have influence on yield. Hence, attempts were made to see whether suitable models can be fitted to predict total yield Y as well as annual yield based on the above characters. No model could be identified for predicting total yield of cocoa based on growth characters, with reasonable predictability. This is due to the peculiar nature of variability in yield exhibited by cocoa. Jain and Agrawal (1987) also reported low predictability for yield prediction based on growth characters.

To understand the nature of variation in yield for change in growth characters, the graph of total yield Y for girth in the fifth YAP (G_5) is provided in Figure 4. High variability in total yield was exhibited for the same value of G_5. In this situation, the variability in yield can be exploited by determining the optimum range for the different growth characters.

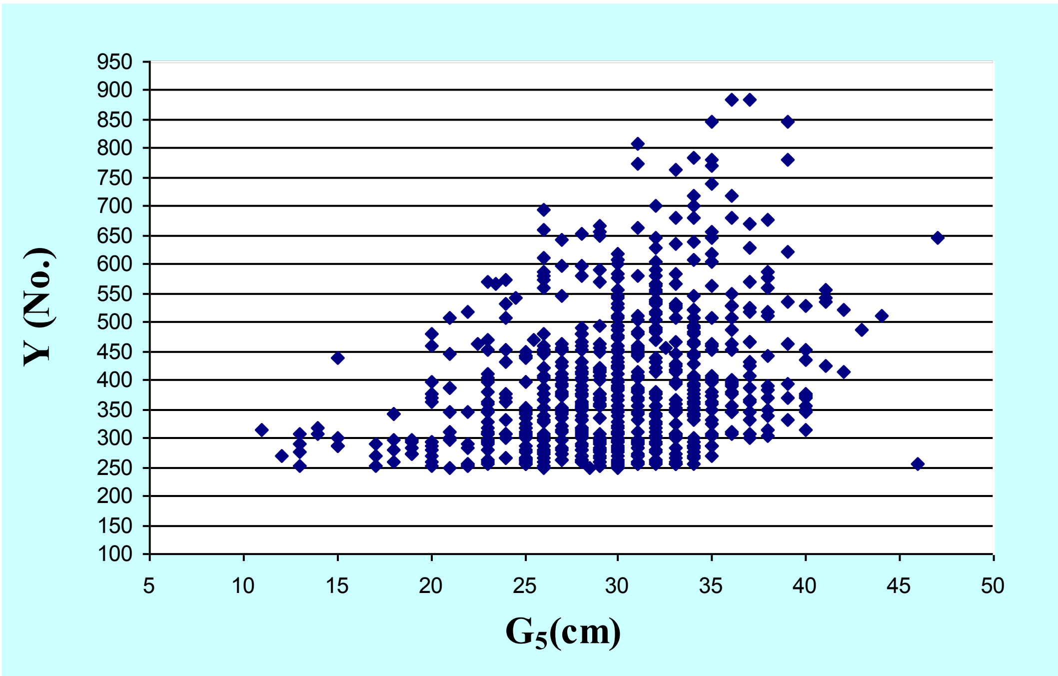


Figure 4: Total yield for girth in the fifth year after planting

4.4 Determination of optimum growth characters for maximum total yield

The optimum range for the different growth characters viz., girth G_i, i = 0 to 12, height H_i, i = 0 to 2 and spread S_2 and also precocity P, which will give maximum yield, were derived. The results are provided in the following sections.

The range, mean, SE and CV for girth G_i (i = 0 to 12), height H_i (i = 0 to 2), spread (S_2), annual yield (Y_2 to Y_{13}), total yield (Y) and precocity (P) is given in Table 12. From the table, it could be seen that the coefficient of variation (CV) for girth and height is decreasing with increase in age of the plant. The CV for annual yield and precocity were high compared to that of the growth characters girth, height and spread. All the values were above 50 per cent. Bhat *et al*. (1990) got CV in the range 16.53 to 109.1 percent for annual yield. High CV for annual yield has been reported by Cheriyan *et al.* (1996) also. For total yield Y, CV was only 31.76 per cent.

4.4.1 Optimum girth for maximum total yield

The methodology for determining optimum girth G_i, i = 0 to 12 are outlined in section 3.4.5.1 and the results are presented here. Different classifications were tried for each G_i (i = 0 to 12) and the degrees of freedom (df) and mean square (MS) in the analysis of variance (ANOVA) table for the classification which gave minimum within group MS are presented in Table 13. The width and number of classes vary for different girth G_i, i = 0 to 12 accordingly.

Table 12: Range, mean, SE, and CV for girth, height, spread, yield and precocity

Character	Number of plants	Range (cm)	Mean (cm)	SE	CV
G_0	660	3-15	6.86	0.07	24.46
G_1	660	5-21	11.67	0.14	31.04
G_2	660	6-33	18.70	0.19	25.86
G_3	660	7- 38.5	24.61	0.21	21.63
G_4	660	11-47	29.75	0.21	18.29
G_5	660	15- 54	34.07	0.21	15.93
G_6	660	20- 57	36.49	0.21	15.06
G_7	660	21.5- 59	38.34	0.22	14.55
G_8	660	24- 62	40.45	0.21	13.87
G_9	660	27- 67	43.69	0.24	14.31
G_{10}	660	28- 67	45.50	0.25	14.31
G_{11}	660	29- 68	47.15	0.26	13.87
G_{12}	660	31- 72	49.17	0.26	13.77
H_0	660	12- 191	95.83	1.21	32.39
H_1	660	45- 290	128.83	1.57	31.34
H_2	660	50- 430	257.10	2.51	24.98
S_2	614	25- 445	256.94	2.96	28.54
Y_2	287	1-45	10.02	0.52	88.55
Y_3	550	1-85	14.67	0.56	89.67
Y_4	617	1- 116	27.50	0.80	72.37
Y_5	642	1- 125	33.55	0.80	60.54
Y_6	656	1- 151	35.65	0.82	58.89
Y_7	657	1- 158	36.48	0.91	64.00
Y_8	655	3- 170	44.67	1.08	61.69
Y_9	657	1- 217	46.46	1.06	58.32
Y_{10}	659	2- 265	60.81	1.30	55.05
Y_{11}	655	1- 157	39.40	0.92	59.65
Y_{12}	642	1- 211	34.94	0.96	69.31
Y_{13}	639	1- 125	28.96	0.86	75.33
Y	660	250- 1168	399.11	4.93	31.76
P	649	1- 254	76.19	1.87	62.49

Table 13: ANOVA for total yield Y for the classification based on G_i (i =0 to12)

Character for classification	Source of variation	df	Mean Square
G_0	Between Groups	2	26805.62
	Within Groups	657	14714.21
	Total	659	
G_1	Between Groups	3	119640.30**
	Within Groups	656	14269.87
	Total	659	
G_2	Between Groups	10	74352.13**
	Within Groups	649	13829.82
	Total	659	
G_3	Between Groups	7	137041.60**
	Within Groups	652	14770.79
	Total	659	
G_4	Between Groups	6	189379.50**
	Within Groups	653	14477.14
	Total	659	
G_5	Between Groups	6	307959.89**
	Within Groups	653	13387.58
	Total	659	
G_6	Between Groups	8	302145.33**
	Within Groups	651	12554.0472
	Total	659	
G_7	Between Groups	7	278562.86**
	Within Groups	652	13251.39
	Total	659	
G_8	Between Groups	8	259576.08**
	Within Groups	651	13077.17
	Total	659	
G_9	Between Groups	6	325826.80**
	Within Groups	653	13223.41
	Total	659	
G_{10}	Between Groups	10	197000.60**
	Within Groups	649	13281.73
	Total	659	
G_{11}	Between Groups	9	195042.70**
	Within Groups	650	13591.48
	Total	659	
G_{12}	Between Groups	7	218634.30**
	Within Groups	652	13894.80
	Total	659	

4.4.1 (a) Girth in the initial year of planting (G_0)

Girth in the initial year of planting (G_0) ranged from 3 to 15 cm with a mean of 6.86 cm. The classification with width of 6 cm gave minimum within group MS for total yield Y and there were three groups (Table 13). The frequency distribution, mean values of G_0, mean, SE, CV, and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 14. Under this classification, 75.61% of the total plants are in the girth range 6-12 cm with a mean girth of 7.54 cm. The mean total yield in this group is 402.02 pods. The SE of mean, CV and 95% confidence interval are lowest in this group. Although the plants having G_0 greater than or equal to 12 cm had highest mean for Y (423.5), only 0.61% of the total plants had this girth and also CV is high. Thus, optimum value for initial girth G_0 is **6-12** cm. The mean values for total yield Y in the different groups of G_0 and the optimum range for G_0 are graphically represented in Figure 5(a).

4.4.1 (b): Girth in the first year after planting (G_1)

G_1 ranged from 5cm to 21 cm (Table 12) with a mean of 11.67 cm. The classification with width of 5 cm gave minimum within group MS and maximum significance for total yield Y (Table 13) and there were four groups. The frequency distribution, mean values of G_1, mean, SE, CV, and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 15. As indicated by the superscript 'a', the Y means of the groups 1, 2 and 3 did not differ significantly. For groups 2, 3 and 4 mean G_1 is greater than population mean 11.67 cm. 452 plants out of 660 (68.48%) which belonged to the groups 2 and 3 had G_1 in the range 10-20 cm. For the plants with girth more than 20 cm, although the mean of total yield Y is significantly higher, 95% confidence interval and SE of mean are very high and the frequency per cent is low (2.27%). Hence, the optimum girth one YAP (G_1) for getting maximum total yield is **10-20 cm**. The mean values for total yield Y in the different groups of G_1 and the optimum range for G_1 are graphically represented in Figure 5 (b).

Table 14: Classification of plants based on G_0

Group No.	G_0 Range (cm)	Frequency		G_0 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<6	157	23.79	4.59	381.11	9.95	32.71	361.52	400.76	39.24
2	**6-12**	**499**	**75.61**	**7.54**	**402.02**	**5.38**	**29.88**	**391.46**	**412.59**	**21.13**
3	≥12	4	0.61	13.50	423.50	12.00	39.91	395.32	451.45	56.13

Table 15: Classification of plants based on G_1

Group No.	G_1 Range (cm)	Frequency		G_1 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<10	193	29.24	7.47	365.30^{a}	7.09	26.98	351.31	379.30	27.98
2	**10-15**	**311**	**47.12**	**11.77**	**406.00^{a}**	**7.16**	**31.10**	**391.91**	**420.10**	**28.18**
3	**15-20**	**141**	**21.36**	**16.34**	**412.72^{a}**	**10.87**	**31.28**	**391.23**	**434.20**	**42.99**
4	≥20	15	2.27	20.38	486.85^{b}	35.25	26.11	410.04	563.70	153.61

Table 16: Classification of plants based on G_2

Group No.	G_2 Range (cm)	Frequency		G_2 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<10	22	3.33	8.16	314.41^{a}	15.32	22.86	282.60	346.30	63.72
2	10-12	40	6.06	10.79	325.20^{a}	11.38	22.13	302.20	348.20	46.04
3	12-14	39	5.91	12.68	350.67^{ab}	12.78	22.76	324.80	376.50	51.75
4	14-16	77	11.67	14.56	389.21^{bc}	11.35	25.59	366.60	411.80	45.21
5	16-18	76	11.52	16.57	398.43^{bc}	15.10	33.05	368.40	428.50	60.17
6	**18-20**	**106**	**16.06**	**18.51**	**395.84^{bc}**	**11.52**	**29.96**	**373.00**	**418.70**	**45.68**
7	**20-22**	**110**	**16.67**	**20.63**	**400.49^{bc}**	**11.79**	**30.87**	**377.10**	**423.90**	**46.72**
8	**22-24**	**76**	**11.52**	**22.58**	**419.39^{cd}**	**15.05**	**31.28**	**389.40**	**449.40**	**59.95**
9	**24-26**	**71**	**10.76**	**24.56**	**431.01^{cd}**	**15.32**	**29.96**	**400.50**	**461.60**	**61.13**
10	26-28	32	4.85	26.63	466.90^{cd}	26.32	30.88	413.10	520.70	107.66
11	≥28	11	1.67	29.23	449.55^{d}	35.42	26.13	370.60	528.50	157.86

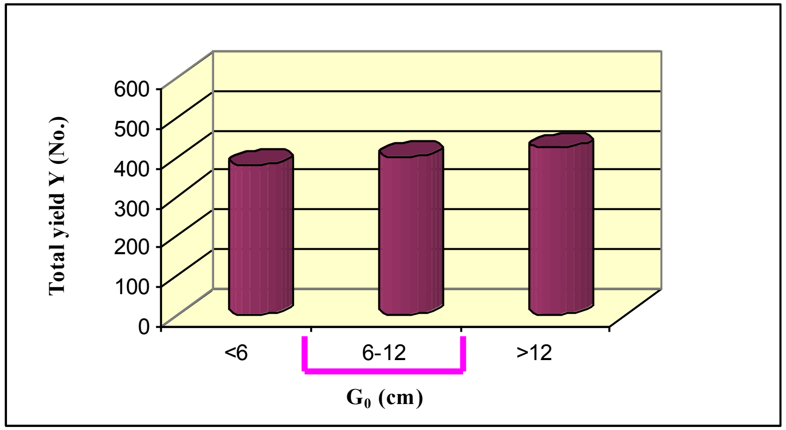


Figure 5 (a): Mean values for Y in the different groups of G_0

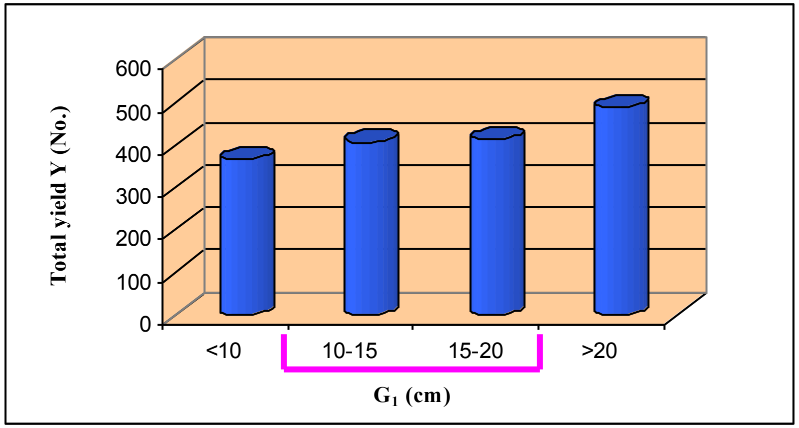


Figure 5 (b): Mean values for Y in the different groups of G_1

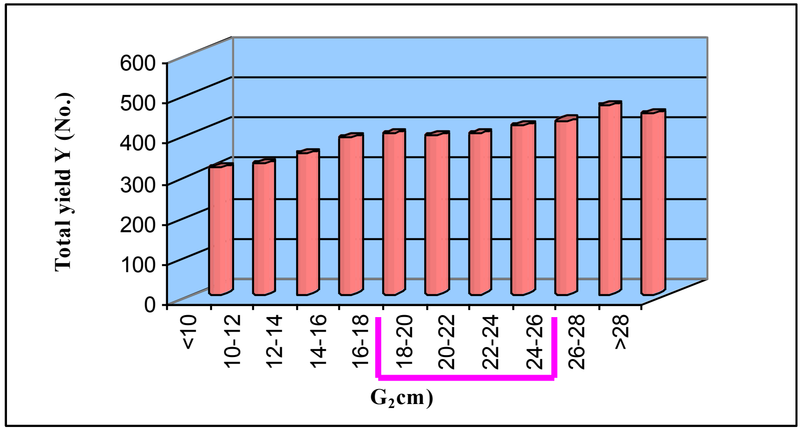


Figure 5 (c): Mean values for Y in the different groups of G_2

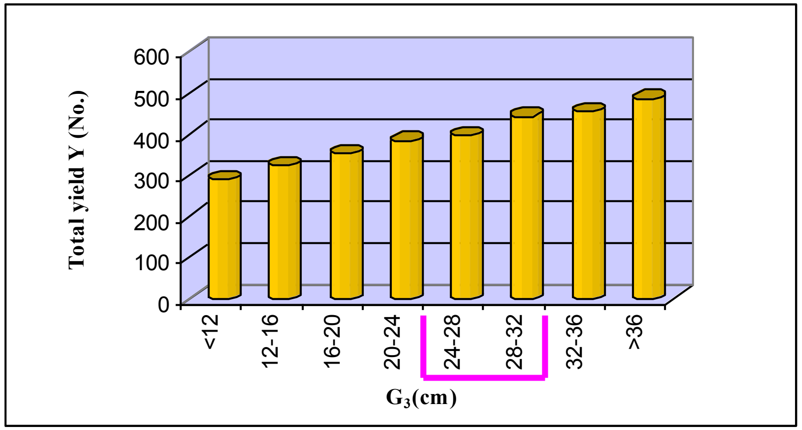


Figure 5 (d): Mean values for Y in the different groups of G_3

4.4.1 (c): Girth two years after planting (G_2)

G_2 ranged from 6 to 33 cm with a mean of 18.70 cm. The classification with width 2 cm gave minimum within group MS and there were 11 groups (Table 13). The frequency distribution, mean values of G_2, mean, SE, CV, and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 16. 363 plants out of 660 (55.01%) which belonged to the groups 6, 7, 8 and 9 had G_2 in the range 18-26 cm. Also, these four groups did not differ significantly with respect to total yield Y. The last two groups (10 and 11) having G_2 greater than or equal to 26cm accounted for only 6.52% of the total plants and SE and 95% confidence interval for mean of total yield Y was very high in these two groups. Also, for plants having G_2 greater than or equal to 28 cm (11^{th} group), the mean for Y got reduced. Taking all these factors into account, optimum range for G_2 is **18-26 cm** for getting maximum total yield. The mean values for total yield Y in the different groups and the optimum range for G_2 are shown in Figure 5 (c).

4.4.1(d): Girth three years after planting (G_3)

G_3 ranged from 7 to 38.5 cm with a mean of 24.61 cm. Based on G_3, classification with a width of 4 cm gave minimum within group MS and there were eight groups (Table 13). The mean values of G_3 and mean, SE, CV, and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 17. From the table, it could be observed that 52.88% of the plants had girth 24-32 cm and mean above 24.61cm. Also, the plants in this girth range (fifth and sixth groups) did not differ significantly with respect to total yield Y. The last two groups having high mean for Y had high SE and the confidence interval was also very high. Also, these two groups contributed only 7.12% of the total plants. Hence, the optimum girth at three YAP is **24-32** cm. The mean values for total yield Y in the different groups are shown in Figure 5 (d). The optimum range for G_3 is indicated in the graph.

4.4.1 (e): Girth four years after planting (G_4)

G_4 ranged from 11 to 47 cm with a mean of 29.75 cm. Based on G_4, classification with a width of 5 cm gave minimum within group MS and there were seven groups (Table 13). The mean values of G_4 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 18. From the table, it could be observed that 52.42% of the total plants had girth 30-40 cm and above the population mean 29.75cm and these two groups are homogeneous with respect to Y as indicated by the superscripts. For the seventh group of plants having G_4 greater than or equal to 40 cm, the frequency was only 3.03% and the confidence interval was very high. Also, the mean total yield Y in this group had a reduction from 468.96 in the sixth group to 439.9. Hence, the optimum girth at four YAP is derived as **30-40** cm. The mean values for total yield Y in the different groups and the optimum range for G_4 are shown in Figure 5 (e).

4.4.1 (f): Girth five years after planting (G_5)

The range of G_5 is 15 to 54 cm and its mean is 34.07 cm. The classification of plants based on G_5 with width 4cm gave minimum within group variance and there were 7 groups (Table 13). The mean values of G_5 and mean, SE, CV, and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 19. From the table, it could be observed that 37.12% of the total plants had G_5 greater than or equal to 36 cm and more and greater than the population mean 34.07cm. For the seventh group which accounted for only 3.33% of the total 660 had the highest SE of mean and 95% confidence interval and the mean total yield got reduced. Taking account of all these facts, the optimum range for G_5 is recommended as **36-44 cm.** The mean values for total yield Y in the different groups of G_5 and the optimum range for G_5 are given in Figure 5 (f).

Table 17: Classification of plants based on G_3

Group No.	G3 Range (cm)	Frequency		G3 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<12	10	1.52	9.65	288.90^{a}	7.07	7.74	272.91	304.89	31.98
2	12-16	25	3.79	14.32	322.72^{ab}	12.30	19.11	297.26	348.18	50.92
3	16-20	87	13.18	18.05	352.54^{abc}	9.86	26.09	332.94	372.14	39.20
4	20-24	142	21.52	21.84	384.59^{bcd}	9.03	27.98	366.74	402.44	35.70
5	**24-28**	**209**	**31.67**	**25.65**	**399.00^{cde}**	**8.90**	**32.32**	**381.45**	**416.54**	**35.09**
6	**28-32**	**140**	**21.21**	**29.74**	**443.18^{def}**	**12.20**	**32.80**	**418.98**	**467.39**	**48.41**
7	32-36	33	5.00	32.98	456.12^{ef}	23.30	29.28	408.77	503.48	94.71
8	≥36	14	2.12	37.04	486.75^{f}	35.90	25.57	407.68	565.82	158.14

Table 18: Classification of plants based on G_4

Group No.	G_4 Range (cm)	Frequency		G_4 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<15	8	1.21	12.88	292.25^{a}	8.58	8.31	271.95	312.60	40.60
2	15-20	17	2.58	17.41	297.35^{a}	10.47	14.52	275.16	319.60	44.39
3	20-25	73	11.06	22.32	355.88^{ab}	10.48	25.15	334.99	376.80	41.77
4	25-30	196	29.70	27.19	369.66^{b}	7.26	27.47	355.35	384.00	28.62
5	**30-35**	**251**	**38.03**	**31.84**	**415.29^{bc}**	**8.47**	**32.31**	**398.61**	**432.00**	**33.36**
6	**35-40**	**95**	**14.39**	**36.39**	**468.96^{c}**	**15.49**	**32.19**	**438.21**	**499.70**	**61.50**
7	≥40	20	3.03	41.40	439.90^{c}	22.22	22.58	393.40	486.40	93.00

Table 19: Classification of plants based on G_5

Group No.	G_5 Range (cm)	Frequency		G_5 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<24	25	3.79	20.38	297.08^{a}	10.01	16.85	276.42	317.74	41.32
2	24-28	41	6.21	25.866	323.95^{a}	10.49	20.74	302.75	345.16	42.41
3	28-32	125	18.94	29.872	345.50^{a}	7.00	22.66	331.64	359.35	27.71
4	32-36	224	33.94	33.686	391.75^{b}	7.87	30.07	376.25	407.26	31.01
5	**36-40**	**156**	**23.64**	**37.481**	**437.21^{bc}**	**10.70**	**30.57**	**416.06**	**458.35**	**42.29**
6	**40-44**	**67**	**10.15**	**41.291**	**500.33^{d}**	**19.40**	**31.73**	**461.60**	**539.06**	**77.46**
7	≥44	22	3.33	46.432	456.18^{cd}	21.53	22.14	411.40	500.96	89.56

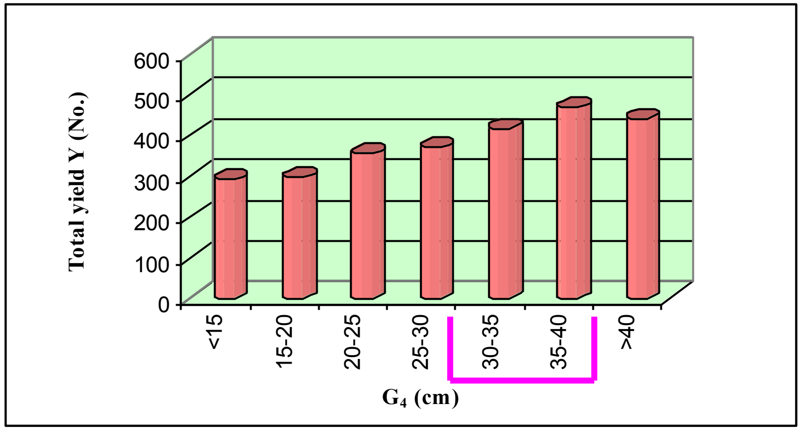


Figure 5 (e): Mean values for Y in the different groups of G_4

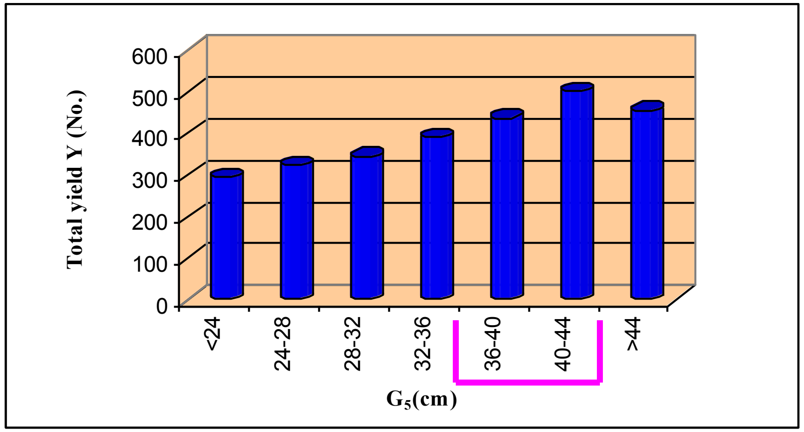


Figure 5 (f): Mean values for Y in the different groups of G_5

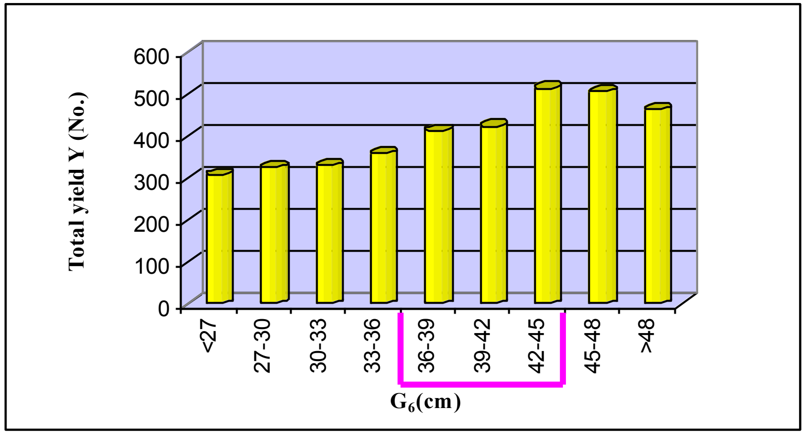


Figure 5 (g): Mean values for Y in the different groups of G_6

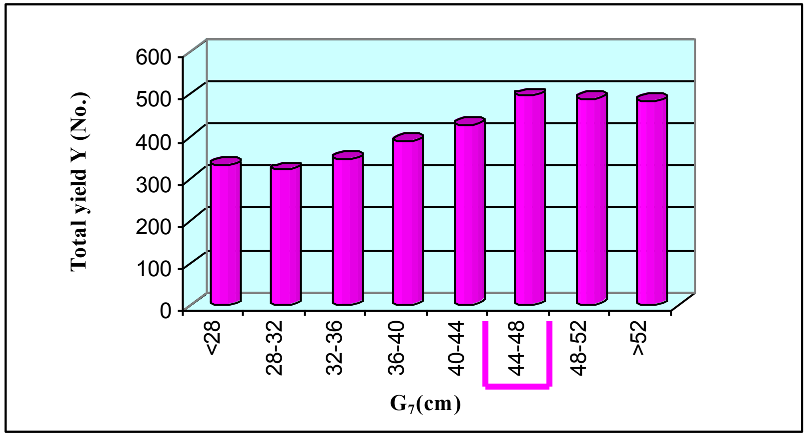


Figure 5 (h): Mean values for Y in the different groups of G_7

4.4.1 (g): Girth six years after planting (G_6)

G_6 ranged from 20 to 57 cm with a mean of 36.49cm. Based on G_6, classification with a width of 3 cm gave minimum within group MS and there were nine groups (Table 13). The mean values of G_6 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 20. Of the 55.76% plants which had G_6 greater than or equal to 36 cm, confidence interval for mean of Y was very high for groups 8 and 9 where, the plants had G_6 greater than or equal to 45 cm and accounted for only 5.91 per cent of the total plants. 49.85% of the plants had come under girth 36-45 cm in the sixth YAP. Hence, the optimum for G_6 is recommended as **36-45 cm**. The mean values for total yield Y in the different groups of G_6 and the optimum range for G_6 are given in Figure 5 (g).

4.4.1 (h): Girth seven years after planting (G_7)

G_7 ranged from 21.5 to 59 cm with a mean of 38.34cm. Based on G_7, classification with a width of 4 cm gave minimum within group MS and there were eight groups (Table 13). The mean values of G_7 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 21. Plants with G_7 greater than or equal to 48 cm, although had high mean total yield, accounted for only 4.09% and confidence interval and SE for mean of Y are very high in this range. Plants having girth 44-48 cm had significantly high mean for total yield and accounted for 12.58 per cent of the total plants. Hence, the optimum girth at seventh YAP is recommended as **44-48 cm**. The mean values for total yield Y in the different groups of G_7 and the optimum range for G_7 are shown in Figure 5 (h).

4.4.1(i): Girth eight years after planting (G_8)

G_8 ranged from 24 to 62 cm with a mean of 40.45cm. Based on G_8, classification with a width of 3 cm gave minimum within group MS (Table 13) and

Table 20: Classification of plants based on G_6

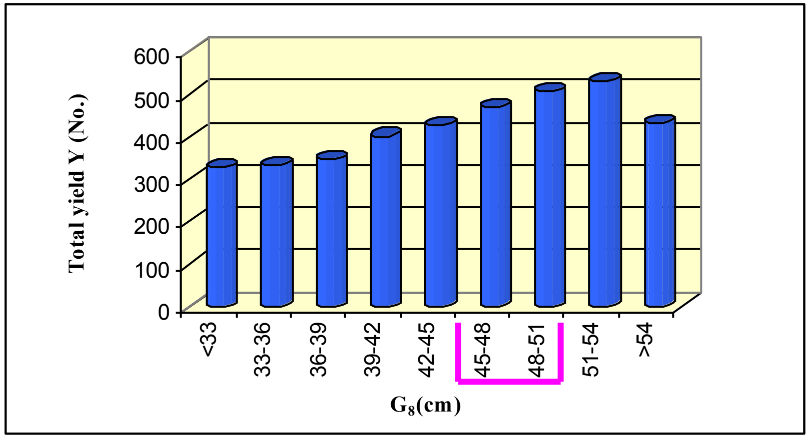
Group No.	G_6 Range (cm)	Frequency		G_6 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<27	27	4.09	24.04	308.11^{a}	57.95	18.81	285.19	331.04	45.85
2	27-30	31	4.70	28.29	325.13^{a}	74.87	23.03	297.67	352.59	54.92
3	30-33	88	13.33	31.17	330.35^{a}	71.47	21.64	315.21	345.50	30.29
4	33-36	146	22.12	34.23	359.45^{a}	93.47	26.00	344.16	374.74	30.58
5	**36-39**	**147**	**22.27**	**37.14**	**413.19^{b}**	**112.41**	**27.21**	**394.87**	**431.51**	**36.64**
6	**39-42**	**112**	**16.97**	**40.02**	**424.75^{b}**	**113.26**	**26.67**	**403.54**	**445.96**	**42.42**
7	**42-45**	**70**	**10.61**	**42.99**	**514.54^{c}**	**181.05**	**35.19**	**471.37**	**557.71**	**86.34**
8	45-48	24	3.64	45.71	506.79^{c}	142.96	28.21	446.43	567.16	120.73
9	≥48	15	2.27	51.40	464.67^{bc}	121.17	26.08	397.56	531.77	134.21

Table 21: Classification of plants based on G_7

Group No.	G_7 Range (cm)	Frequency		G_7 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<28	18	2.73	25.75	334.94^{ab}	17.88	22.64	297.23	372.66	75.43
2	28-32	54	8.18	30.22	321.41^{a}	11.21	25.62	298.93	343.89	44.96
3	32-36	139	21.06	33.99	345.66^{ab}	6.66	22.72	332.49	358.84	26.35
4	36-40	192	29.09	37.57	388.52^{bc}	7.76	27.66	373.22	403.81	30.59
5	40-44	147	22.27	41.52	428.44^{cd}	10.42	29.49	407.85	449.04	41.19
6	**44-48**	**83**	**12.58**	**45.48**	**497.08^{e}**	**18.44**	**33.80**	**460.4**	**533.77**	**73.37**
7	48-52	18	2.73	49.69	488.28^{de}	28.18	24.49	428.82	547.74	118.92
8	≥52	9	1.36	54.94	484.00^{de}	57.36	35.55	351.72	616.28	264.56

Table 22: Classification of plants based on G_8

Group No.	G_8 Range (cm)	Frequency		G_8 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<33	43	6.52	30.07	326.93^{a}	13.67	27.42	299.40	354.51	55.11
2	33-36	83	12.58	34.48	333.93^{a}	6.81	18.59	320.40	347.48	27.08
3	36-39	133	20.15	37.29	348.81^{ab}	7.91	26.15	333.20	364.46	31.26
4	39-42	154	23.33	40.18	401.14^{bc}	8.49	26.26	384.40	417.91	33.51
5	42-45	105	15.91	43.00	428.63^{cd}	11.61	27.75	405.60	451.65	46.05
6	**45-48**	**75**	**11.36**	**46.35**	**469.53^{de}**	**20.45**	**37.71**	**428.80**	**510.27**	**81.47**
7	**48-51**	**45**	**6.82**	**48.94**	**507.67^{ef}**	**22.45**	**29.67**	**462.40**	**552.92**	**90.52**
8	51-54	9	1.36	51.50	529.78^{f}	43.17	24.45	430.20	629.34	199.14
9	≥54	13	1.97	56.92	433.54^{cd}	29.92	24.89	368.30	498.74	130.44



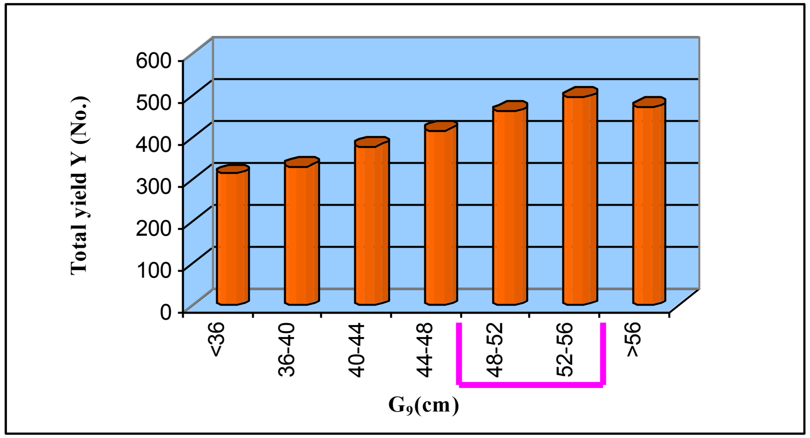
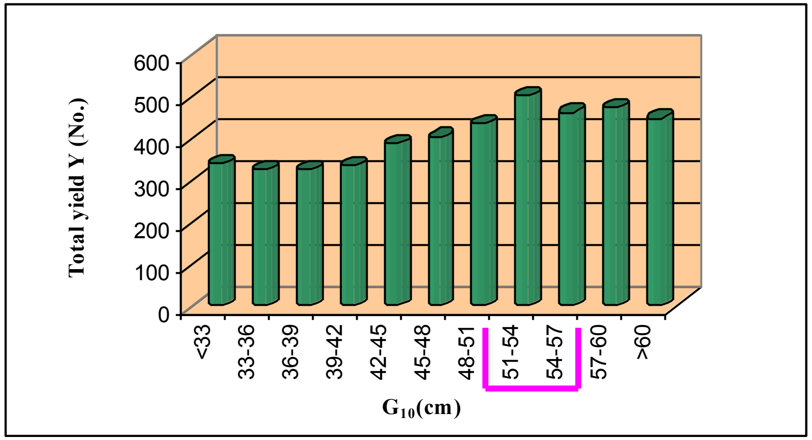


Figure 5 (i): Mean values for Y in the different groups of G_8

Figure 5 (j): Mean values for Y in the different groups of G_9



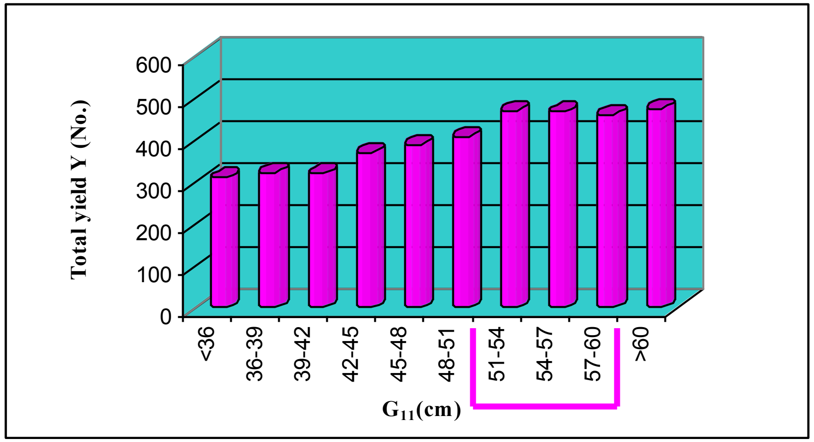


Figure 5 (k): Mean values for Y in the different groups of G_{10}

Figure 5 (l): Mean values for Y in the different groups of G_{11}

there were nine groups. The mean values of G_8 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 22. The highest mean for Y was recorded for plants having G_8 in the range 51-54 cm. (group 8). But the 95% confidence interval was very high and frequency per cent was very low (1.36) for this group. Also, only 3.35 per cent had G_8 greater than or equal to 51 cm. Plants in the girth range 45-51 cm gave significantly high mean total yield and accounted for 18.18% of the total plants. Considering the frequency distribution, the mean values for total yield Y and the 95% confidence interval, the optimum girth recommended at eighth YAP is **45-51 cm**. The mean values for total yield Y in the different groups of G_8 and the optimum range for G_8 are shown in Figure 5 (i).

4.4.1 (j): Girth nine years after planting (G_9)

G_9 ranged from 27 to 67 cm, with a mean of 43.69 cm. Based on G_9, the classification with width 4cm gave minimum within group variance (Table 13) and there were seven groups. The frequency distribution, mean values of G_9 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are presented in Table 23. From the table it could be observed that only 47.87 per cent plants had G_9 greater than or equal to 44 cm, above the population mean of 43.69 cm. Plants in the last three groups (groups 5, 6 and 7) got significantly high yield (Y) compared to the low girth groups. Plants in the seventh group ($G_9 \geq 56$ cm) had low mean for Y and the 95% confidence interval was highest. Taking account of all these, **48-56 cm** is identified as optimum girth at nineth YAP (G_9). The mean values for total yield Y in the different groups of G_9 and the optimum range for G_9 are presented in Figure 5 (j).

4.4.1 (k): Girth ten years after planting (G_{10})

G_{10} ranged from 28 to 67 cm with a mean of 45.5 cm. For G_{10}, the classification of plants with width 3cm gave minimum within group MS (Table 13) and there were 11 groups. The frequency distribution, mean of G_{10}, mean, SE, CV, 95% confidence limits and interval for Y are provided in Table 24. From the table, it could be observed that 343 out of the 660 plants (51.97%) had G_{10} greater than or equal to the population average 45.5 cm. Plants with G_{10} in the range 51-60 cm had significantly high mean total yield compared to other groups. But, for plants having girth 57-60 cm which accounted for 2.58% of total plants, the 95% confidence interval was very high. Mean total yield got reduced when G_{10} was greater than or equal to 60 cm. Hence, **51-57** cm appears to be the optimum for girth at 10^{th} YAP, for maximizing total yield Y. The mean values for total yield Y in the different groups of G_{10} and the optimum for G_{10} are given in Figure 5 (k).

4.4.1 (l): Girth 11 years after planting (G_{11})

G_{11} ranged from 29 to 68 cm with a mean of 47.15 cm. For G_{11}, the classification of plants with width 3cm gave minimum within group variance (Table 13) and there were 10 groups. The frequency distribution, mean of G_{11}, and mean, SE, CV, 95% confidence limits and interval for Y are presented in Table 25. From the table, it could be observed that 279 out of 660 plants (42.27%) had G_{11} greater than or equal to 48 cm at 11^{th} YAP. Plants having G_{11} greater than or equal to 51 cm had significantly high mean for Y, as indicated by the superscripts. Plants with G_{11} greater than or equal to 60 cm had the highest mean for total yield Y. But it accounted only 3.64% of the total population and the 95% confidence interval for mean of total yield is very high. Hence **51-60** cm is the optimum girth at 11 YAP. The mean values for total yield Y in the different groups of G_{11} and the optimum for G_{11} are given in Figure 5 (l).

4.4.1(m): Girth 12 years after planting (G_{12})

G_{12} ranged from 31 to 72 cm with a mean of 49.17 cm. The classification based on G_{12} gave minimum within group MS for width 4 cm (Table 13) and there were 8 groups. The frequency distribution (no. and per cent), mean of G_{12}, and mean, SE, CV, 95% confidence limits and interval for Y are presented in Table 26.

Table 23: Classification of plants based on G_9

Group No.	G_9 Range (cm)	Frequency		G_9 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<36	50	7.58	33.14	314.30[a]	10.44	23.48	293.33	335.27	41.94
2	36-40	112	16.97	37.81	331.55[a]	6.56	20.93	318.56	344.55	25.99
3	40-44	182	27.58	41.32	380.03[b]	7.43	26.38	365.37	394.70	29.33
4	44-48	146	22.12	45.21	417.35[b]	9.77	28.30	398.03	436.67	38.64
5	**48-52**	**102**	**15.45**	**49.37**	**463.77[c]**	**16.44**	**35.80**	**431.17**	**496.38**	**65.21**
6	**52-56**	**42**	**6.36**	**53.19**	**497.24[c]**	**21.13**	**27.53**	**454.57**	**539.90**	**85.33**
7	≥56	26	3.94	59.73	472.08[c]	25.99	28.08	418.54	525.61	107.07

Table 24: Classification of plants based on G_{10}

Group No.	G_{10} Range (cm)	Frequency		G_{10} mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<33	10	1.52	30.50	338.30[a]	52.51	49.08	219.52	457.08	237.56
2	33-36	20	3.03	34.30	323.95[a]	19.96	27.56	282.17	365.73	83.56
3	36-39	53	8.03	37.08	324.38[a]	8.84	19.84	306.63	342.12	35.49
4	39-42	98	14.85	40.20	333.26[a]	7.08	21.02	319.21	347.30	28.09
5	42-45	136	20.61	42.99	385.50[ab]	8.99	27.21	367.71	403.29	35.58
6	45-48	126	19.09	45.85	401.54[bc]	10.18	28.47	381.39	421.69	40.30
7	48-51	74	11.21	49.14	434.42[bcd]	13.94	27.60	406.64	462.20	55.56
8	**51-54**	**68**	**10.30**	**51.96**	**500.19[e]**	**21.85**	**36.02**	**456.58**	**543.8**	**87.22**
9	**54-57**	**40**	**6.06**	**55.03**	**461.00[de]**	**21.99**	**30.17**	**416.51**	**505.49**	**88.98**
10	57-60	17	2.58	57.88	472.76[e]	29.50	25.73	410.22	535.31	125.09
11	>60	18	2.73	62.61	446.61[bcd]	25.24	23.98	393.36	499.86	106.50

Table 25: Classification of plants based on G_{11}

Group No.	G_{11} Range (cm)	Frequency		G_{11} mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<36	16	2.42	33.38	310.69[a]	19.32	24.87	269.51	351.86	82.35
2	36-39	40	6.06	37.14	322.48[ab]	11.51	22.57	299.19	345.76	46.57
3	39-42	65	9.85	40.08	320.35[ab]	7.52	18.93	305.33	335.38	30.05
4	42-45	102	15.45	43.09	371.41[bc]	9.51	25.86	352.55	390.28	37.73
5	45-48	158	23.94	45.95	390.69[c]	8.71	28.02	373.48	407.89	34.41
6	48-51	92	13.94	48.87	408.26[c]	12.38	29.10	383.66	432.86	49.20
7	**51-54**	**73**	**11.06**	**51.93**	**469.96[d]**	**19.93**	**36.22**	**430.24**	**509.68**	**79.44**
8	**54-57**	**55**	**8.33**	**54.58**	**467.42[d]**	**19.72**	**31.29**	**427.88**	**506.96**	**79.08**
9	**57-60**	**35**	**5.30**	**57.89**	**460.54[d]**	**21.42**	**27.51**	**417.01**	**504.07**	**87.06**
10	≥ 60	24	3.64	63.38	475.46[d]	27.50	28.33	418.58	532.34	113.76

The mean values for Y are significantly higher for plants with G_{12} greater than or equal to 52 cm. 33.64% of total plants had G_{12} greater than or equal to 52 cm and significantly high mean for total yield Y compared to other groups. Hence, the optimum girth 12 YAP (G_{12}) for getting maximum total yield is **52 cm or more**. The mean values for total yield Y in the different groups of G_{12} and the optimum for G_{12} are given in Figure 5 (m).

Table 26: Classification of plants based on G_{12}

Group No.	G_{12} Range (cm)	Frequency		G_{12} mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<36	8	1.21	33.38	308.75^{a}	22.03	20.18	256.66	360.84	104.18
2	36-40	39	5.91	37.82	331.92^{ab}	15.11	28.42	301.34	362.50	61.16
3	40-44	68	10.30	41.43	335.24^{ab}	8.53	20.98	318.21	352.26	34.05
4	44-48	155	23.48	45.48	376.01^{b}	8.38	27.73	359.46	392.55	33.09
5	48-52	168	25.45	49.14	384.66^{b}	8.42	28.35	368.05	401.27	33.22
6	**52-56**	**106**	**16.06**	**53.41**	**475.70^{c}**	**15.68**	**33.93**	**444.61**	**506.78**	**62.17**
7	**56-60**	**72**	**10.91**	**57.39**	**442.53^{c}**	**15.44**	**29.60**	**411.75**	**473.31**	**61.56**
8	**≥60**	**44**	**6.67**	**63.50**	**454.77^{c}**	**19.88**	**29.00**	**414.68**	**494.87**	**80.19**

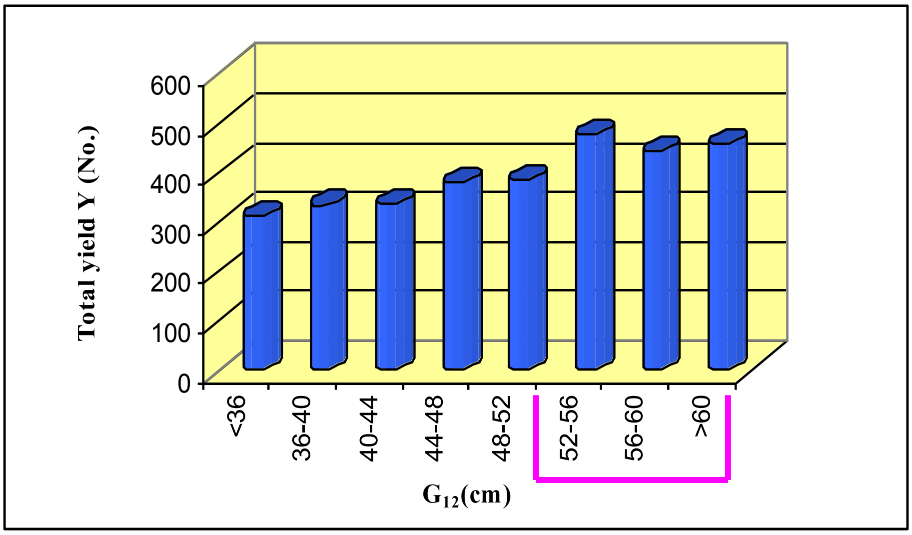


Figure 5 (m): Mean values for Y in the different groups of G_{12}

4.4.2 Optimum height for maximum total yield

The methodology for determining optimum height H_i, i = 0 to 2 for maximizing total yield are given in section 3.4.5.1. For H_0, H_1 and H_2 different classifications were tried and the df and MS in the ANOVA for the classification which gave minimum within group MS are presented in Table 27. Accordingly, the width and number of classes vary for different heights H_i, i = 0 to 2.

4.4.2 (a) Height in the initial year of planting (H_0)

The initial height H_0 ranged from 12 to191cm with a mean of 95.83 cm. Based on H_0, classification with a width of 50 cm gave minimum within group MS (Table 27) and there were four groups. The mean values of H_0 and mean, SE, CV and 95% confidence limits and interval for total yield Y in the different groups are provided in Table 28. 95% confidence interval was very high for plants having H_0 greater than or equal to 150 cm and accounted for only 2.27% of the total plants. Total yield Y was largest for plants having height 100-150 cm in the initial YOP. Also, in this height group, the 95% confidence interval was very low. Hence, the optimum for H_0 is 100-150 cm. The mean values for total yield Y in the different groups based on H_0 are given in Figure 6 (a).

4.4.2 (b): Height one year after planting (H_1)

Height one YAP (H_1) ranged from 45 to 290 cm with a mean of 128.83 cm. Based on H_1, classification with a width of 25 cm gave minimum within group MS and there were eight groups. But, there was no significant difference between groups for total yield Y (Table 27).

Table 27: ANOVA for total yield based on H_i (i= 0 to2), S_2, P and $(HD^2)_0$

Character for classification	Source of variation	df	Mean Square
H_0	Between Groups	3	19325.43
	Within Groups	656	16054.68
	Total	659	
H_1	Between Groups	7	16695.44
	Within Groups	652	16062.85
	Total	659	
H_2	Between Groups	5	93887.75**
	Within Groups	654	15474.63
	Total	659	
S_2	Between Groups	12	30887.00**
	Within Groups	601	15796.80
	Total	613	
P	Between Groups	9	158955.70**
	Within Groups	637	12738.76
	Total	646	
$(HD^2)_0$	Between Groups	2	18695.30
	Within Groups	657	16061.58
	Total	659	

** Significant at 1% level
* Significant at 5% level

Table 28: Classification of plants based on H_0

Group No.	H_0 Range (cm)	Frequency		H_0 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<50	64	9.70	31.80	392.30	15.40	31.41	361.52	423.08	61.56
2	50-100	249	37.73	80.38	388.80	8.340	33.83	372.38	405.21	32.83
3	100-150	332	50.30	117.05	408.30	6.80	30.32	394.97	421.70	26.73
4	≥ 150	15	2.27	155.87	395.10	31.60	30.98	327.29	462.85	135.56

The frequency distribution (no. and per cent), mean of H_1, mean, SE, CV, 95% confidence limits and interval for total yield Y in the different groups are presented in Table 29. From the table, it could be observed that plants having H_1 greater than or equal to 225cm, although had highest mean for total yield, the 95% confidence interval was very high. Hence, height upto 225cm is ideal for one YAP. The mean values for total yield Y in the different groups of H_1 are shown in Figure 6 (b).

4.4.2 (c): Height, two years after planting (H_2)

Height of the plants at two YAP ranged from 50-430 cm and the mean was 257.1 cm. When the plants were classified based on H_2, classification with width of 50 cm gave minimum within group MS and there were six groups. There was high significant difference between groups for total yield Y (Table 27). The frequency distribution (no. and per cent), mean of H_2, SE, CV, 95% confidence limits and interval for total yield Y in the different groups are presented in Table 30. From the table, it could be observed that the mean total yield Y is significantly higher for plants with H_2 greater than or equal to 200 cm, as indicated by the superscripts. The mean values for total yield Y in the different groups of H_2 are given in Figure 6 (c).

Height two YAP showed significant influence on total yield. In the progeny trial studied, the plants were not systematically pruned and as such some plants have developed two tiers within this two year period. Hence, the plants might have smothered the neighboring plants and this might have contributed to the difference in yield.

Table 29: Classification of plants based on H_1

Group No.	H_1 Range (cm)	Frequency		H_1 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<75	41	6.21	64.27	384.66	17.86	29.73	348.57	420.75	72.18
2	75-100	80	12.12	89.95	392.78	14.00	31.88	364.91	420.64	55.73
3	100-125	246	37.27	111.85	388.94	8.05	32.48	373.08	404.81	31.73
4	125-150	148	22.42	134.41	412.85	10.72	31.57	391.68	434.03	42.35
5	150-175	44	6.67	160.32	398.86	17.86	29.71	362.84	434.89	72.05
6	175-200	48	7.27	189.77	413.23	22.86	38.33	367.23	459.23	92.00
7	200-225	38	5.76	209.79	401.89	13.37	20.50	374.81	428.98	54.17
8	≥ 225	15	2.27	243.73	451.93	35.82	30.69	375.12	528.75	153.63

Table 30: Classification of plants based on H_2

Group No.	H_2 Range (cm)	Frequency		H_2 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	100-150	22	3.33	119.55	340.00^{a}	19.51	26.91	299.43	380.57	81.14
2	150-200	66	10.00	169.77	341.85^{a}	10.37	24.65	321.14	362.56	41.42
3	200-250	173	26.21	216.79	389.45^{b}	9.18	31.02	371.32	407.57	36.25
4	250-300	189	28.64	266.16	405.54^{b}	9.71	32.92	386.38	424.70	38.32
5	300-350	165	25.00	312.78	422.79^{b}	10.13	30.76	402.79	442.78	39.99
6	≥ 350	45	6.82	377.46	435.29^{b}	20.70	31.91	393.56	477.01	83.45

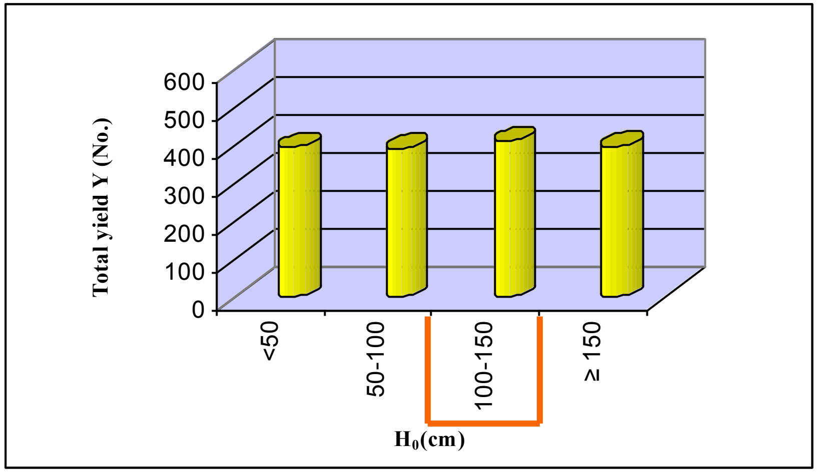


Figure 6 (a): Mean values for Y in the different groups of H_0

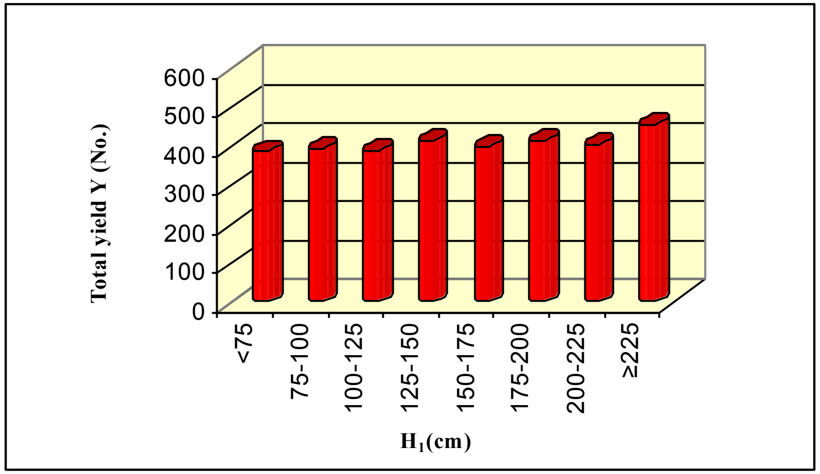


Figure 6 (b): Mean values for Y in the different groups of H_1

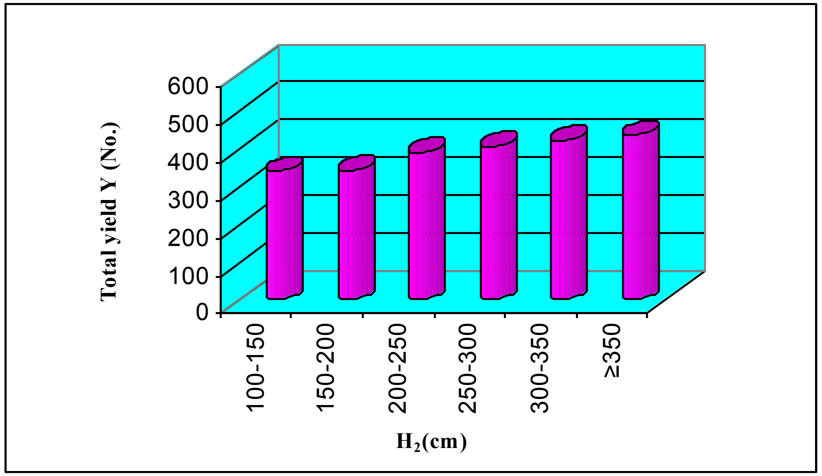


Figure 6 (c): Mean values for Y in the different groups of H_2

4.4.3 Optimum spread (S_2) for maximum total yield

Spread of the plants ranged from 25 to 445 cm with a mean of 256.94cm. When the plants were classified based on S_2, classification with width of 25 cm gave minimum within group MS and there were 13 groups. There was high significant difference between groups for total yield Y. The corresponding ANOVA is given in Table 27. The frequency distribution (no. and per cent), mean of S_2, mean, SE, CV, 95% confidence limits and interval for total yield Y in the different groups are presented in the Table 31. The mean values for total yield Y in the different groups of S_2 are depicted in Figure7. From the table and figure, it could be observed that variation in yield and spread does not have any correspondence. Hence, an optimum for S_2 can not be identified. This leads to the conclusion that spread is not a determining factor of the yield potential of a cocoa tree and this is true as it is restricted by pruning.

4.4.4 Optimum precocity (P) for maximum total yield Y

Precocity ranged from 1 to 254 pods with a mean of 76.19 pods. Based on precocity (P), the classification with width 20 gave minimum within group MS and there were 10 groups. The corresponding ANOVA is given in Table 27. There was high significant difference between groups for total yield Y. The frequency distribution (no. and per cent), mean of P, mean, SE, CV, 95% confidence limits and interval for total yield Y in the different groups are presented in the Table 32. The mean values for total yield Y in the different groups of P and the optimum for P are shown in Figure 8. From Table 32, it could be observed that only 27.04 % plants had precocity greater than or equal to 100 pods. Bhat *et. al*. (1990) also got low percentage of high yielders in a study on cocoa.

From Table 32 and Figure 8, it could be observed that mean total yield increased with increase in precocity and plants having precocity greater than or

Table 31: Classification of plants based on S_2

Group No.	S_2 Range (cm)	Frequency		S_2 mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<125	30	4.89	95.25	326.83[a]	12.64	21.18	301.00	352.70	51.69
2	125-150	21	3.42	135.70	438.71[bc]	44.97	46.98	344.90	532.50	187.60
3	150-175	35	5.70	161.10	404.49[bc]	25.22	36.89	353.20	455.80	102.50
4	175-200	53	8.63	185.90	391.42[ab]	17.64	32.82	356.00	426.80	70.81
5	200-225	49	7.98	211.60	407.94[bc]	18.04	30.96	371.70	444.20	72.55
6	225-250	68	11.07	236.60	408.24[bc]	13.82	27.91	380.70	435.80	55.15
7	250-275	74	12.05	261.00	388.01[ab]	15.27	33.86	357.60	418.50	60.87
8	275-300	76	12.38	283.70	402.70[bc]	15.28	33.08	372.30	433.10	60.89
9	300-325	105	17.10	308.90	393.43[ab]	11.48	29.89	370.70	416.20	45.52
10	325-350	53	8.63	336.20	407.58[bc]	16.11	28.77	375.30	439.90	64.65
11	350-375	21	3.42	360.80	468.52[c]	22.46	21.97	421.70	515.40	93.71
12	375-400	20	3.26	384.60	417.15[bc]	19.11	20.48	377.20	457.10	79.98
13	≥ 400	9	1.47	412.10	469.78[c]	47.11	30.08	361.10	578.40	217.30

Table 32: Classification of plants based on Precocity (P)

Group No.	P Range (cm)	Frequency		P mean (cm)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	0-20	68	10.51	10.84	329.53[a]	8.14	20.37	313.29	345.77	32.48
2	20-40	95	14.68	30.35	363.07[ab]	9.97	26.77	343.27	382.87	39.60
3	40-60	102	15.77	50.76	379.35[ab]	11.40	30.31	356.77	401.94	45.17
4	60-80	118	18.24	69.86	391.27[bc]	9.70	26.92	372.07	410.48	38.41
5	80-100	89	13.76	89.21	399.71[bc]	11.60	27.32	376.71	422.71	46.00
6	100-120	66	10.19	109.24	437.32[cd]	17.00	31.56	403.39	471.25	67.86
7	120-140	42	6.49	129.98	436.74[cd]	19.00	28.15	398.43	475.05	76.62
8	140-160	32	4.95	149.25	473.66[de]	27.80	33.23	416.92	530.40	113.48
9	160-180	16	2.47	170.75	500.75[e]	39.70	31.73	416.07	585.43	169.36
10	≥180	19	2.94	207.74	549.89[f]	26.40	20.90	494.51	605.28	110.77

Table 33: Classification of plants based on $(HD^2)_0$

Group No.	$(HD^2)_0$ Range (cm^3)	Frequency		$(HD^2)_0$ mean (cm^3)	Total yield Y			95% Confidence		
		No.	%		Mean	SE	CV	Lower limit	Upper limit	Interval
1	<500	362	54.85	272.00	392	6.73	144.25	379.2	405.6	26.46
2	500-1000	253	38.33	703.10	408	7.88	58.04	392.6	423.6	31.01
3	≥1000	45	6.82	1228.44	403	18.6	32.78	365.2	440.1	74.9

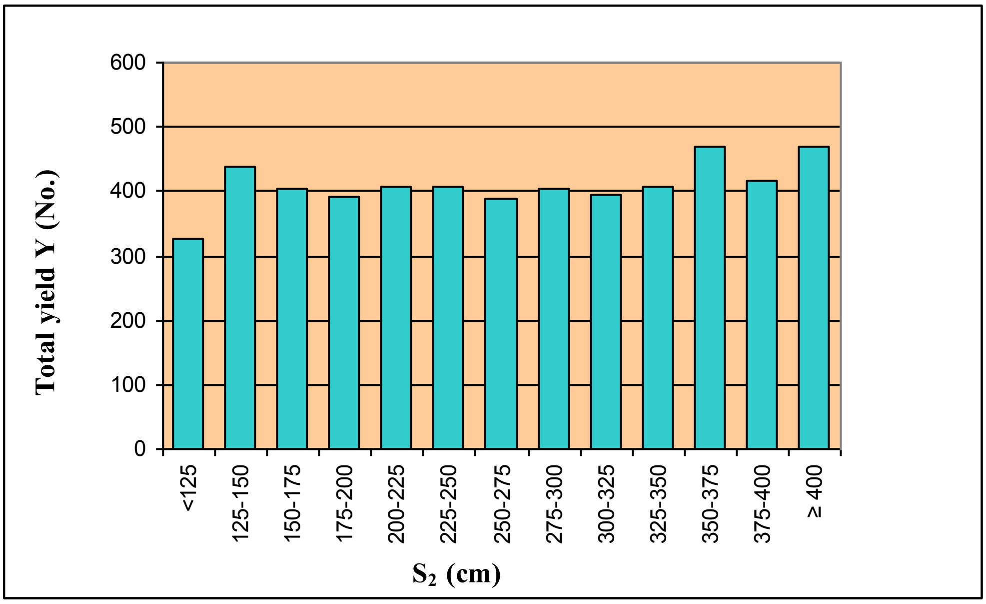


Figure 7: Mean values for Y in the different groups of S_2

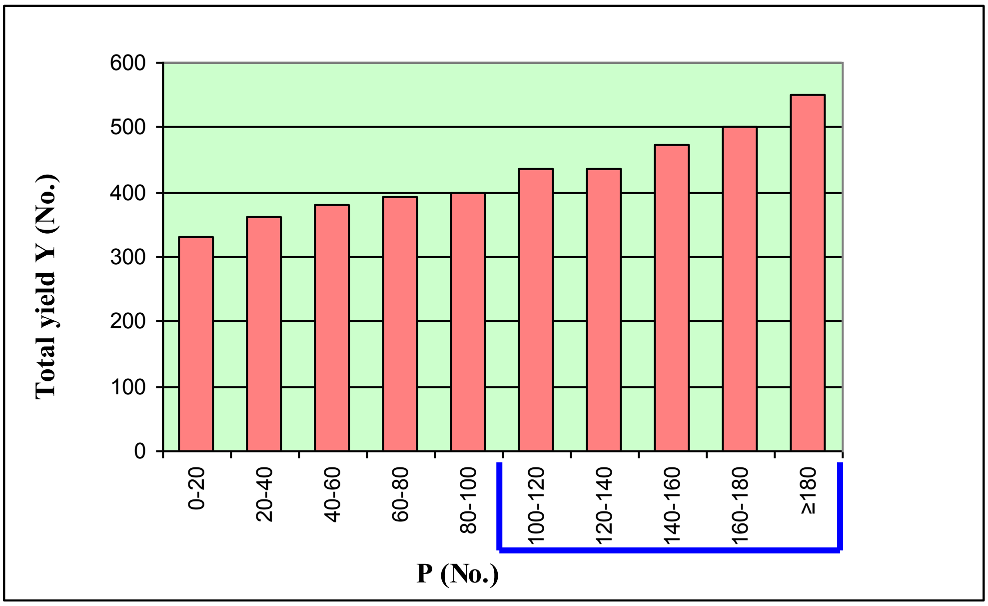


Figure 8: Mean values for Y in the different groups of P

equal to 100 pods gave better total yield, which is true practically also. Hence, plants with minimum precocity of 100 pods will have high yield potential.

The detailed analyses to find out optimum for girth, height and precocity to get maximum total yield Y indicated that the optimum combinations of these characters are also to be derived.

4.4.5 Optimum HD^2 in the initial year of planting for maximum total yield

Generally, seedlings with high HD^2 values are selected for planting in Kerala Agricultural University. Hence, to have an idea about the influence of HD^2 in the year of planting $(HD^2)_0$, plants were classified into groups with respect to this character and minimum within group MS was obtained for width 500 cm^3. The ANOVA for this classification is given in Table 27. The frequency distribution (No. and per cent), mean of initial HD^2 and mean, SE, CV, 95% confidence limits and interval for total yield Y are provided in Table 33. It could be observed that, total yield Y is highest for plants with $(HD^2)_0$ in the range 500-1000 cm^3 and 38.33% of the plants belonged to this group. Hence, 500-1000 cm^3 is ideal for $(HD^2)_0$. The mean values for total yield Y in the different groups of $(HD^2)_0$ are presented in Figure 9.

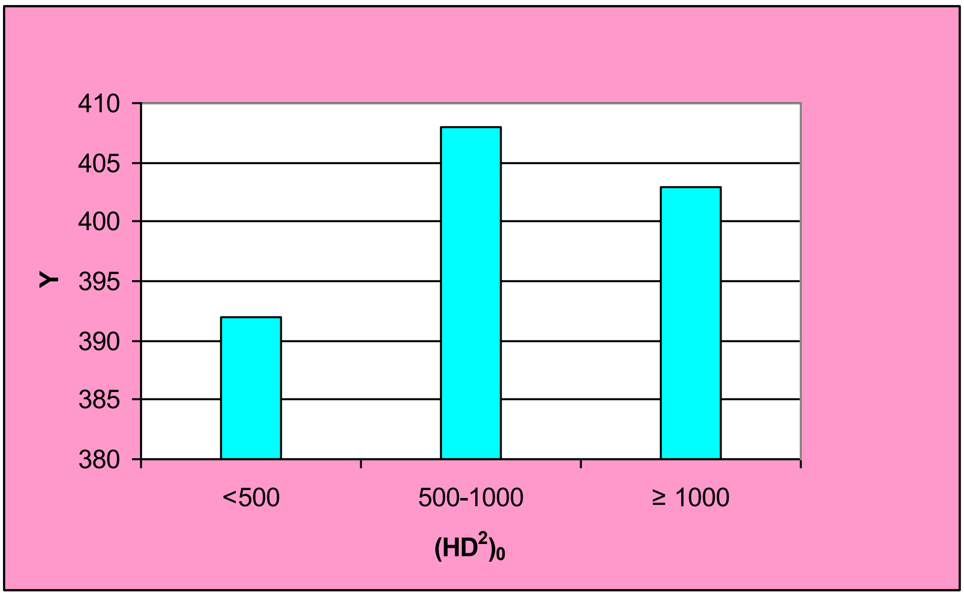


Figure 9: Mean values for Y in the different groups of $(HD^2)_0$

The optimum range derived, for girth G_i (i = 0 to 12), initial height H_0 and precocity (P) for maximum total yield Y are provided in Table 34.

Table 34: Optimum of growth characters for maximum yield

Growth characters	Optimum range (cm)
G_0	6-12
G_1	10-20
G_2	18-26
G_3	24-32
G_4	30-40
G_5	36-44
G_6	36-45
G_7	44-48
G_8	45-51
G_9	48-56
G_{10}	51-57
G_{11}	51-60
G_{12}	≥ 52
H_0	100-150
P	≥100 pods

4.5 Determination of optimum combination of characters for maximum yield

In sections 4.4.1 to 4.4.5, optimum for girth, height, precocity, and HD^2 in the initial year were obtained for getting maximum total yield. Some practically useful combinations of the above characters which gave maximum total yield were tried and are presented in the following sections.

4.5.1 Optimum combination of two characters

In the foregoing sections, it was observed that girth and height in the early years influence total yield Y. Hence, attempts have been made to find the optimum combination of the two characters in the initial year of planting as well as first and second YAP, for maximum total yield Y.

4.5.1 (a) Girth and Height in the initial year (G_0 and H_0)

Of the different classifications tried based on G_0 and H_0, to derive their optimum combination, the classification with width 6 cm for G_0 and 50 cm for H_0 gave significant interaction between the two for total yield Y. The ANOVA is given in Table 35. The frequency distribution, mean and CV of Y for the different combinations of G_0 and H_0 is presented in Table 36. The highest mean for Y (460.8) was obtained for G_0 in the range 0-6 cm and H_0 in the range 0-50 cm (Table 41). But this accounted for only 14 plants (2.13%) of the total 660 plants. Plants in the combination of 6-12 cm for G_0 and 100-150 cm for H_0 represented 37.5% of the population under study and had the next highest mean for Y (421.2). In the univariate case, optimum for G_0 was obtained as 6-12 cm and for H_0, 100-150 cm. This result is established when the two variables (G_0 & H_0) were taken in combination also. Thus, to maximize total yield Y, the optimum initial girth G_0 is **6-12** cm and initial height H_0 is **100-150** cm.

Table 35: ANOVA for total yield based on the classification of G_0 and H_0

Source of variation	df	Mean Square
G_0	1	3240.70
H_0	3	11147.64
G_0 H_0	3	84415.06**
Error	648	14334.34
Total	655	

Table 36: Classification based on G_0 and H_0

H_0 / G_0	0-50				50-100				100-150				150-200			
	Frequency		Y		Frequency		Y		Frequency		Y		Frequency		Y	
	No	%	Mean	CV	No	%	Mean	CV	No	%	Mean	CV	No	%	Mean	CV
0-6	14	2.13	460.80	34.78	56	8.54	390.40	36.86	83	12.65	363.40	27.01	4	0.61	340.00	31.55
6-12	50	7.62	373.10	28.10	192	29.27	384.30	30.02	**246**	**37.50**	**421.20**	**29.39**	11	1.68	415.10	30.35

4.5.1 (b) Girth and Height one year after planting (G_1 and H_1)

To derive the optimum combination of girth and height one YAP, different classifications based on the two characters were tried and the interaction between G_1 and H_1 was highly significant for the classification with width 2 cm for G_1 and 50 cm for H_1. The ANOVA for the same is given in Table 37. The frequency distribution (no. and per cent), mean and CV for total yield Y in the different combination of $G_1$and H_1 is given in Table 38.

The data furnished in Table 38 indicated that the plants with 10-12 cm girth and below 100 cm height recorded comparatively higher total yield. The plants with still higher girths showed progressive reduction in total yield, with the exception of two plants, which recorded the highest total yield of 741.

The data on optimum G_1 with H_1 (100-150 cm) indicated that plants with thicker stems generally produced higher total yield. The plants with 14-16 cm girth recorded the highest total yield of 438.3 and above this girth there was a reduction in yield.

The results on optimum girth G_1 with H_1(150-200 cm) did not show definite trend in yield pattern. The yield was the highest when the girth was greater than or equal to 18 cm, but the frequency of such plants in the population was only 0.61%.

The plants with H_1 greater than or equal to 200 cm also did not show definite trend in yield pattern. However, the highest yield of 488.5 was reached by the plants with girth greater than 18 cm. Lack of any definite trend can be attributed to the difference in shade levels within the plantation and genetic variability among the plants in the population.

A critical evaluation of the results pointed out that the optimum for G_1 was 10 cm and above and for H_1an optimum cannot be recommended. This was true with the results obtained when optimum was derived for G_1 and H_1 separately.

Table 37: ANOVA for total yield based on the classification of G_1 and H_1

Source of variation	df	Mean Square
G_1	6	59548.96**
H_1	3	7157.08
G_1H_1	18	25602.94**
Error	633	15387.62
Total	659	

Table 38: Classification based on G_1 and H_1

H_1 / G_1	<100				100-150				150-200				≥ 200			
	Frequency		Y		Frequency		Y		Frequency		Y		Frequency		Y	
	No	%	Mean	CV	No	%	Mean	CV	No	%	Mean	CV	No	%	Mean	CV
6-8	37	5.61	340.00	25.73	40	6.06	356.63	26.18	11	1.67	370.55	17.66				
8-10	24	3.64	386.10	32.03	64	9.70	376.00	27.79	11	1.67	337.27	21.92	6	0.91	424.00	20.53
10-12	33	5.00	434.00	27.57	88	13.33	388.47	30.78	21	3.18	412.05	26.51	6	0.91	413.30	13.33
12-14	20	3.03	397.70	26.39	75	11.36	396.95	31.48	14	2.12	432.36	61.59	11	1.67	430.20	23.29
14-16	3	0.45	358.70	12.41	60	9.09	438.30	38.61	19	2.88	410.42	27.10	9	1.36	413.20	24.11
16-18	2	0.30	741.00	20.04	39	5.91	424.82	34.04	12	1.82	442.17	27.24	17	2.58	389.50	30.15
≥ 18	2	0.30	257.50	0.27	28	4.24	415.39	25.71	4	0.61	447.25	28.44	4	0.61	488.50	28.56

4.5.1 (c) Girth and Height two years after planting (G_2 and H_2)

For girth and height at two YAP (G_2 and H_2), the classification with width 5cm for G_2 and 100 cm for H_2 gave significant interaction between the two. The ANOVA for the same is given in Table 39. The frequency distribution (no. and per cent), mean and CV for total yield Y in the different combinations of G_2 and H_2 are given in Table 40. The results with height less than 200 cm showed that the yield did not increase progressively with girth (G_2). In plants with heights 200-300 cm, there was progressive increase in yield except with plants having 20-25 cm girth. The highest yield of 448.8 cm was obtained with the thickest plants of greater than 25 cm girth.

The data on plants with greater than 300 cm height revealed that the increase in yield was progressive, with the highest yield in plants with the thickest trunk (>25 cm), though the frequency of such plants in the population was low.

The data showed significant influence of height on total yield. This is due to the fact that in the population studied, the plants were not systematically pruned, which led to variation in height. The optimum height under which cocoa is grown is 150-200 cm in one tier (POP, KAU, 2007). In the present study 87 % of the plants produced second or third tier due to unscientific pruning and these plants might have produced much better growth with much denser canopies and consequent higher yield. These plants might also had a smothering effect on the shaded plants with one tier. Hence, the results could not be highlighted.

4.5.2 Three – way combination

Analyses to derive the optimum of the single growth characters and two characters in combination showed that girth is the most important character which determines the yield potential of cocoa and at each stage of its growth, there is an optimum for girth. In the case of height (H_1 and H_2), it was not possibile to derive an optimum which maximizes total yield Y. But, with initial height H_0, maximum

Table 39: ANOVA for total yield based on classification of G_2 and H_2

Source of variation	df	Mean Square
G_2	4	107669.30^{**}
H_2	2	106255.76^{**}
G_2H_2	8	66493.66^{**}
Error	645	13516.34
Total	659	

Table 40: Classification based on G_2 and H_2

H_2 / G_2	<200				200-300				≥ 300			
	Frequency		Y		Frequency		Y		Frequency		Y	
	No	%	Mean	CV	No	%	Mean	CV	No	%	Mean	CV
<10	4	0.61	360.00	39.81	7	1.06	285.70	7.49	11	1.67	316.10	17.32
10-15	12	1.82	379.70	27.71	60	9.09	342.30	24.58	46	6.97	353.10	22.45
15-20	20	3.03	355.40	28.43	146	22.12	408.80	34.33	55	8.33	398.80	27.83
20-25	36	5.45	319.40	19.29	118	17.88	405.80	30.26	73	11.06	458.10	26.20
≥ 25	16	2.42	340.10	22.37	31	4.70	448.80	27.70	25	3.79	570.20	27.75

total yield was obtained upto 150 cm. Plants with precocity greater than or equal to 100 pods was shown to have high yield. Hence, three way combination was studied with G_0, H_0 and P.

4.5.2 (a): Initial year girth (G_0), height (H_0) and precocity (P)

Three way classification based on initial girth with class width 6 cm, initial height with class width 50 cm and precocity with class width 50 (no.), gave significant interaction between the three. The frequency distribution (no. and per cent), mean and CV for total yield Y in the different combinations of G_0, H_0 and P is given in Table 41. From the Table, it could be observed that 6 plants (0.93%) with initial girth (G_0) 0-6 cm, initial height (H_0) 100-150 cm and having greater than or equal to 100 pods produced mean total yield of 503.67. A mean total yield of 477.65 was obtained for G_0 6-12 cm, H_0 50-100 cm and having precocity greater than or equal to 100 pods. But only 34 plants (5.26%) belonged to this group. 114 plants (17.62%) having G_0 6-12 cm, H_0 100-150 cm and precocity greater than or equal to 100 pods gave the next highest mean of 455.67 pods. Thus, plants with initial girth 6-12 cm, initial height 100-150 cm and precocity greater than or equal to 100 pods is derived as the optimum for high yield potential for the plants under study. The data provided in the three way table (Table 41) can be taken as a guide for identifying high yielding plants.

The frequency distribution of plants in the different ranges of total yield Y is exhibited in Figure 10 for the entire population and for the plants with the optimum G_0, H_0 and P. It is evident from the figure that plants with the optimum combination of the three characters give high yield. In the population, only 39.97% plants produced 400 pods and more. But, for the plants with the optimum G_0, H_0 and P, the corresponding figure is 60.52%. Thus, the high yielding plants can be identified at five years after planting and this is a valuable information for people engaged in cocoa cultivation.

Table 41: Classification based on G_0, H_0 and P

G_0	H_0	P	Frequency		Mean	CV
			N	%		
0-6	<50	<50	26	4.02	362.46	28.71
		50-100	11	1.70	433.91	34.88
		≥100	2	0.31	**496.00**	32.22
	50-100	<50	41	6.34	347.80	27.44
		50-100	30	4.64	404.63	32.77
		≥100	10	1.55	**491.00**	34.54
	100-150	<50	9	1.39	342.56	16.64
		50-100	12	1.85	364.08	26.97
		≥100	6	0.93	**503.67**	37.97
6-12	<50	<50	6	0.93	370.17	22.28
		50-100	11	1.70	**473.18**	28.15
		≥100	3	0.46	351.33	28.75
	50-100	<50	56	8.66	335.91	18.42
		50-100	72	11.13	387.56	29.07
		≥100	34	5.26	**477.65**	31.92
	100-150	<50	64	9.89	358.09	26.44
		50-100	125	19.32	391.71	26.07
		≥100	114	17.62	**455.67**	29.41
	≥150	<50	1	0.15	260.00	
		50-100	8	1.24	375.88	21.94
		≥100	6	0.93	**443.17**	35.97

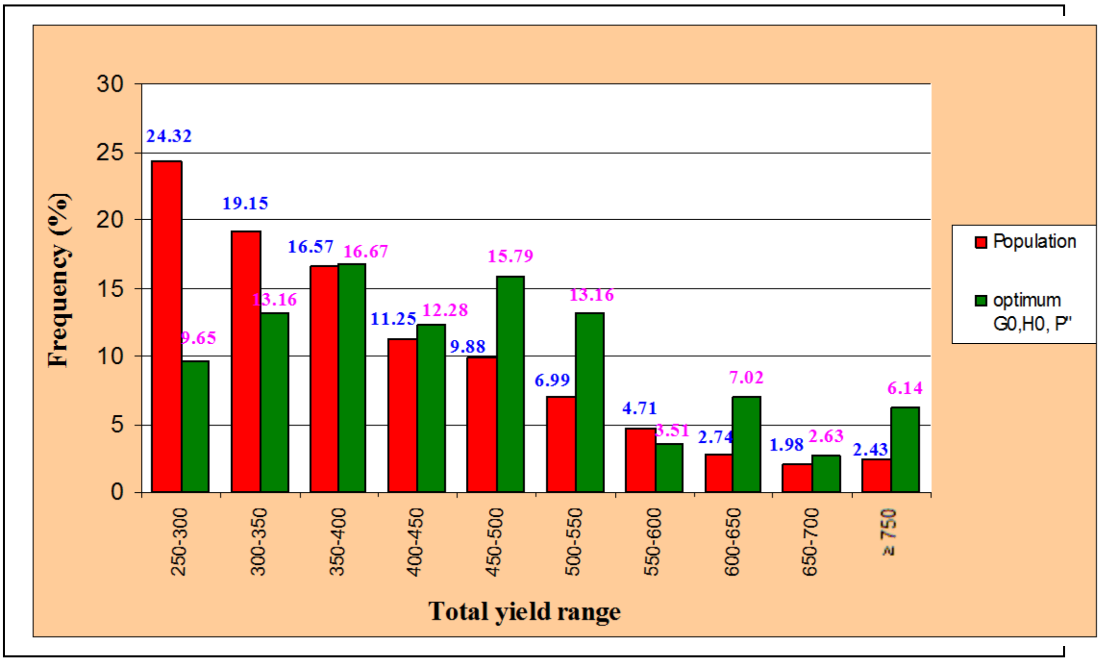


Figure 10: Frequency distribution of plants in the different ranges of total yield Y

The following observations could be made from the study:

Girth is the major determining factor of yield potential of a cocoa plant. The plants should attain an optimum girth at all stages of its growth. Usually, the plants are maintained at an optimum height upto one tier by pruning and hence after planting, height cannot be considered as an important factor influencing the yield potential. At the time of planting, seedlings should have an optimum girth and height (6-12 cm and 100-150 cm for the plants under study). Yield data on individual plant should be gathered upto fifth YAP and the total yield for five years (precocity) worked out. Those plants with minimum precocity of 100 pods and having optimum initial girth and height will give high yield. Thus, high yielding plants can be identified at fifth YAP.

Summary

5. SUMMARY

The present study entitled "Yield prediction in Cocoa (*Theobroma cacao* L.)" was carried out in the Department of Agricultural Statistics, College of Horticulture, Kerala Agricultural University, Vellanikkara, Thrissur during 2006-2009.

The study was undertaken to understand the influence of growth characters on the yield of cocoa, to determine the age at yield stabilization, to identify the optimum range for growth characters and early yield and to identify yield prediction models, if any, based on the growth characters and early yield.

Data collected from a progeny trial of the Cadbury-KAU Co-operative Cocoa Research Project, Vellanikkara, pertaining to Forastero variety of cocoa, planted in 1989 under the shade of rubber were used. Individual plant data on girth (13 years), height (three years), spread (one year) and pod yield (12 years) of 660 plants were analyzed. Graphical method, correlation and regression analyses, one- way, two-way and three-way analysis of variance, frequency distribution and 95% confidence interval were used.

The salient findings are summarized below.

- Stabilized yield for the population of cocoa plants was obtained from sixth year after planting.

- High significant correlation was observed between girth in a particular year and yield in the same year as well as subsequent four to five years. It could be established that girth is a determining factor of yield. Total yield for 12 years is influenced by girth of the plant at all stages of its growth

- Close association between girths of the plants in the different years and heights in the early years is established.

- Spread in the second year after planting did not show any significant correlation with girth and yield.

- HD^2 of seedlings showed influence on the yield of the plant upto age at yield stabilization. HD^2 in the first and second year after planting have clear influence on the yield after yield stabilization year.

- Correlation between Initial HD^2 and precocity was non significant. But HD^2 in the first and second year after planting had significant correlation with precocity.

- The correlation between precocity and total yield Y was highly significant.

- All known models were fitted for predicting total yield and annual yield based on growth characters and early yield. But very low predictability was obtained indicating that yield cannot be predicted based on growth characters. This is due to the peculiar nature of variability in yield exhibited by cocoa. This variability in yield was exploited by determining optimum range for the different growth characters and early yield (precocity), for maximizing total yield.

- The optimum ranges derived for girth in the i^{th} year after planting $G_i, i = 0$ to12 are G_0 : 6-12 cm, G_1: 10-20 cm, G_2: 18-26 cm, G_3: 24-32 cm, G_4: 30-40 cm, G_5: 36-44 cm, G_6: 36-45 cm, G_7: 44-48 cm cm, G_8: 45-51 cm, G_9 :48-56 cm, G_{10}: 51-57 cm, G_{11}: 51-60 cm and G_{12}: 52 cm or more.

- The optimum range derived for initial height H_0 is 100-150 cm.

- Precocity greater than or equal to 100 pods was derived as optimum.

- The optimum combinations of girth and height in the initial year (G0 and H0) are 6-12 cm and 100-150 cm respectively.

- The optimum combination of initial girth (G_0), initial height (H_0) and precocity (P) are 6-12 cm, 50-150 cm and greater than or equal to 100 pods respectively.

- Initial screening for seedlings can be made for girth of 6-12 cm and height of 100-150 cm. These can be further screened at five years after planting for a precocity of greater than or equal to 100 pods for identifying high yielding plants. Proper management should be given for the plants to attain the optimum girth at different stages of plant growth.

References

REFERENCES

Adenikinju, S.A.1974. Analysis of growth patterns in cocoa seedlings as influenced by bean maturity. *Exp. Agric.* 10: 141-147

Adenikinju, S.A.1975. Relation ships between leaf area per seedling and growth parameters in cocoa. In: *Vth Iinternational Cocoa Research Proceedings*: Atanda, O.R. (ed.), 1-9 September, 1975; Ibadam, Nigeria, pp.195-198

Akinyele, B.O. and Osekita, O.S. 2006. Correlation and path coefficient analyses of seed yield attributes in okra (*Abelmoschus esculentus* (L.)Moench). *Afr. J. Biotech.* 5 (14): 1330-1336

Alphi, K. and Prabhakaran, P.V. 1991. Forecasting of sugarcane yield. *Agric.Res. J. Kerala*. 29: 63-66

Alvium, P.de T. 1981. Recent studies on environmental physiology of cocoa. In: Proc.7th Intern.Cocoa Res. Conf., Lagos, Nigeria, pp. 85-89

Anand, S.C. and Torrie, J. H. 1963. Heritability of yield and other traits and inter-relationship among traits in the F3 and F4 generations of three soyabean crosses. *Crop Sci*. 3(6): 508-511

Atanda, D. A. 1972. Correlation studies in *Theobroma cacao* L. *Turrialba* 22: 81-89

Balasimha, D. 2002. Physiology of cocoa. In: *National Seminar on Technologies for Enhancing Productivity in Cocoa:* Bhat, R., Balasimha, D. and Jayasekhar, S. (ed.), 29-30 November, 2002., CPCRI, Karnataka, pp. 67-69

Bartely, B.G.D. 1970. Yield variation in the early productive years in trails in cacao. *Euphytica*.19: 199-206

Bhagavan, S. and Kumaran, P. M. 1990. Yield and yield attributes in cashew – an analysis through multivariate approach. *J. Plantn. Crops* 18: 351-355

Bhat, S. K., Bhagavan, S., and Nair, R.V. 1990. Identification of high yielding trees in cacao (*Theobroma cacao* L.). *Indian J. agric. sci.* 60(9): 641-642

Bhat, V. R., Sujatha, K., Ananda, K.S., Nair, R.V., and Virakthmath, B.C. 2000. Evaluation of cocoa, *Recent advances in plantation crops research*.105-109

Chaube, N.A. and Ratnalikar, D.V.1982. On forecasting cotton production using partial harvest data. *J. Indian Soc. agric. stat.* 34:129

Cherian., H. 1993. Genetic analysis of yield attributes in cocoa (*Theobroma cacao L.*). MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 146p.

Cherian, H., Vijayakumar, N.K. and Nair, R.V. 1996. Evaluation of variability in crosses and their parent populations of cocoa (*Theobroma cacao L.*). *J. Plantn. Crops* 24(1): 43-49

Dhaliwal, T.S. 1968. Correlations between yield and morphological characters in Puerto Rican and Columnaris varieties of *coffea arabica* L. *J. Aric. Univ*. 52: 29-37

Esker, A.B., Beek, M.A. and Toxopeus, H. 1977. Variation and correlations of some pod and bean values in cocoa (*Theobroma Cacao* L.) with reference to the parental effects on fruit setting and bean number. *Cocoa Growers Bull*. 28: 25-26

Francies, R.M. 1998. Genetic analysis of certain clones, hybrids and inbreds in cocoa. Ph.D thesis, Kerala Agricultural University, Thrissur. 213p.

George, P. S. 1982. Seedling progeny analysis in selected cashew (*Anacardium occidentale* L.) Types. MSc(Ag) thesis, Kerala Agricultural University, Vellayani, Trivandrum, 131p.

George, M.V. and Vijayakumar, K. 1979. Forecasting of cashew yield. *J. Indian Soc. agric. stat*. 31:95

George, M.V., Vijayakumar, K. and Amarnath, C.H. 1984. Preharvest forecasting of cashew yield based on biometrical characters. *Proc. Sym. Plantn. Crops*; 1992; Kasargod, 41-45

Glendinning, D.R. 1960. The relation ship between growth and yield in cocoa varieties. *Euphytica*. 9(1): 351-355

Glendinning, D.R.1963. The inheritance of bean size, pod size and number of beans per pod in cocoa with a note on bean shape. *Euphytica*. 12(3): 311-322

Glendinning, D.R.1966. The relation ship between growth and yield in cocoa varieties. *Euphytica*. 9(35): 1-355

Greenwood, M. and Posnette, A.F. 1950. The growth of flushes of cocoa. *J. Hort.Sci*. 25(3): 164-174

Hewison, H.K. and Ababio, N.1929. Flower and fruit production of Theobroma Cacao. Dept. Agric. Gold Coast Yearbook, p. 89-94

Iyer, C.P.A., Subbaiah, M.C., Subramanyam, M.D. and Prasada Rao,G.S. 1989. Screening of germplasam and correlation among certain characters in mango. *Acta Hort*. 231: 83-88

Jain, R.C. and Agrawal, R. 1987. Yield Forecast based on growth indices in. *Biometrical J* . 27(4): 435-439

Jain, R.C., Jha, M.P. and Agrawal, R. 1985. Use of Growth Indices in Yield Forecast. *Biometrical J* . 27(4): 435-439

Jose, C.T. 1996. A study of yield variability in cococa. *J. Plantn. Crops* 24(2): 126-129

KAU, 2007, *Package of Practices Recommendations*, Kerala Agricultural University, Directorate of Extension, Trichur, India, p.239

Kesavachandran, R. 1979. Propogational studies on cocoa (*Theobroma cacao* L.). MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 207p.

Krishnakumar, N.1983. Yield prediction in coconut based on foliar N, P and K values. MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 145p.

Latha, A. 1992. Growth and yield of cashew in relation to foliar and soil nutrient levels. MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 132p.

Long worth, J.F. and Freeman , G.H. 1963. The use of trunk girth as a calibrating variate for field experiments on cocoa trees. *J.Hort.Sci*.38:61-67

Mallika, V.K., Rekha, C., Rekha, K., Swapna, M. and Nair, R.V. 1996. Evaluation of pod and bean characters of cocoa hybrids in their early years of bearing. *J. Plantn. Crops* 24 (supplement): 363-369

Mallika, V.K., Nair, R.V., Prasannakumari Amma, S. and Abraham, K. 2000. Comparison of yield in hybrids and clones of cocoa (*Theobroma cacao* L.). *J. Plantn. Crops* 28(3): 222-225

Manoj, P.S. 1992. Biometrical studies in cashew (*Anacardium occidentale* L.) hybrids. MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 94 p.

Mohan, K.V.J, Bhargavan, S and Kumaran, P.M. 1987. Classification of cashew accessions in germplasam using index score method. *Turrialba* 37(4): 369-373.

Mohan, K.V. J. and Prakash, G. 1971. Regression and correlation of fibre yield and its component in sannhemp (Crotalaria juncea L.). *Indian J. agric. sci.* 41: 378-381

Murthy, K.N., and Bavappa, K.V.A. 1960. Abnormalities in arecanut. *Arecanut J*. 10(3): 19-24

Nalini, P.V. 1997. Productivity in relation to branching pattern and pruning in cashew (*Anacardium accidentale* L.). Ph.D thesis, Kerala Agricultural University, Thrissur, 142p.

Nair, R. V. 1983. Mother tree selection and nursery techniques in cocoa. *Indian cocoa, arecanut and spices J.* 7(2) 33-24

Nair, R.V., Appaiah, G.N. and Nampoothiri, K.U.K. 1990. Variability in some exotic accessions of cocoa in India. *Indian Cocoa, Arecanut Spices J.* 14(2):49-51

Nayar, M.N.C., George, T.E. and Mathew, L. 1979. The relationship between height, girth and spread with yield in cashew. *Cashew Causerie* 3(2): 13-14

Pankajakshan, A.S. and Minnie, G. 1961. Character association studies in coconut seedlings. *Indian Cocon. J.* 14(2):67-68

Parameswaran, N.K. 1979. Factors affecting yield in cashew. MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 74p

Parameswaran, N.K., Damodaran, V.K. and Prabhakaran, P.V. 1984. Factors influencing yield in cashew (*Anacardium occidentale* L.). *Indian Cashew J.* 16(3): 9-15

Pound, F.J. 1932. The genetic constitution of the cacao crop. *Annual Report of Cacao Research*, Imperial College of Tropical Agriculture, Trinidad. 2:9-25

Pound, F.T. 1933. Criteria and method of selection in cacao. *Annual Report of Cacao Research*, Imperial College of Tropical Agriculture, Trinidad.2: 27-29

Prasannakumari Amma, S., Mallika, V.K., Manoharan, S., Namboothiri, R. and Nair, R. V. 2002. An insight into the preselection method in cocoa. *National Seminar on Technologies for Enhancing Productivity in Cocoa*. 29-30 November, 2002., CPCRI, Karnataka, pp. 52-53

Prasannakumari Amma, S., Mallika, V.K., Rao, G.S.L.H.V. P. and Sudheesh, M.V. 2005. Crop weather relationships of cocoa. *Proceedings of National Workshop on Drought Management in Plantation Crops*; pp.22-23

Rajamony, L. 1981. Studies on the floral biology and fruit set in cocoa (*Theobroma cacao* L.). MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 88p.

Rajamony, L., Jayaprakash Naik, B. and Neelakantan Potty, N. 1984. Seed biometrics and seedling vigour in cocoa. *Indian cocoa, arecanut and spices J.* 8(2): 52.

Rao, A.V.D., Ravisankar, C. and Reddy, M.L.N. 2002. Correlation between nut yield and plant characters in cashew (*Anacardium occidentale L.*). *J. Res. ANGRAU* 30(1): 98-100

Reddy, S.N., Lingaiah, H.B. and Krishnappa, K.S. 1996. Correlation studies in cashew. *Cashew Bull*. 32(3): 15-19

Senanayake, Y.D.A. and Samaranayake, P. 1976. Growth of nursery root stock seedlings of Hevea brasiliensis. *J. Natn. Sci. Coun*., Srilanka.

Sreekanth, P.D., Yadukumar, N. and Gangadhara Nayak, M. 2004. Cashew yield forecasting under different planting densities. *J. Plantn. Crops* 32(3):58-63

Sridevi, R. 1999. Estimation of genetic parameters from specific crosses of cocoa (*Theobroma cacao* L.). MSc(Ag) thesis, Kerala Agricultural University, Thrissur, 220p.

Soria, V.J. 1975. The genetics and breeding of cacao. *Proc. V Int. Cocoa Res. Conf.* Ibadan, Nigeria. pp. 18-24

Subramonian, N. and Balasimha, D. 1982. Variability in pod and bean characters in some cacao hybrids. In: *Pro. Plantation Crops*: Vishveswara, S. (ed.). CPCRI, Vittal, India. pp. 168-174

Togay, N., Togay, Y., Yildirim, B. and Dogan, Y. 2008. Relationships between yield and some yield components in Pea (*Pisum sativum* ssp arvense L.) genotypes by using correlation and path analysis, *African J. of Biotech.* 7 (23): 4285-4287

Toxopeus, H. and Jacob, V. J. 1970. Studies on pod and bean values of *Theobroma Cacao* L. in Nigeria – II. *Neth. J. Agric. Sci*. 18(3): 188-194

Yield Prediction in Cocoa (*Theobroma cacao* L.)

By

JAYASREE K.

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirement for the degree of

Master of Science in Agricultural Statistics

Faculty of Agriculture

Kerala Agricultural University

Department of Agricultural Statistics
COLLEGE OF HORTICULTURE
VELLANIKKARA, THRISSUR-680 656
KERALA, INDIA
2009

ABSTRACT

The present investigation, "Yield prediction in Cocoa (*Theobroma cacao* L.)" was undertaken to determine the age at yield stabilization, to identify the optimum range for growth characters and early yield and to identify yield prediction models, if any, based on the growth characters and early yield of cocoa.

For this purpose, the data were collected from a progeny trial of the Cadbury-KAU Co-operative Cocoa Research Project, Vellanikkara, pertaining to Forastero variety of cocoa, planted in 1989 under the shade of rubber. Individual plant data on girth (13 years), height (three years), spread (one year) and pod yield (12 years) of 660 plants were analyzed. Graphical method, correlation and regression analyses, analysis of variance, frequency distribution and 95% confidence interval were used.

From graphical analyses, it was found that stabilized yield for the plant was obtained from sixth year after planting. Correlation studies established that girth is an important determining factor of yield potential of cocoa. Height in the early years has significant association with girth and yield of the plant. HD^2 in the initial year of planting has clear influence on the yield of the plant upto age at yield stabilization. HD^2 in the first and second year after planting have clear influence on the yield after stabilization year. Precocity has significant influence on total yield. No model could be obtained for predicting total yield of cocoa based on growth characters with reasonable predictability.

There exists optimum for girth at different stages of plant growth and was derived from planting to 12 years after planting, for maximizing yield. The optimum ranges for seedling height and precocity, optimum combination of girth and height of seedlings and optimum combination of initial girth, initial height and precocity was derived, for maximizing yield.