DEVELOPMENTAL PHYSIOLOGY OF BANANA CORM (*Musa* AAB NENDRAN) IN RELATION TO PHENOLOGY, YIELD AND QUALITY

By

BINU JOHN SAM

(2004 22 01)

THESIS

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Horticulture

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF POMOLOGY AND FLORICULTURE
COLLEGE OF AGRICULTURE
VELLAYANI THIRUVANANTHAPURAM–695 522
KERALA INDIA

2011

DECLARATION

I hereby declare that the thesis entitled "**Developmental physiology of banana corm (*Musa* AAB Nendran) in relation to phenology, yield and quality**" is a bonafide record of research work done by me during the course of research and the 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

Vellayani

BINU JOHN SAM
(2004-22-01)

DECLARATION

Certified that the thesis "**Developmental physiology of banana corm (*Musa* AAB Nendran) in relation to phenology, yield and quality**" is a bonafide record of research work done independently by Mr. BINU JOHN SAM under my guidance and supervision and that it has not formed the basis for the award of any degree, diploma, fellowship or associateship to him.

KAU HQ

Dr. SAJAN KURIEN
Major Advisor, Advisory Committee
Professor & Associate Director of Research
PI, ICAR Niche Area of Excellence
Directorate of Research
Kerala Agricultural University

CERTIFICATE

We, the undersigned members of the Advisory Committee of Mr. BINU JOHN SAM, a candidate for the Degree of Doctor of Philosophy in Horticulture, agree that the thesis entitled "**Developmental physiology of banana corm (*Musa* AAB Nendran) in relation to phenology, yield and quality**" may be submitted by Mr. Binu John Sam, in partial fulfillment of the requirements for the degree.

Dr. SAJAN KURIEN
Chairman of Advisory Committee
Prof. of Horticulture &
Assoc. Director of Research
Directorate of Research
Kerala Agricultural University

Dr. C.S. JAYACHANDRAN NAIR
Professor and Head,
Dept. of Pomology and Floriculture
College of Agriculture
Vellayani,
Thiruvananthapuram

Dr. P. SURESH KUMAR
Professor and Head,
Radiotracer Lab
College of Horticulture
Vellanikkara, Thrissur

Dr. ROY STEPHEN
Associate Professor,
Dept. of Plant Physiology
College of Agriculture
Vellayani, Thiruvananthapuram

Dr. B.R. RAGHUNATH
Professor and Head,
Dept. of Plant Biotechnology
College of Agriculture
Vellayani, Thiruvananthapuram

EXTERNAL EXAMINER

Dr. C. K. Narayana
Head & Principal Scientist
IIHR, Bangalore

2nd Examiner: Dr. N. K. Kumar
Dean, TNAU, CBE

ACKNOWLEDGEMENTS

This moment of worth could not have achieved without and support and blessings of many, so with much gratitude I remember all those who have stood with me in this endeavour.

Dr. Sajan Kurien, *Chairman, Advisory Committee, Professor and Associate Director, KAU HQ, Vellanikkara, Thrissur, deserves a lot more of gratitude beyond words for his valuable guidance, critical analysis, sustained interest and perpetual support especially during stressful situations of career and research. I am indeed honoured to submit my thesis under his guidance.*

I am thankful to ***Dr. C.S. Jayachandran Nair,*** *Professor & Head, Dept. of Pomology and Floriculture, College of Agriculture, Vellayani, Thiruvananthapuram for the meticulous help and fruitful advice during various stages of the study which has helped me a lot in times of need.*

I am deeply obliged to ***Dr. Suresh Kumar P.,*** *Professor, Radiotracer Lab, College of Horticulture, Vellanikkara, Thrissur, for rendering me his valuable help ad assistance needed for my radiotracer analysis work.*

I express my sincere thanks to ***Dr. K. Rajmohan,*** *Professor & Head, Dept. of Plant Biotechnology, College of Agriculture, Vellayani, Thiruvananthapuram for his valuable guidance and cordial support given throughout my course.*

Dr. Roy Stephen, *Associate Professor has always been my well wisher and his support and guidance throughout my research work is gratefully acknowledged.*

My profound sense of gratitude goes to ***Prof. S. Krishnan,*** *Dept. of Agricultural Statistics, College of Horticulture, Vellanikkara, Thrissur, for his most precious help which invariably helped my statistical analysis.*

The support of ***Dr. B.R. Reghunath,*** *Professor and Head, Dept. of Plant Biotechnology, College of Agriculture, Vellayani, Thiruvananthapuram and member of my Advisory Committee is gratefully acknowledged.*

I wish to place on record the support and financial help extended by the ***Department of Science and Technology,*** *Ministry of Science and Technology, Government of India without which this project might not have been materialized*

It is also with much obligation, I thank the ***Associate Director,*** *RARS, Kumarakom for allowing me to work in the DST project as a part of my research.*

The help rendered by the ***Staff of RARS, Kumarakom,*** *especially my fellow RAs and the labourers of RARS farm have a valuable place in the completion of research, which I would like to remember thankfully.*

I take this opportunity to thank ***Dileep, Ravikumar, Bindu, Vandana*** *and* ***Priyakumari*** *for their support and help during this project.*

It is my pleasant privilege to express gratefulness to my beloved wife ***Sona*** *and our little cutie* ***Ponnus*** *for standing behind me as a rock in times of hardships during this period and when very often I was away from them in pursuit of my course work and seminars.*

It gives me immense pleasure to extend my sincere gratitude to my dearest friend ***Aby,*** *for his valuable help and support.*

I thank ***my parents*** *and* ***my In-laws*** *for their all round support and encouragement in completing this project. A special note of gratitude to our* ***Vallianty*** *for her constant encouragement, which I lovingly cherish.*

Dear ***Appachen*** *and* ***Ammachi,*** *this is the time for you to rejoice in heaven in seeing me completing my Doctoral programme.*

Above all, I submit this venture before ***God Almighty,*** *for blessing me with strength and courage to successfully fulfill my study.*

A word of apology to those, if I have not mentioned in person and a note of thanks to each and everyone stood by my side for the successful completion of this endeavour

Binu John Sam

CONTENTS

DEDICATED TO

All My Well Wishers

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

Abbreviation		Expansion
%	-	Percent
AGR	-	Absolute Growth Rate
AVS	-	Active Vegetative Stage
BARC	-	Bhabha Atomic Research Centre
BRITS	-	Board of Radiation and Isotope Technology
CAR	-	Corm Area Ratio
CD	-	Critical Difference
CGR	-	Crop Growth Rate
cm	-	Centimeter
cpm	-	counts per million
CRD	-	Completely Randomized Design
cu. Ft.	-	Cubic feet
CWR	-	Corm Weight Ratio
DAP	-	Days After Planting
et al.	-	And others
EVS	-	Early Vegetative Stage
FAO	-	Food and Agricultural Organization
FBD	-	Flower Bud Differentiation
FBI	-	Flower Bud Initiation
Fig.	-	Figure
g	-	Gram
GDD	-	Growing Degree Days
GI	-	Galvanized Iron
Harv	-	Harvest
HCl	-	Hydrochloric Acid
HTU	-	Helio Thermal Units

IAA	-	Indole 3-Acetic Acid
ITU	-	Iso Thermal Units
KAU	-	Kerala Agricultural University
kg	-	Kilogram
l	-	Litre
LAUZ	-	Length of Apical Unbranched Zone
mg	-	Milligram
NAR	-	Net Assimilation Ratio
No.	-	Number
NS	-	Non Significant
°C	-	Degree Celsius
P	-	Phosphorus
PCBA	-	Paclobutrazol
ppm	-	Parts per Million
PTU	-	Photo Thermal Units
PVC	-	Poly Vinyl Chloride
RBD	-	Randomized Block Design
RBZ	-	Root Bearing Zone
SCA	-	Specific Corm Area
SCI	-	Secondary Corm Initiation Stage
SCW	-	Specific Corm Weight
SE	-	Standard Error
Sh	-	Shooting
SR	-	Synthetic Resin
TC	-	Tissue Culture
Vs.	-	Versus

Introduction

INTRODUCTION

The global area estimated under bananas is nearly one million hectares (FAO, 2003) and is the 4th most significant foodstuff after rice, corn and milk (INIBAP, 2002). World production of Musa in 2006 was estimated at 102 million tons of which 68% was classified as bananas and 32% as plantains (FAO, 2006). These simple data emphasize the importance at the international level. At the national level, the importance is much more as it has now become the leading fruit crop both in area and production.

The main developmental stages of banana have been well documented. Morphologically, the plant is characterized by a subterranean stem or corm with the growing point or tip more or less centralized and enclosed by concentrically arranged overlapping leaves. The tip grows out into a full fledged plant that eventually produces the bunch. Each plant successively produces bunches from laterally produced suckers. The suckers develop at their own rhythm and do not follow a synchronous cycle (Tixier *et al.*, 2006). Hence the sucker, *ie.* the propagule and the underlying corm are the basic paramount units that will define the health of a banana plant and its crop duration cycle.

The Corm:Leaf interaction is one of the theories advanced towards flowering concept in banana. Any improvement in this line would pave the way for the significant breakthrough in hastening the flowering and yield besides improving the bunch and finger characters; the main considerations that govern consumer preference.

A third and major aspect in banana cultivation is the weak corm and high mat conditions that result in easy toppling by wind or any extraneous forces. A basic understanding on development of the corm and its physiology is an imperative pre-requisite to overcome this problem. The development of the corm in relation to other plant parts and resource sharing between various functional parts is another area to receive attention. This aspect deserves merit and serious attention as it will answer whether productive and efficient channelization of resources in terms of accumulation and utilization to yield and yield components and structural components are satisfied or not, thus explaining the key limitations that determine productivity. Moreover little information is available on root production, ramification and functional efficiency of our major clones and any step in this direction would help in maximizing efficiency of utilization of inputs and thereby reduction in cost of cultivation and ultimately savings.

For these reasons, the present research aimed at understanding the development of the corm were taken up from different angles. The experiment – I is aimed to study the seasonal effects on biotic events and yield in banana by following a bimonthly planting scheme. Experiment – II is focused to have an insight on the anatomy and developmental physiology of the corm and basic study of root habits. Here the precise time of development of the corm and root production characters will be studied. Hastening secondary corm formation and impact on yield and crop life span forms the crux of the experiment – III during the second year. The experiments will be focused on hastening of secondary corm development and early replacement of original corm by advocating different hormonal treatments to the planted suckers of a definite corm size based on the

first year's experiment. Experiment – IV is aimed at studying the efficiency of absorption and translocation of nutrients to different sites using ^{32}P and translocation of photosynthates to various organs and sites using ^{14}C.

Above all, an overall picture of corm and root development is expected to emerge from this pioneering work.

Review of Literature

REVIEW OF LITERATURE

Very few research works exist on the topic of investigation. Hence a comprehensive approach has been adopted to bring all the relevant literature that exists on the aspects of study on the crop. As alternate approach of including pertinent literature that exists on other crops has also been made, but within the broad realm of the study.

In the orderly cycle of development, the plants undergo complex patterns of change. In the case of banana, the physiological changes begin from the stage of sucker treatment for planting. All stages henceforth from planting to juvenility, ontogenic transformation to flowering and harvest are intrinsically linked to one another and influenced by environmental conditions.

2.1 Corm Development

The banana plant comprises essentially of three major regions – the massive rhizome or corm, the pseudostem and the inflorescence. The massive rhizome or the corm (Simmonds, 1966) or the rhizomal sympodium (Hottum, 1955) grows from a cambial region located beneath the vegetative growing point which further differentiates into two principal regions – the central cylinder and the cortex. The growing point or the apical meristem is a small dome shaped structure that is located within the centre of the corm at the base of the pseudostem at or about the soil level (Summerville, 1944;

Chakrabarty and Rao, 1984; Koshy, 1989). Simmonds (1966) divided the course of development of banana plant on morphological terms into three stages – the vegetative, the floral and the fruiting phases. The life of the plant was divided into five stages by Turner (1972) namely corm formation, commencement of lateral bud growth, floral initiation, bunch emergence and harvest. All these physiological changes take place in banana on the growing tip situated at the centre of the corm.

Stover (1979) calculated the rate of growth and found that it averaged to 1.0 cm per day and was as low as 0.4 cm in November – January. Hence he divided the growth into four stages juvenile (10-14 leaves), adult pre-floral (15-25 leaves), floral initiation (28-31 leaves) and post floral (when all the leaves have emerged).

Swennen *et al.* (1987) in his classical address in the INIBAP workshop held at Burundi has hypothesized that there could be three distinct types of corm development, 1) no increase in the size of the planted corm. A new corm develops upon the planted one; 2) the planted corm grows in size thereby annihilating any traces of the planted corm; 3) a limited increase in the size of the planted corm and a comparable development of a second corm on the planted corm. This categorization was more of speculative than based on any scientific investigation.

No further work has been attempted on the corm physiology. Stover and Simmonds (1987) has opined that there could be a stage of maximum development of corm and has termed it as a bulking stage. Swennen *et al.* (1987), has stressed the

importance of corm development and highlighted it as a priority area for future research, in both plantain and banana. In striking comparison, in crops like Elephant Foot Yam, the Corm Bulking Rate (CBR), Corm Bulking Efficiency (CBE) have been attempted at length (Das and Sen, 1995 and Verma *et al.*, 1992) as the corm means the economic yield. In banana, the corm development has received little attention. The few works that exist are on the influences of season on corm size (Chakrabarthy and Rao, 1984; Chattopadhyay *et al.*, 1980).

The work involving growth regulators have mostly been restricted to the bunch yield and yield components and the corm aspects have been overlooked.

The nutrient translocation studies in banana can be broadly categorized into those involving a) fertilizer standardization studies and b) root activity studies. While the former was taken care of by dry weight of corms at terminal stage of crop, the latter was not given emphasis owing to the risk arising due to radiation as tracers have been fed to distinct soil horizons. Though in some of the studies, growth of corms has been recorded, they do not implicitly focus on corm development *per se*.

The carbon assimilation and its partitioning on corm development is another area which has received least attention probably because of the large number of leaves, canopy volume and technical difficulties. The corm is a reservoir of nutrient reserves in the early phase of sucker development and has been emphasized in literature on quality of suckers (Stover and Simmonds, 1987; Eckstein and Robinson, 1995; Robinson, 1995 and

Gowen, 1995). Hence a healthy and efficient corm besides providing anchorage is a reserve pool of nutrients on which the plant could bank upon in emergency at any given point of time. It is, in this aspect that studies on corm development gains importance.

Increase in dry weight have been reported as a function of various aspects like location (Calvo and Araya, 2001), root zone temperature, seasons (Chakrabarthy and Rao., 1980), irrigation (Bassoi *et al.*, 2001), corm size (Kurien, 2006), organic matter content and fertilizers. Root zone temperature has been conclusively proved to affect leaf carbon assimilation (Ramcharan *et al.*, 1991). Differential accumulation of dry matter in different growing months probably as a result of biotic phase variation has been reported by Chan *et al.* (1999). Corm bulking as a function of source efficiency has also been reported by Chinese workers (Chan *et al.*, 1998) in Elephant Foot Yam.

2.2 Root

This chapter aims to broadly categorize, classify and document the available literature under the broad realms of the experiments undertaken.

While the debate is on as to whether the propagule in banana is a corm or a rhizome, the real crux is that banana clump is a rhizomatous but the individual plant is borne on a corm. To be more precise, banana is one of the largest rhizomatous herbs in the world (Ping *et al.*, 2002). Simmonds (1982), reported that even in seedlings, the primary seedling roots die off and is replaced by adventitious roots. On the contrary, in

plants propagated by suckers, roots are formed in groups of three to four by the cambium in the corm (Skutch, 1932; Riopel and Steeves, 1964). At early stage individual roots are white and fleshy, healthy and later become corky.

The primary root can be divided into three zones

1) the distal zone having the active growing tip is of 7-8 cm long and covered by root hairs of approximately 2 mm length

2) the adjacent proximal zone devoid of root hairs and varying in length

3) the proximal zone containing secondary roots and the longest (Swennen *et al.*, 1986).

In the rich and varied crop cafeteria, bananas are second only to sugarcane as far as nutrient removal is concerned. This aspect on the one side emphasizes the nutrient requirement and on the more important side reveals the inherent healthy root system, the effective foraging capacity and efficiency of roots. Nevertheless most of the available literature is directly linked with morphological characters and yield response and studies related to root characters are meager, if not scanty.

Root system in banana consists of individual roots that are borne on the corm. The first level of variation is root order: main roots, also called axile, nodal or tap roots (wrong terminology but figures in literature) and mainly referred to as primary roots responsible for soil exploration, first order laterals (secondary roots) and second order laterals (tertiary roots). The primary root grows eight times faster than first order laterals

which in turn grow faster than the second order laterals (Meyer, 1975; Pages *et al.*, 2000; Lecompte *et. al.*, 2001 and Lecompte and Pages, 2007).

In general, root elongation rate is linked with root diameter (Araya and Blanco, 2001; Lecompte *et al.*, 2002 and Lecompte and Pages, 2007)

Carbon nutrition has been reported to influence both the number of lateral roots per unit length and lateral root diameters (Pages *et al.*, 2000). However, the resource sharing between adjacent roots is still unclear.

Though not in banana, recent basic studies have proved that lateral root development is under the influence of growth regulators.

Functionally the primary roots may be further subdivided into

1) pioneers with high and low density of secondary roots

2) feeders which are much longer than pioneers (Swennen *et al.*, 1986)

The feeders account for 2/3rd of the total length and are more important for water and nutrient uptake. Young roots are initially pioneer type and eventually become feeder type (Swennen *et al.*, 1986)

Lehmann and Abe (2003) in their classical paper on roots has opined that "despite the usually lower relative root activity in the subsoil compared to the top soil per unit

soil, the large volume of sub soil in comparison to mostly shallow top soil is as important resource for crop nutrient and water intake".

The deepest root activity is for fruit crops such as Citrus, Guava and Mango. Monocots including Oil Palm, Coconut and Banana have root activity that can be both shallow and deep. Regional and temporal variations of subsoil root activity for the same tree species can be both deep and shallow.

In banana, the physical distribution of root have been reported by Mohan and Rao (1984), Valsamma *et al.* (1987), Sancho (1994), Murthy and Iyengar (1997), Bassoi *et al.* (2001), Kumar and Nalina (2001), Araya and Blanco (2001), Araya *et al.* (1998a) and Araya *et al.* (1998b).

On the other hand, studies on root activity using tracers which accounts for physiologically active roots alone have been reported by, Shobhana *et al.* (1989), Mohan and Rao (1988) and Murthy and Iyengar (1996).

More advanced work have been carried out involving radiotracer techniques on intra and intermat competitions by Kurien *et al.*, (2006a), nutrient cycling from the mother plant to daughter suckers (Kurien *et al.*, 2002) and crop competitions in a banana based cropping system (Kurien *et al.*, 2006b).

The main factors that affect root growth summarized by Stover and Simmonds, (1987) and Lecompte and Pages (2007), are temperature, mechanical impedance, soil water content and soil aeration.

The optimum temperature for root growth in banana is reported to be 25^0C (Turner and Lahav, 1983 and Robinson and Alberts, 1989).

Published reports also point to no significant differences between main root and lateral roots on this aspect (McMichael and Burke, 1998). Comparing field grown and glass house grown bananas, Lecompte and Pages (2007) also derived the same results.

Thick roots are more affected by mechanical impedance than thinner ones. It has also been shown that mechanical impedance to root growth in a given soil type is affected by soil porosity and water content (Turner and Thomas, 1998). Thus the second factor is mediated by third and fourth factors.

Broadly the factors affecting root growth and development can be categorized as internal and external

2.2.1 Internal Factors

2.2.1.1 Ploidy and Genome Level – Among the internal factors, the relative combination of the ploidy status and genome composition to the variability of root traits

is an established factor (Blomme *et al.*, 2000). They further established that with increasing ploidy level, the magnitude of plant characteristics tend to increase and that there was a clear relationship between shoot and root growth according to the genome group. The proportion of primary, secondary and tertiary roots also shows a definite relationship (Swennen *et. al*, 1987). In *acuminata* (AA) the proportion of tertiary roots in diploids and triploids is 77% whereas it is 46% for plantains (Swennen *et. al*, 1986). The contribution made by the secondary roots is much greater for plantains than for bananas. In general, the capacity to form primary, secondary and tertiary is a varietal character (Swennen *et. al*, 1987).

2.2.1.2 The diameter – The apical diameter can be considered as a good indicator of growth potential and lateral root development (Lavigne, 1987; Lecompte *et al.*, 2001 and 2002).

2.2.1.3 Length of Apical Unbranched Zone (LAUZ) – Among the traits studied, LAUZ was confirmed as the most stable and good predictor of root growth rate for all types of roots.

2.2.1.4 Aerenchyma development – is a qualitative factor of development affecting root porosity and in turn the physical resistance to gaseous diffusion (Aguilar *et al.*, 1998).

2.2.1.5 Shoot Traits – The shoot traits (Blomme *et. al,* 2001) have confirmed that root weight follows an asymptotic function of corm weight.

2.2.2 External factors

The exogenous factors are both environmental and soil related.

2.2.2.1 Soil Factors

2.2.2.1.1 Type of soil – Bananas and plantain roots generally prefer a loose soil (Sioussaram, 1968; Gousseland, 1983 and Swennen *et. al*, 1987).

2.2.2.1.2 Organic matter – Bananas and plantains requires soils rich in humus. Braide and Wilson (1980) have attributed the reduction in organic matter status of the soil to be the chief cause of rapid decline in yield in plantains.

2.2.2.1.3 Bulk Density – Reduction in soil bulk density due to increased tillage results in better shoot and enhanced root development (Blomme *et al.*, 2002).

2.2.2.1.4 Stress – Stress in any form affect root growth and development. This could be factors from pH (Wendericks, 1985), flooding, drought, salinity, compaction of soil or biotic stress (Swennen *et. al*, 1987). Different types of root ramifications under adverse conditions have been reported by Lavigne (1987), LassoudieÁ re and Maubert (1971) and Swennen (1984).

2.2.2.1.5 Management – Soil nutrient status or supplements, pH amendments, irrigation and water management, weed management (Braide and Wilson, 1980), mulch (Robinson, 1993) all affect root growth and development.

2.2.2.2. Environmental Factors

2.2.2.2.1 Temperature – The root zone temperature has a direct play on absorption, translocation and even leaf carbon assimilation. High soil temperature adversely affect root ramification (Swennen, 1984 and Wendericks, 1985)

2.2.2.2.2 CO_2 – Carbon assimilation by uptake of CO_2 is the basis of all growth in plants. However, works on photosynthesis and translocation are very limited. Studies by Schaffer *et al.,* (1996) have revealed that CO_2 enrichment increased leaf area and net dry weight. Study clearly indicated that at both 350 μ mol CO_2 mol^{-1} and 1000 μ mol CO_2 mol^{-1} root growth rate was enhanced. Leaf carbon assimilation was highest in banana (Ramacharan *et al.*, 1991) when root zone temperature was 33°C.

2.2.2.2.3 Oxygen – Under oxygen deficiency, a property of wet soils, root growth and functions are influenced by the respiratory demand for O_2 in root tissues, the transport of O_2 from shoot to root and supply of O_2 in the medium. Respiratory O_2 concentration decreases with the distance from the root apex. Re-aeration after 4 hours of anoxia restored root elongation rate to 50% of continuously aerated roots. Whereas anoxia for more than 6 hours killed the root tips (Aguilar *et al.*, 1998). Hypoxia / Anoxia is due to the difference in permeability of the epidermal – hypodermal cylinder with increasing distance from root apex. The difference in O_2 concentration between cortex and stele was small compared to other monocots and in O_2 deficient environment, the stele would be the first to suffer anoxia (Aguilar *et al.*, 1998).

2.2.2.2.4 Degree Days – Studies of LeCompte and co-workers (2003) fully confirm that root growth rate is influenced by degree days and established a linear regression between root growth rate and root apical diameter, soil porosity and sum of degree days (base at 14°C).

2.2.2.3. Mechanical Factors

2.2.2.3.1 Mechanical Impedence – like high percentage of coarse stones, soil compaction which does not permit soil porosity, affect root growth and in turn functionally the effective foraging capacity.

2.2.2.3.2 Root injury – affects the root growth. It could also lead to a lot of secondaries and tertiaries.

2.2.2.3.3 Leaf pruning – affects the root growth and development and the extent of reduction in root dry weight and root length is greater than reduction in leaf area (Blomme *et. al.*, 2001).

Materials & Methods

MATERIALS AND METHODS

The studies on *"Developmental physiology of banana corm (Musa AAB Nendran) in relation to phenology, yield and quality"* was carried out from August, 2005 to October, 2007 at the research farm of the Regional Agricultural Research Station, Kumarakom of the Kerala Agricultural University.

The research farm is located at $9^0\ 3^1$ latitude and $76^0\ 3^1$ longitude, following a bund and channel system type of cultivation typical of *'Kuttanad'* part of the problem zone. Cultivation is generally taken up 0.6 m below m.s.l and cultivation of horticulture crops especially banana is taken up on the raised bunds of reclaimed lands at approximately 0.5 m above m.s.l. The area enjoys a typical warm humid tropical climate. The soil of the area belongs to the order inseptisol / entisol with a pH of 5.0 – 5.5.

The materials and methods are summarized experiment wise

3.1. Seasonal effects on biotic events and yield in banana

The materials used in the study were uniform sword suckers of three months age subjected to a secondary selection for uniformity in size and weight. The suckers were of the cultivar *'Chengalikodan'*, the most preferred clone of Nendran in the area and weighing 1.250 ± 0.05 kg.

The suckers were planted beginning from 15th August, 2005 at bimonthly intervals. Three plants each were sampled by destructive analysis at fortnightly intervals to study the various aspects of corm and roots. Thirty plants were maintained solely for the purpose of taking observations of all morphological parts and were carried upto harvest so that all yield and yield contributing aspects were observed and recorded.

The sections of the growing apex was prepared as per standard procedures (Biju *et al.*, 1997) and the changes in the growing point were observed and categorized as early vegetative stage (EVS), active vegetative stage (AVS), flower bud initiation (FBI) stage and flower bud differentiation (FBD) stage. The visual parameters of new corm formation for Secondary Corm Initiation (SCI), time of emergence of bunch as shooting and stage of full maturity as stage of harvest were categorized. Thus the biotic events were fixed at EVS, AVS, SCI, FBI, FBD, Shooting and Harvest.

3.1.1 Rooting pattern

The root production pattern was understood by observing the characters at each fortnight. Initially one half of the base of the plant (soil) was covered with decaying leaves and the root production was observed at fortnightly intervals. This gave a basic understanding.

After two fortnights of observations, this could not be done as the roots get entangled and the soil from the sides fall and compaction takes place, covering off the

entire mulched demarcated semi-circle part of the bole of the plant. Due to the anchorage, this part cannot be lifted up and with the slightest of force, the roots get broken. Hence, destructive analysis was carried out by excavating the entire root system from 1.25 m radius from the bole of the plant and using jet sprays of water, the soil covering the roots were removed (Plates 1 to 3).

Plate - 1

Plate - 2

Plate - 3

Excavation methodology to study root characters

The observations on all root characters were recorded. Though labour intensive and cumbersome, this method facilitated a holistic study of the entire root system. This root production was finally linked with the physiological / biotic phases of the crop.

3.2 Developmental Physiology of the corm – Anatomy of the secondary corm formation and basic study of root habits

3.2.1 Anatomy of corm development

The histology of corm development was studied by primarily observing the external (outward) changes of the corm. The growing points of the plants destructively

sampled were excised and sections were prepared as per standard procedure. The development of the corm at each of the stages were studied by observing under a microscope and the anatomical changes at each of the identified biotic phase was studied in depth and photomicrographs of each stage taken using a microscope with on-screen attachments.

Once the developmental changes were clearly understood, this was repeatedly checked in all other five plantings of the calendar year to confirm the findings.

3.2.2 Rooting pattern

The rooting pattern of all the three graded corm sizes *viz,* large, medium and small were studied separately as mentioned in the root studies in the above experiment.

3.3 Studies on corm development using suckers of different graded sizes

Three graded sizes of corms were selected

a) Large sized suckers – 3.250 $\pm$ 0.050 kg.

b) Medium sized suckers – 2.250 $\pm$ 0.050 kg.

c) Small sized suckers – 1.250 $\pm$ 0.050 kg.

The suckers selected were from a common large plantation of the cultivar *'Chengalikodan'*.

The corms were planted in the main season (August – October) of planting in the state namely October 15th, based on the most ideal season of planting (KAU, 2001). Two plants were sampled every fortnightly as described above by excavation techniques and all morphological observations were recorded. The samples of each tissue were dried and dry weights of each tissue part worked out and expressed in grams.

Simultaneously, another set of 30 plants were left for taking the observations of all the morphological aspects of shoot, the yield and bunch characters under each corm weight category and were recorded.

3.4 Studies on the influence of depth of planting on corm development and yield.

In order to ascertain whether clump lifting is a genetic character with the development of the secondary corm, a full fledged experiment was laid out with suckers of small size (1.250 $\pm$ 0.050 kg.). Thirty suckers were planted at three depths *viz;* 10 cm below ground level, 20 cm below ground level, 30 cm below ground level, which formed the three treatments. Two plants each were sampled at EVS, AVS, FBI/FBD and shooting. Twenty plants were set apart for recording the observations at fortnightly intervals and yield and bunch characters at harvest.

3.5 Hastening secondary corm formation and impact on yields using plant growth regulators

Two separate experiments with the same objective and using the same plant growth regulators (PGR) but using two different methodologies *viz;* a) corm dip method and b) corm injection method formed the basic approach. The experiment was carried out with uniform suckers as planting material (1.250 $\pm$ 0.050 kg.) and of 3 months age.

Growth promoters *viz;* Indole 3-acetic acid (IAA) and Naphthalene acetic acid (NAA) both at 250 and 500 mgl^{-1} (ppm) concentrations, a growth retardant *viz;* Paclobutrazol (PCBA) at the above same concentrations and a growth inhibitor *viz;* Abscissic acid (ABA) at 500 ppm formed the seven treatments.

3.5.1 Corm dip method

The growth regulators were prepared at the above concentration and the prepared suckers were dipped such that they were fully immersed and kept overnight (6.00 pm to 6.00 am). They were then taken out and dried for five days in shade and planted.

Fifteen plants each treated with each of the above chemicals at the definite concentrations formed the seven treatments and time taken to reach each of the biotic stages was recorded. The treatments were given at the SCI stage. Observations on all morphological and physiological characters of the plants, yield and individual finger characters were recorded.

3.5.2 Corm injection method

The corm injection method was based on the pre-standardised method by boring three small nail holes obliquely 5cm above the corm at around 8.30 am. Fifteen plants were selected for each of the treatments. The seven treatments as above were prepared as per standard procedures and 100 ml (33+33+34 ml) was delivered through each hole using a graduated syringe. The time of application coincided with the SCI stage. All the morphological and physiological characters of both the plant and yield were taken and recorded. The time taken to reach each biotic phase was also observed and recorded

3.6 Retention studies of banana corm and its influence on crop cycle and yield.

The influence of the planted primary corm on the growth and development of the banana plant at different biotic stages was studied using a full fledged experiment involving four different treatments *viz;*

a) *In situ* retention of the whole plant

b) *Ex situ* planting with primary corm detached and intact initiated secondary corm

c) *Ex situ* planting with half cut shoot and intact primary corm and initiated secondary corm

d) *Ex situ* planting with full primary corm and intact initiated secondary corm

Twenty plants each at secondary corm formation stage formed the four treatments. The time taken to reach each of the biotic stages was recorded. Observations on all morphological and physiological characters of the plants, yield and individual finger characters were also recorded.

3.7 Efficiency of absorption of ^{32}P

3.7.1 Procurement and dilution of ^{32}P activity

P-1 form of ^{32}P in HCl solution was procured from the Board of Radiation and Isotope Technology (BRIT) of the Bhabha Atomic Research Centre (BARC), Mumbai. (Plate 4). 1000ppm of P was prepared using KH_2PO_4. 39.45m of ^{32}P was diluted in 1200 ml of 1000ppm P such that the specific activity was standardized to 32.625mCi/g of P.

3.7.2 Application of ^{32}P

^{32}P was applied to the active root zone of banana by pre laying 10 PVC pipes per plant of 30cm length and ¾ cm diameter. For this PVC pipes of 31 cm length were cut and pre-laid in drilled soil holes of 30cm depth such that 1 cm protruded above the soil surface. (Plate 5). The distance was 20cm from the base of the plants as per pre-standardised studies (Kurien *et al.*, 2006b).

Plate 4
Soil applicator and radioactive P

Plate 5
Layout of the tubes around each plant

Plate 6
Administering labeled P using soil applicator

5ml of the activity was given per hole (plate 6) such that each plant received a total volume of 50ml or 1.63mCi of activity. Thus, the activity given per hole and plant remained the same. Plants belonging to the seven biotic phases (EVS, AVS, SCI, FBI, FBD, Shooting and Half maturity) formed the seven treatments and the ^{32}P was given using a calibrated soil applicator for root activity studies.

Sampling of all tissues (Primary corm, Secondary corm, Roots, D-leaf, D-petiole, Pseudostem, Boot Leaf, Male bud, D-finger) were done on the fifth, tenth and fifteenth day after application. The radiochemical analysis was done as per standardized procedure and the recovery of activity in each tissue was expressed as counts per minute per gram (*cpm/g*) of dry tissue using a liquid scintillation counter (Hidex Triathler Multi Label Tester, Turku, Finland). Finally, the readings were corrected for background radiation and expressed as *cpm/g* of dry tissue and reduced to a common zeroth hour. The experiment was replicated thrice in a Completely Randomized Design.

3.8 Translocation of photosynthates using ^{14}C

3.8.1 Development of leaf chamber

A prototype apparatus enclosing the full leaf lamina retaining its correct orientation and inclination and at the same time remaining air tight was one of the fundamental requirements. The present apparatus was evolved after a series of 'trial and error' studies and modifications brought about at each and every stage. This apparatus was termed as ***Leaf Chamber*** for ^{14}C studies.

3.8.2 Procedure involved in the making of the lower and upper parts of the Leaf Chamber

Two wooden frames, one forming the lower frame and other forming the upper frame were made of the same dimension. The length of the frame was 2.75m and breadth 1.5m, as a fully developed banana leaf measures 2.5m length and 0.7m breadth. The outer frame was made of coconut wood of 2 inch width and 1 inch thickness. A nylon fish net was fixed on the frame to support the leaf such that the leaf margin ends were well held on the frame and did not in any way intercept the light. To the inner side of this was Thermocol (polystyrene) of equal width and ½ inch thickness neatly fixed using an adhesive.

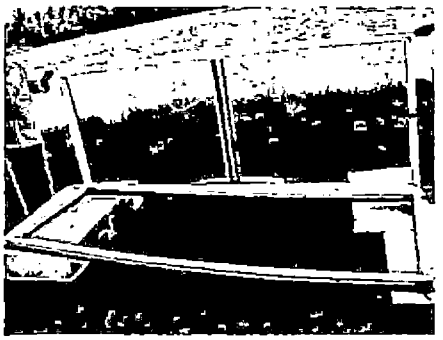


Plate – 7

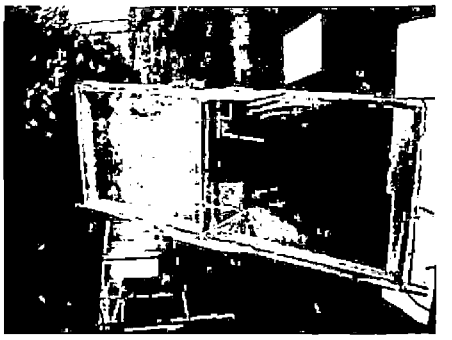


Plate – 8

Leaf Chamber with upper portion raised (No.7) and covered (No. 8) for ^{14}C studies

Over the Thermocol, teak frame of same width and ½ inch thickness was placed and held firmly by drilling in small nails. Over this, a first lining of sponge of same ¼ inch thickness was neatly pasted with Fevicol (SR) adhesive. Over this lining, a sponge padding of same width and ½ inch thickness was given with rubber adhesive. This was covered with a sheet of polythene (400 gauge) to cover the entire lower frame with the edges folded over the coconut wood frame and further fastened firmly at very short intervals with drawing pins (thumb-tacks / thumb-pins) on all the four sides. This formed the lower part of the leaf chamber.

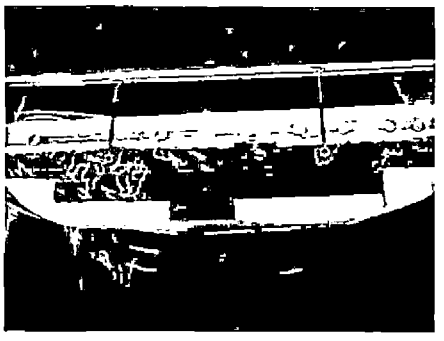


Plate 9

Plate 10

Methodology developed to keep the leaf chamber airtight

A similar frame made of coconut wood which was lined with Thermocol in the same dimensions and over which teak frame of the same dimension was fixed using nails formed the base frame. Three strips of sponge of 2 inch width and ¼ inch thickness each stuck neatly one over the other using rubber adhesive formed the upper cover.

Plate 11

Plate 12

Leaf placement into the chamber without change in orientation and inclination

Additionally, on the lower mid part of the breadth of the frame a carving was given for placing the petiole of the leaf. Prior to placing the leaf, the carved area was lined and plugged with cotton. After placing the leaf petiole, non-absorbent cotton was placed in the groove of the petiole and the exterior of the petiole. This was further plugged with cotton and made airtight.

Aluminium pipe of 9 mm diameter was placed in the inner part of the upper frame (as light falls on top part and temperature build up starts on the upper part) to form two concentric circles. At the bends (corners) they were provided with tight fitting rubber tube joints. The pipes were held firmly with small clamps provided in the interior on the wooden frame.

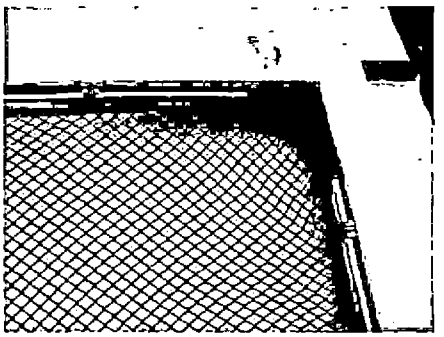


Plate 13

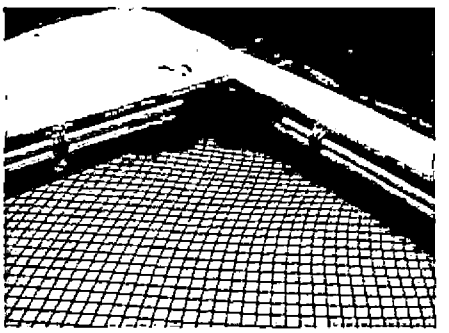


Plate 14

Stages in fabrication of leaf chamber

The inlet on the top side was connected to a rocker pump and the outlet was given rubber tubing outside the frame to collect the circulated water into the same bucket from where the pumping was done. Initially, water was circulated but the leaf began drooping and sides wavy, showing initial symptoms of scorching.

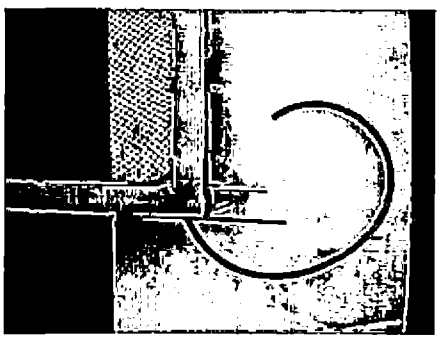


Plate 15

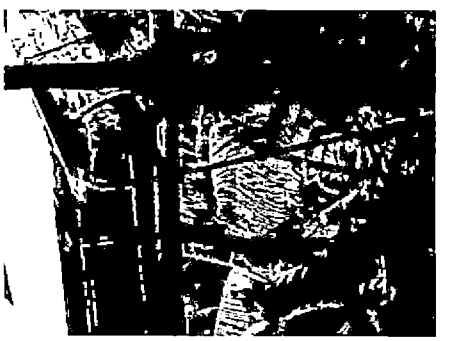


Plate 16

Provision for maintenance of inner air temperature by providing water inlet and outlet

Hence, another improvisation was made by reducing the temperature of the circulating water. For this, ice blocks of 2x1x1 cu.ft. were kept inside the bucket to maintain the temperature so that there was a steady circulation of ice cold water. With this change, the leaf remained healthy and retained its composure even upto 45 minutes of study.

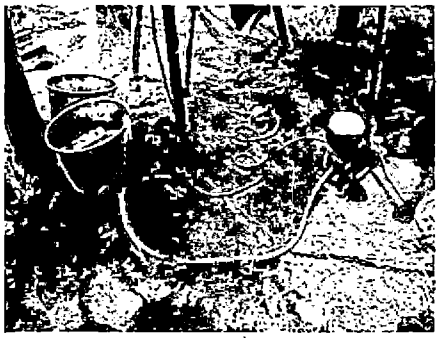


Plate 17
Provision of continuous supply of ice cold water

Plate 18
Circulation of ice cold water by using rocker sprayer

The centre part of either side of the lower frame was joined by a 2 inch wide and 1 inch thick mid frame that held a suspended glass crucible (top 5 cm diameter) and covered with a wire gauge except on top part. The crucible was suspended from the mid frame using a small thin wire.

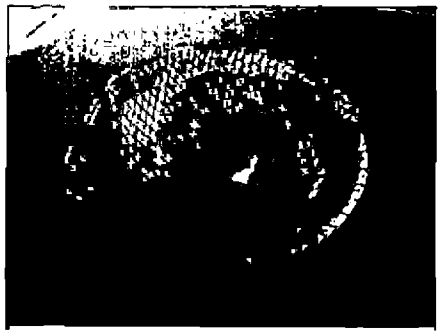


Plate 19
Preparation of crucible for placement of activity (labeled ^{14}C)

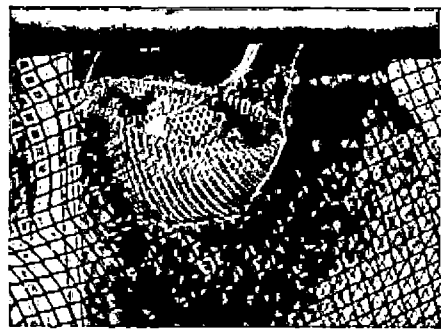


Plate 20
Suspension of crucible in the lower part of frame in the mid portion of chamber

Opening of the polythene sheet just below the crucible was made possible by a neat lining which could be well stuck using transparent adhesive tape thus permitting the replacement of a known aliquot of activity prior to releasing the labeled $^{14}CO_2$. For each application, fresh adhesive tapes were used.

One end of an i/v infusion set with control unit was connected to a graduated wash bottle filled with dilute HCl (N/10). This was suspended sufficiently higher outside the frame. The fine end of the infusion set was placed in such a way that the droplets fill only into the crucible. The tube was passed through the frame such that the entry was made air tight and reinforced with a roofing compound (H&J IFOMARK –'SUPER' Roofing Compound). The regulator of the infusion set was free outside the frame and this permitted to discharge a known volume of the acid into the crucible which held a known strength of radio activity (^{14}C).

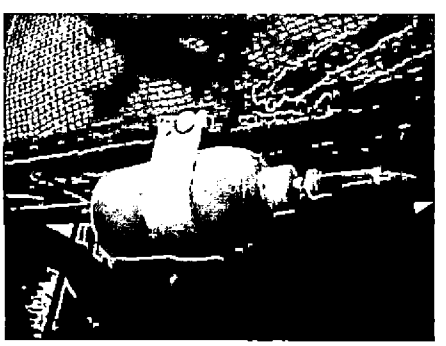


Plate 21
Attachment of calibrated wash bottle for discharge of HCl

Plate 22
Connection of IV infusion set to regulate the amount of HCl from wash bottle to crucible containing ^{14}C

The upper part of the frame was also covered with polythene sheet (400 gauge) and held firmly by using 'Thumb Tacks' (Drawing Pins) on all the sides of the frame. Prior to this, both the outer and lower frame were provided with roofing compound to avoid any possible leakage at joints or drilled in holes. Four galvanized iron (GI) flat protrusions at each end on the linear plane on both the frames were provided. On all four sides at ½ feet distance, 6" GI hooks were provided on the top frame which fitted tightly into its corresponding fasteners on the lower frame.

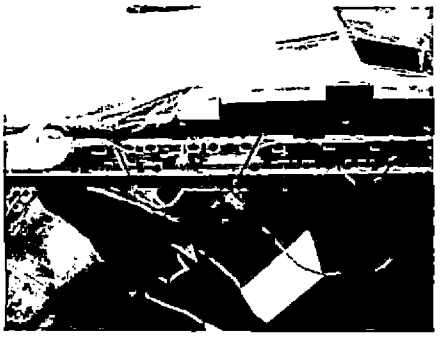


Plate 23

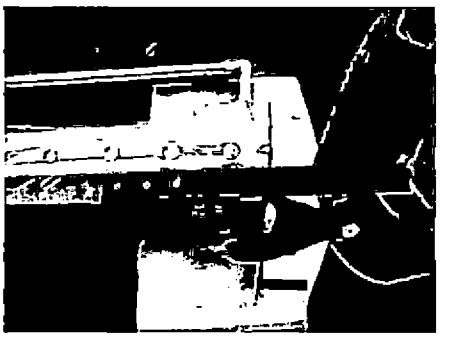


Plate 24

Plugging the entire wooden surface with roofing compound and GI flat rod on all four corners for holding the frame in position

The frame was mounted based on the inclination and orientation of leaf by digging in GI poles and then fitting the lower frame on the four ends of the GI poles such that the orientation of the leaf remained unchanged. The upper frame was subsequently placed and safely fastened using all the hooks provided.

Plate 25a

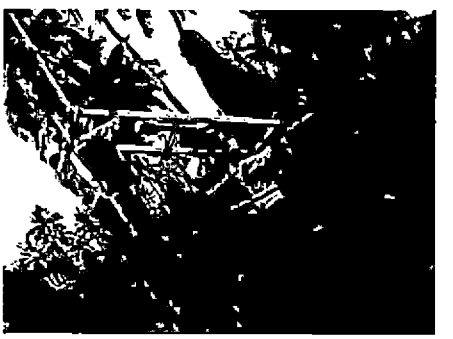


Plate 25b

Positioning of leaf chamber as per orientation of leaf and placement of upper chamber

3.8.3 Stages of improvisation in standardization of apparatus

The initial apparatus (prototype) was purely based on a Thermocol frame covered with polythene sheet. The initial difficulty was in maintaining the erect position as wind could change the inclination and orientation of leaf. Further, the leaf chamber was not sturdy enough to be used for full sized leaves in the study and the safe placement of labeled isotope for evolution of labeled CO_2 became both a difficulty and a question. Hence the first change on leaf chamber using wooden frame was brought about as mentioned above.

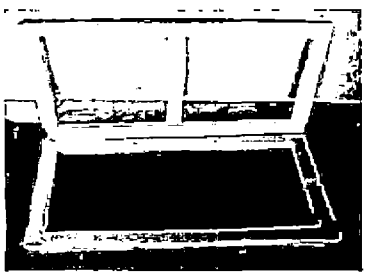


Plate 26a

Plate 26b

The initial apparatus (prototype) based on a Thermocol frame

Another improvisation became necessary as even within a short time lapse the inner temperature of the chamber increased. This led to the scorching and desiccation of leaf inside the chamber caused heating up resulting in scorching of leaf. Hence modification of regulated ice cold water flow was made which overcame the defect.

The third crucial challenge was in confirming the air tight nature of the apparatus. Ten lighted incense sticks (Agarbathi) were placed inside the frame. The entire frame was held vertically fitted rightly ensuring all locks were in position and was checked from all sides to see whether there was any leakage of smoke. To be cent per cent fool proof, air was blown through the four sides of the apparatus to confirm any trace of smoke.

3.8.4 Placement of leaf

Four GI pipes were bored in the ground in the direction of the 2nd fully opened leaf of the experimental plant. The lower frame was first placed as per the orientation of the leaf and the four ends were well fastened. Care was taken to see that the petiole of the leaf was correctly placed in the groove provided in the lower frame. The upper frame was then correctly mounted on the top of the lower frame and all hooks tightly fastened.

The groove provided for the petiole was plugged with cotton from outside and inside the petiole and further sealed with adhesive tape drawn to the side of the frame.

3.8.5 Placement and discharge of activity

The nature of the activity was as Na_2CO_3 solution in water and hence standardization using unlabelled Na_2CO_3 was done using different strengths of HCl and narrowed down to N/10. The evolution of CO_2 was instantaneous but 25 minutes were given for the leaf to absorb the released CO_2. This was based on previous studies from other crops. 15ml of HCl was required for complete discharge of CO_2. However after 15 minutes of giving the 15ml HCl another 10 ml was discharged to the crucible again to confirm that no radioactive CO_2 is left. The total process was completed in 25 minutes after which the sealed opening of the crucible area of the polythene sheet (hitherto referred as window) on the lower frame was detached and opened. The spent liquid was drained out into a radioactive waste collection unit maintained for the purpose. The

crucible was repeatedly washed, cleaned, dried with tissue paper and made ready for the next treatment application.

Plate 27

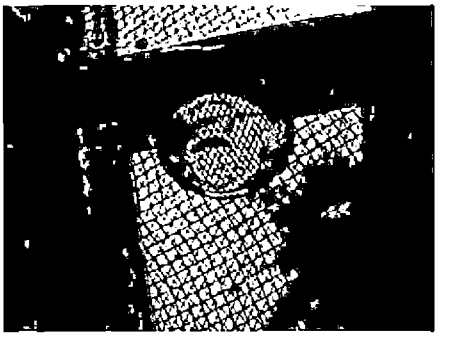


Plate 28

Placement of activity in the crucible and sealing the window / aperture airtight prior to dispensation of HCl

Activity ^{14}C in the aqueous form of Na_2CO_3 (Code No. LCC 37) was obtained from Board of Radiation and Isotope Technology (BRIT) of Bhabha Atomic Research Centre (BARC), Mumbai and was made available in 1.0ml vials containing 0.5mCi (18.5 MBq). 1.0ml vial was made upto 10ml by adding 9ml of 0.1N Na_2CO_3 just prior to application. From this 10ml, 5ml (0.25mCi) was taken and placed in the crucible. Single plant formed the experimental material for each treatment in a replication. Prior to this the 2nd fully opened leaf was placed in position and the apparatus sealed and made airtight.

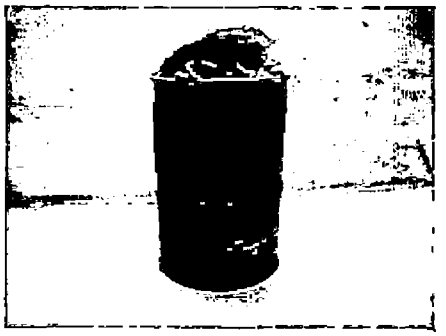


Plate 29
Activity received from BRITS (BARC) in sealed protected container

Plate 30
Activity as aqueous form of Na_2O_3 in 1.0 ml vials containing 0.5 mCi

The window outlet in the leaf chamber provided for placing the activity was also sealed, ensuring no leakage. The rocker pump was put into action to regulate the inner leaf chamber temperature. Now the control unit of the i/v infusion set was gently opened out to discharge 15ml of HCl and stopped. Time was monitored on release of HCl. Instant release of CO_2 could be observed as bubbles. After 15 minutes another 10ml was discharged again into the crucible. At the end of 25 minutes the window was opened, the spent radioactive waste was taken and drained out to a container for radioactive waste.

In this experiment the seven biotic phases formed the treatment which was repeated thrice in a CRD.

The treatments were

1. Plants in Early Vegetative Phase
2. Plants at Active Vegetative Phase
3. Plants in the Secondary Corm Initiation Phase
4. Plants in Flower Bud Initiation Phase
5. Plants in Flower Bud Differentiation Phase
6. Plants in the Shooting Phase
7. Plants at Half Maturity Phase

The 2nd fully opened leaf of each plant was the experimental leaf fed with $^{14}CO_2$. Activity was diluted and applied to each plant in the same manner. Samples of all different tissues were drawn on 15th days after application after destructive analysis of

treated plants. Radiochemical analysis of ^{14}C was done using cocktail scintillator (cock tail – W) by adding 15ml of the scintillator and then reading the sample using a Liquid Scintillation Counter (Hidex Triathler Multi Label Tester, Turku, Finland). Readings were corrected for background radiation and finally expressed as *cpm/g* of dry tissue.

3.9 Observations recorded

The various observations that were recorded are as follows

a) Morphological characters

i. Height – Height was recorded from the collar to the origin of the petiole of last fully emerged leaf at the time of observation and expressed in cm.

ii. Collar girth – The girth of pseudostem at 5 cm above the collar (junction of the pseudostem and the corm) was taken as collar girth and expressed in cm.

iii. Total number of leaves produced – The total number of leaves produced inclusive of the last fully emerged leaf is counted and expressed in numbers

iv. New leaves produced – The number of new fully emerged leaves produced in a fortnight is counted and expressed in numbers

v. D-Leaf area – Leaf area of the D-Leaf (the second newest fully emerged leaf) commuted as length of the leaf x breadth of the leaf x 0.8 and expressed as cm^2

vi. Total canopy area at each phase – The product of the D-Leaf area and the actual number of functional leaves present on the plant at the time of observation and expressed as cm^2.

vii. Leaf retention at each phase – The actual number of functional leaves present on the plant at each stage expressed in numbers.

b) Corm

Two plants were excavated as per standard procedures at fortnightly intervals and observations on the following aspects were recorded

i. Dry weight – the samples were oven dried and the dry weights are expressed as g.
ii. Cross sectional length of each part – cortex and central cylinder – expressed as cm
iii. Longitudinal length – expressed as cm
iv. Depth of rooting – expressed as cm
v. Root bearing zone (RBZ) – expressed as cm

c) Roots

i. Total number of roots – under each flush at fortnightly intervals were recorded
ii. Average length of longest five roots
iii. Proximal diameter – the diameter of the root at the initiating point on the corm measured by Vernier Calipers and expressed in cm.
iv. Distal diameter– the diameter of the root one cm from the end point (distal end) measured by Vernier Calipers and expressed in cm.
v. Length of apical unbranched zone (LAUZ) – expressed as cm
vi. Number of secondaries and tertiaries – expressed as numbers
vii. Root hairs per cm length of the root– expressed as numbers
viii. Total dry weight – expressed as g.

d) Bunch and yield characters

i. Bunch weight – in kg
ii. Total number of hands – in nos.
iii. Total number of fingers – in nos.
iv. D-finger weight – in g
v. D-finger length – in cm
vi. D-finger girth – in cm
vii. Curvature index – (length of the finger / curvature of the finger) x 100
viii. Pedicel index – (pedicel length / pedicel diameter) x 100
ix. Days taken to ripening – in no. of days
x. Total shelf-life – in no. of days

e) Thermal units

Studies to identify and standardize the base temperature at which growth starts in banana cv. Nendran and the effect of defined regimes of temperature were also taken up during this period. Leaf blade orientation and its inclination are the most important characters that determine the sunlight capture and photosynthetic efficiency which in turn determines the productivity of banana. These two factors are dependent on the angle of attachment of petiole to the pseudostem and leaf blade angle to the petiole.

Tissue Culture plants of *Chengalikkodan* type of Nendran belonging to the same batch culture and subjected to secondary selection for uniformity formed the material of study. Four plants each were kept at controlled condition at temperatures of 10^0, 11^0, 12^0,

13^0, 14^0, 15^0 and 16^0 C respectively. Observations on the leaf inclination / orientation and wilting or yellowing were observed.

Plate 31
TC plants maintained in growth chamber under controlled conditions

The thermal units in growing degree days (GDD) (Rao, 2008), photothermal units (PTU) and heliothermal units (HTU) were worked out based on studies on base temperature (14^0C), standardized in the DST sub-centre at RARS (Kurien, 2004).

The GDD was worked out as → $\frac{(\text{Max temp} + \text{Min temp})}{2}$ - Base temp

and added up on a daily basis for each biotic event

The PTU is worked out as → GDD x Maximum possible sunshine hours in a day

The HTU is worked out as → GDD x Sunshine duration

The GDD, PTU and HTU were worked out from planting to SCI, FBI, FBD, Shooting and Harvest in each of the four field experiments. Comparisons for different seasons of planting were also made.

3.10 Statistical Analysis

The data on the experiments on biotic events and yield for planting at bimonthly intervals was analysed as CRD using analysis of variance technique.

The data on the effects of graded size of corm was analysed as RBD using anova technique, whereas the data on depth of planting and primary corm detachment studies were analysed in a CRD using anova technique (Panse and Sukhatme, 1985).

The data on ^{32}P and ^{14}C were recorded as counts per minute per gram of dry plant tissue of concerned part. They were further expressed on a per cent basis for each stage of application.

Results

RESULTS

The results of the study on *"Developmental physiology of banana corm (Musa AAB Nendran) in relation to phenology, yield and quality"* are explained under the following major sub chapters.

4.1 Seasonal effects on biotic events and yield in banana

Plate 32a

Plate 32b

Crop stand at the research farm of RARS, Kumarakom

4.1.1 Morphological characters

4.1.1.1 Height

Differences were observed in tallness of the crop with the biotic phases (table 1). At EVS, the June planting showed maximum height followed by October. But at AVS, the August and October planting exhibited maximum plant height. At SCI again, the April and August planting excelled in height. At FBI, the April planting was way ahead of the other plantings followed by June planting, which narrowed down to almost equality by FBD and superiority of the latter over the former by shooting. At harvesting, the trend remained the same. Among all the plantings, maximum height was recorded in June planting which was also statistically significant.

Table - 1 . Plant height (cm) at different stages of the six bimonthly plantings

Planting No.	I	II	III	IV	V	VI
EVS	27.03^{c}	30.53^{b}	16.00^{de}	17.20^{d}	14.57^{e}	36.03^{a}
AVS	53.87^{a}	52.50^{a}	35.67^{c}	27.80^{d}	45.31^{b}	45.08^{b}
SCI	100.57^{b}	80.59^{c}	65.23^{e}	70.10^{d}	108.18^{a}	63.07^{c}
FBI	166.97^{c}	150.61^{d}	112.70^{e}	145.07^{d}	235.83^{a}	205.15^{b}
FBD	179.43^{b}	181.58^{b}	124.23^{c}	172.17^{b}	254.83^{a}	250.38^{a}
Shooting	190.35^{e}	251.70^{c}	177.70^{f}	213.03^{d}	267.83^{b}	291.28^{a}
Harvest	191.40^{d}	258.09^{b}	180.57^{e}	219.50^{c}	269.10^{b}	294.68^{a}

Data represents mean value of thirty replications
DMRT Test performed for row comparison
Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

Table - 2 Collar girth at different stages of the six bimonthly plantings

Planting No.	I	II	III	IV	V	VI
EVS	19.07^{a}	7.90^{e}	11.10^{b}	10.98^{b}	11.27^{b}	10.90^{b}
AVS	25.57^{a}	16.10^{d}	19.82^{b}	14.03^{e}	15.43^{d}	18.08^{c}
SCI	34.83^{b}	25.10^{e}	22.96^{d}	26.56^{c}	38.64^{a}	24.83^{e}
FBI	45.93^{c}	40.43^{d}	42.81^{d}	41.19^{d}	57.32^{a}	50.16^{b}
FBD	48.43^{c}	48.06^{c}	45.93^{cd}	44.66^{d}	62.45^{a}	56.58^{b}
Shooting	58.27^{c}	56.77^{c}	50.54^{d}	48.11^{e}	66.11^{a}	63.18^{b}
Harvest	52.67^{c}	56.67^{b}	48.81^{d}	46.00^{e}	60.87^{a}	62.50^{a}

Data represents mean value of thirty replications
DMRT Test performed for row comparison
Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

Table - 3 D-Leaf area (cm^2) at different stages of the six bimonthly plantings

Planting No.	I	II	III	IV	V	VI
EVS	17.96^{e}	22.64^{d}	63.66^{b}	60.65^{b}	94.22^{a}	48.37^{c}
AVS	1540.29^{b}	1095.87^{c}	228.48^{f}	561.76^{e}	811.20^{d}	2196.29^{a}
SCI	3214.24^{b}	2352.10^{c}	811.81^{d}	956.64^{d}	2840.94^{b}	5574.45^{a}
FBI	5398.43^{b}	4196.08^{c}	2534.60^{d}	2198.54^{d}	3954.21^{c}	11703.07^{a}
FBD	5597.28^{b}	5076.62^{c}	3350.93^{d}	2606.46^{d}	4912.90^{c}	13631.21^{a}
Shooting	5824.00^{b}	5146.76^{c}	3623.77^{d}	3192.00^{d}	4978.19^{c}	12720.98^{a}
Harvest	5824.00^{b}	5146.76^{c}	3623.77^{d}	3192.00^{d}	4978.19^{c}	12720.98^{a}

Data represents mean value of thirty replications
DMRT Test performed for row comparison
Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

4.1.1.2 Collar girth

A clear indication of increment in collar girth was observed in all plantings with the stage at shooting showing maximum collar girth (table 2). In the EVS and AVS, maximum growth was observed in August planting, whereas from SCI, it was the April planting that showed maximum collar girth. The June planting showed progressive increase from SCI to narrow down the difference and registered the second highest values. The differences in the main values were also significant.

4.1.1.3 Leaf area

The leaf area in all plantings showed an increase from planting to shooting and a decrease thereafter to harvest (table 3). In the EVS, it was the August planting that recorded maximum area but thereafter the June planting recorded values that were explicitly superior to other plantings.

4.1.1.4 Leaf retention at different stages

The leaf retention in different plantings presented in table 4 showed a varying pattern. Maximum retention of leaf was at FBD in June and October planting, at FBI in August and April planting and at SCI in December and February planting.

4.1.1.5 New leaves produced at biotic phases.

The maximum new leaves produced were in October followed by December plantings (table 5). The general variation observed was comparatively less and ranged from 27.63 to 29.63 and the result however is not significant. However a cross examination of maximum production at various phenological stages revealed that from

Table - 4 Leaf retention at different stages of the six bimonthly plantings

Planting No.	I	II	III	IV	V	VI
EVS	4.00^{d}	5.53^{a}	3.20^{e}	5.93^{c}	5.23^{b}	4.30^{f}
AVS	7.37^{c}	7.93^{b}	9.70^{a}	8.20^{b}	5.93^{d}	8.10^{b}
SCI	12.03^{b}	10.47^{d}	12.50^{a}	9.90^{e}	9.97^{e}	11.30^{c}
FBI	12.63^{b}	12.23^{c}	10.14^{d}	9.43^{e}	13.17^{a}	13.23^{a}
FBD	10.83^{b}	13.40^{a}	10.30^{c}	9.57^{d}	10.23^{c}	13.43^{a}
Shooting	10.57^{b}	8.80^{c}	7.77^{d}	8.67^{c}	7.47^{e}	12.33^{a}
Harvest	4.23^{e}	6.25^{c}	5.85^{d}	7.28^{a}	5.90^{d}	7.07^{b}

Data represents mean value of thirty replications
DMRT Test performed for row comparison
Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

Table - 5 New leaves produced at different stages of the six bimonthly plantings

Planting No.	I	II	III	IV	V	VI
EVS	5.60^{a}	5.10^{b}	2.70^{f}	4.47^{c}	2.97^{e}	3.83^{d}
AVS	5.63^{b}	6.33^{a}	5.13^{c}	3.00^{e}	3.17^{e}	3.80^{d}
SCI	6.13^{b}	6.70^{a}	6.70^{a}	6.37^{b}	5.67^{c}	3.87^{d}
FBI	6.53^{e}	8.73^{c}	10.73^{b}	7.33^{d}	13.13^{a}	10.80^{b}
FBD	2.10^{c}	1.03^{d}	2.07^{c}	2.53^{b}	2.00^{c}	3.60^{a}
Shooting	2.43^{b}	1.30^{d}	2.50^{b}	4.13^{a}	1.80^{c}	1.73^{c}
Harvest	0.00	0.00	0.00	0.00	0.00	0.00
Total	28.43	29.19	29.83	27.83	28.74	27.63

Data represents mean value of thirty replications
DMRT Test performed for row comparison
Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

SCI to FBI stage was maximum in April followed by June and December plantings, whereas at FBI to FBD the maximum leaf emergence was observed in June followed by February and August plantings. The number from FBD to shooting peaked in February followed by December and August. The peculiarity of August plantings was that upto shooting, a more or less continuous and systematic production of new leaves was observed.

4.1.1.6 Morphological characters of roots

One of the most significant contributions is that the present study confirms that root production in sucker planted bananas is cyclic and not continuous. Five flushes of roots have been identified with overlapping of the end period of one cycle with the onset of the other. Within each flush of root production, a peak period is observed coinciding with a distinct physiological stage. The data presented hereunder cross examines the characters of roots at each of these five distinct flushes of roots. The data on the characters of roots are presented in table 6

4.1.1.6.1 Total number of roots

The maximum no. of roots observed in a fortnight was highest in the sixth crop in the case of first, second, fourth and fifth flushes. The December crop recorded the highest number in the third flush, which was followed by June and August planting. The August crop recorded the second highest value in the case of first, second and third flushes; whereas it was December and October planting in the case of fourth and fifth flushes. Statistical significance was also observed in number of roots produced and flushes of roots in various plantings.

Table 6. Root characters of six bimonthly plantings

Flush of Roots	1st flush						2nd flush						3rd flush						4th flush						5th flush					
Crops	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
Total no of roots	38	29	28	32	22	41	86	50	38	36	42	96	31	26	36	28	22	31	62	50	70	56	65	102	42	46	36	32	40	62
Max Length of roots	35.2	29.8	28	26	26.5	39.2	51	45.6	30.2	32.7	39.4	56.8	30.4	32	31.4	26.5	30	29.6	62.4	52	52.4	48.4	68	86.8	30	26	32.5	24	24	42.6
Time to reach max length	45	60	45	45	60	45	90	60	75	45	60	90	75	60	60	60	60	75	105	90	105	105	90	105	75	60	90	60	60	90
prox.dia	0.34	0.32	0.32	0.33	0.33	0.31	0.45	0.45	0.36	0.38	0.44	0.47	0.89	0.84	0.89	0.86	0.84	0.88	0.48	0.46	0.55	0.48	0.44	0.52	0.84	0.84	0.9	0.9	0.88	0.84
Mid dia	0.36	0.32	0.32	0.32	0.33	0.34	0.43	0.42	0.38	0.34	0.44	0.48	0.84	0.84	0.83	0.86	0.84	0.85	0.46	0.44	0.5	0.46	0.4	0.5	0.78	0.84	0.9	0.9	0.85	0.74
Apical dia	0.24	0.28	3	0.3	0.3	0.25	0.49	0.48	0.4	0.38	0.5	0.53	0.54	0.52	0.49	0.5	0.48	0.55	0.48	0.46	0.48	0.48	46	0.54	0.5	0.56	0.55	0.5	0.6	0.43
LAUZ	0	0	0	0	0	0	0	0	0	0	0	0	18.8	14.1	16.5	8.34	10.7	20	21.5	18.7	10.5	6.8	23	32.8	0	0	0	0	0	0
No.of branches	0	0	0	0	0	0	0	0	0	0	0	0	7.4	6	6.4	5.4	6.2	7	8	7	6	6	28	8.6	0	0	0	0	0	0
Av. Leng. of branched roots	0	0	0	0	0	0	0	0	0	0	0	0	6.88	8.56	4.8	8	6.88	7	15.2	14	10.5	10.6	12.6	27.3	0	0	0	0	0	0
root hairs per cm	13.6	10.8	16.5	15	16	17.2	0	0	20	0	0	0	0	0	15	10	0	7.8	10.4	10	26	20	14	10	28	28	20	20	25	33
RBZ (cm)	5.5	5.6	5	4.2	5.4	6.4	6.3	6.95	6.1	5.8	6.4	8.85	6.2	5.6	4.2	4	5.5	7.5	10.4	10.2	8.4	7.5	9.5	14.5	7.4	7.2	5.5	5.3	7	9.5
length of flush	45	60	60	60	60	60	90	75	90	90	105	135	105	60	90	105	110	75	135	150	165	165	165	105	105	105	135	105	105	90

4.1.1.6.2 Maximum length of roots

The maximum length of roots was recorded in June planting in first, second, fourth and fifth flushes, whereas the October and December planting recorded the highest in the third flush.

A comparative evaluation of the length of roots in different plantings revealed that length of roots in the second flush was the maximum in August planting, whereas it was the fourth flush of roots in December, February and April plantings. In the fifth and sixth plantings, the last flushes of roots showed the maximum length and the superiority was also statistically significant.

4.1.1.6.3 Time taken to reach maximum length

The time taken to reach maximum length in the first flush varied from 45-60 days with the August and June planting taking the least time. In the second flush, it varied from 45-90 days with August and June planting taking the maximum time. In the third flush, it varied from 60-75 days with maximum time taken similar as above. The fourth flush varied from 90-105 days again as in the above planting and in the fifth flush, it varied from 60-90 days with maximum time taken in June followed by December and August plantings.

4.1.1.6.4 Thickness of roots

4.1.1.6.4.1 Proximal diameter

The proximal diameter did not vary much with the plantings in the first flush. However, August planting recorded the highest values. In the case of second flush, maximum diameter was recorded in the June planting followed by August and October plantings. In the third flush, variations were very subtle, with August, October and June plantings recording the highest. In the case of fourth flush, the highest proximal diameter was recorded in the December planting followed by June planting. Variations in the fifth flush were comparatively meagre. However, December and February plantings recorded the highest values.

4.1.1.6.4.2 Mid diameter

In the case of the diameter at the mid part, a trend similar to the proximal diameter was observed in the case of first, second, fourth and fifth flushes. But in the case of third flush, the highest values were observed in February planting.

4.1.1.6.4.3 Apical diameter

In the case of apical diameter, values recorded were highest in the case of first flush in December, February and April plantings. In the case of second, third and fourth flushes, it was in June and August plantings whereas in the fifth flush, maximum values were recorded in April followed by October planting.

4.1.1.6.4.4 LAUZ

Qualitative differences were observed in the case of branching. The first, second and fifth flushes showed no branching at all. In the branched third and fourth flushes,

maximum LAUZ was noted in June followed by August planting in the case of third flush, whereas, it was June followed by April plantings in the case of fourth flush. The results revealed that between flushes as well as in plantings the values were statistically non-significant.

4.1.1.6.4.5 Number of branches

In the case of fourth flush, maximum number of branches was observed in April planting followed by June and August, whereas, in the case of third flush, maximum branching was observed in August followed by June. Statistical significance was observed both in the case of maximum number of branches and between various planting dates.

4.1.1.6.4.6 Average length of branched roots

The average length of branched roots was the maximum in June planting in the case of third and fourth flush, the differences being very explicit and significant in the case of fourth flush.

4.1.1.6.4.7 Presence of root hairs

The presence of root hairs was very explicit in the case of fifth, fourth and first flushes. It was also observed in the second and third flush in December planting in the case of the former and February and June plantings in the case of the latter.

4.1.1.6.4.8 Length of flushes

Variations were observed in the length of flushing both between plantings as well as between flushes (fig. 1). In the first flush, the length almost varied between 45-60 days with the least time recorded by August planting. In the second planting, the variation was from 75-135, the lowest being in October and the maximum time taken in June planting. In the case of third flush, the length varied between 60-120 days, the lowest being in October and highest in April planting. The fifth flush which showed maximum length of flushing varied from 105-165, the lowest being in June planting and maximum being in December, February and April plantings. In the case of fifth flush, the length varied between 90-135 days, the lowest being in the June planting and the highest in October planting.

4.1.1.6.4.9 Root Bearing Zone (RBZ)

The RBZ of the fourth flush of roots was embedded at maximum depth in all plantings and the results were significant.

4.1.2 Yield and bunch characters

The data presented in table 7 on yield and bunch characters and table 8 and figure 2 on time taken to reach each physiological stage reveal the overwhelming superiority of the June planting.

4.1.2.1 Bunch weight

The June planting recorded an average yield of 10.04 kg/bunch which was significantly superior to other plantings, followed by Aug planting. April and October planting recorded almost similar weights.

Fig 1. Schedule of Flushes of Roots as Observed in the Bimonthly Planting at RARS, Kumarakom

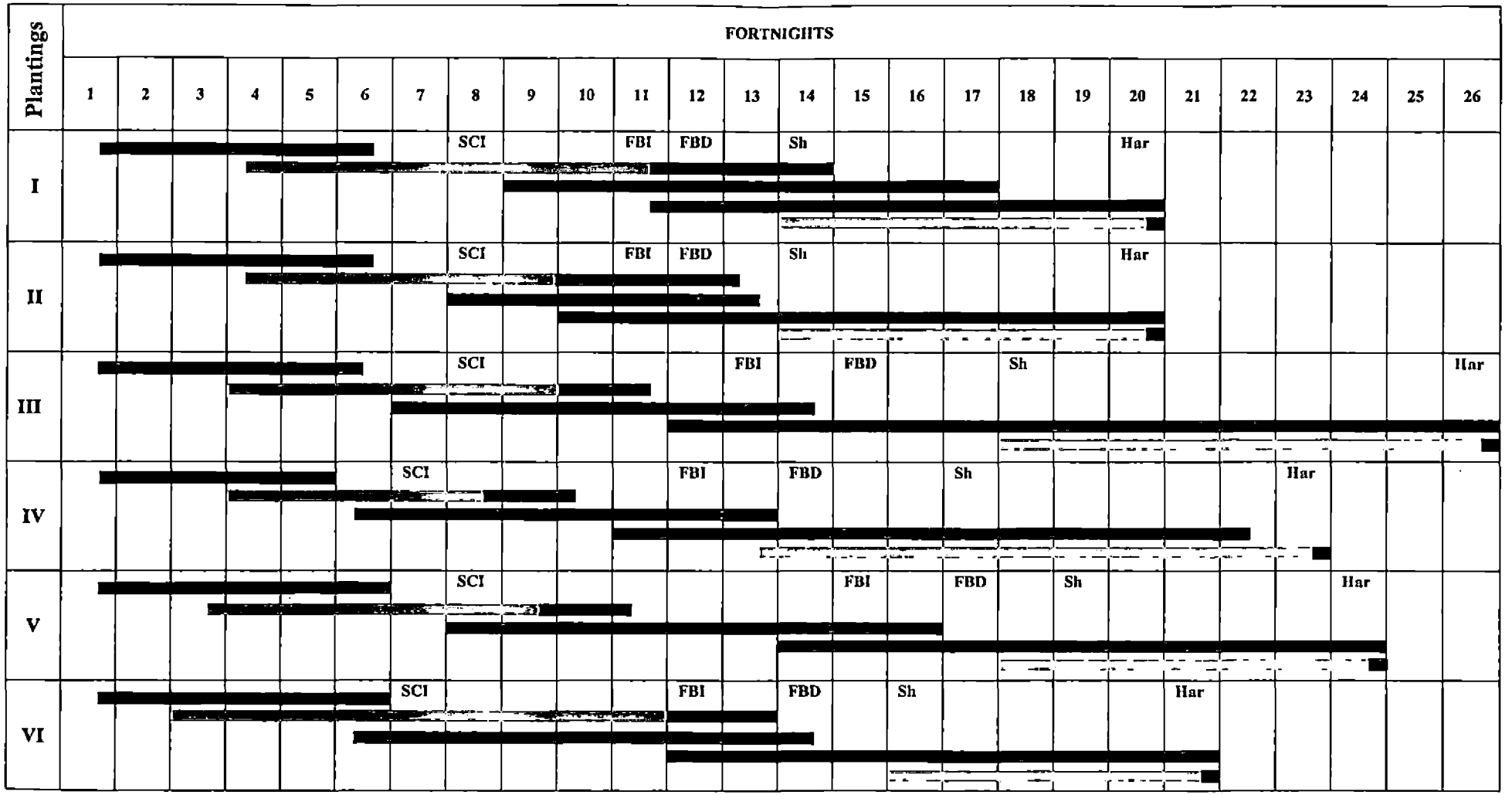


Table 7. Bunch and finger characters in different plantings

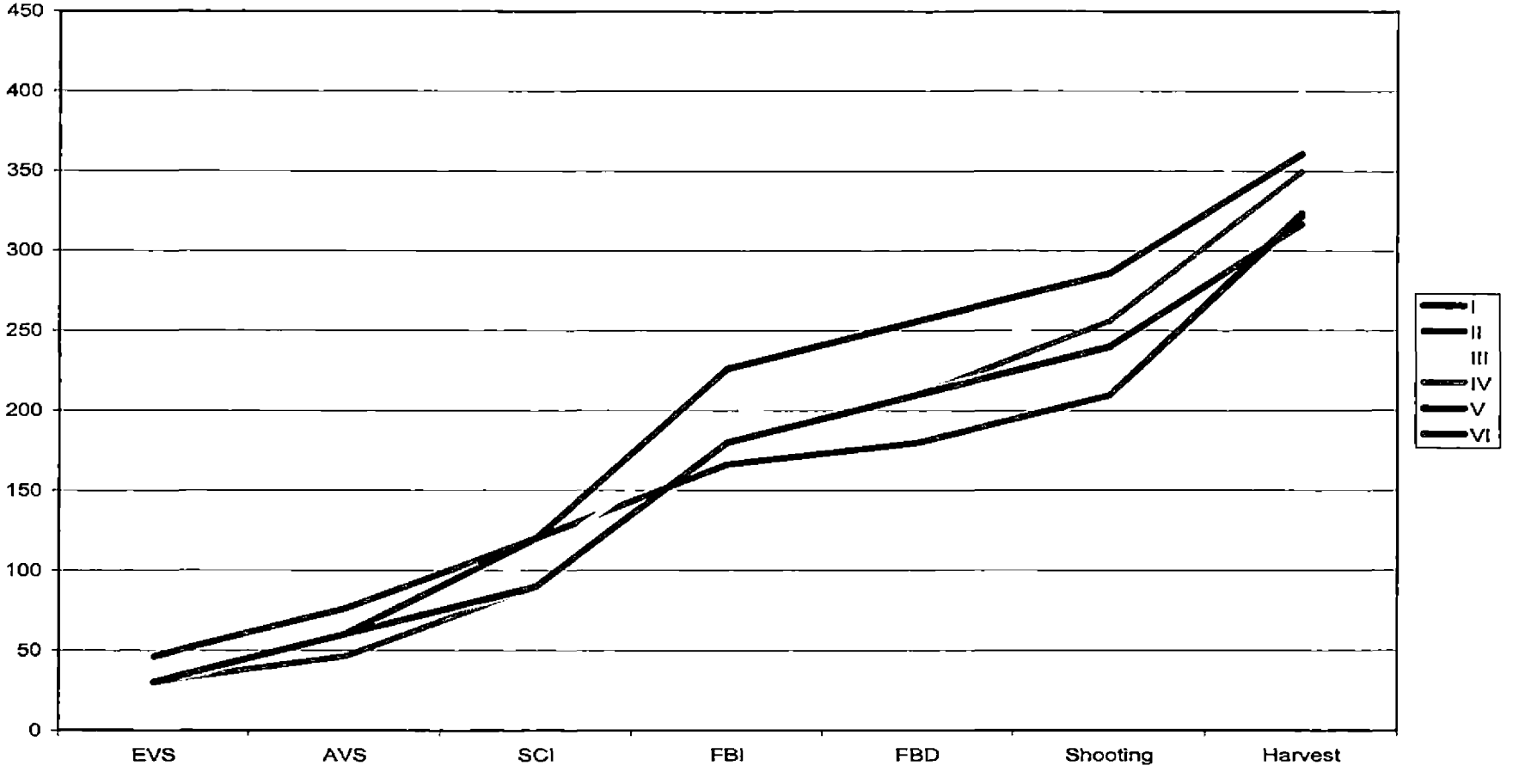
Planting No.	Days to Harvest	Bunch Wt.	No.of fingers	D-finger wt.		Days to Ripening	Shelf Life	Length (cm)	Girth (cm)	Curvature Index	Pedicel Length	Pedicel Index	
				Green	Ripe							Proximal	Distal
I	322.00^{d}	7.92^{b}	48.00^{a}	159.20^{c}	145.00^{b}	6.20^{b}	2.70^{b}	18.40^{bc}	10.85^{c}	537.00^{a}	3.20^{ab}	2.68^{ab}	2.48^{a}
II	324.07^{d}	5.10^{c}	34.50^{b}	128.00^{d}	111.30^{c}	6.97^{ab}	3.43^{a}	16.50^{d}	11.64^{b}	445.00^{bc}	3.10^{b}	2.38^{bc}	2.14^{bc}
III	400.00^{a}	3.45^{d}	19.07^{c}	171.00^{bc}	145.00^{b}	6.87^{a}	2.54^{b}	16.88^{d}	11.67^{b}	455.00^{bc}	3.06^{b}	2.37^{bc}	2.02^{bc}
IV	349.60^{c}	2.69^{e}	12.57^{d}	187.00^{ab}	178.00^{a}	6.60^{ab}	2.63^{b}	19.20^{b}	12.98^{a}	465.00^{b}	3.49^{a}	2.78^{a}	2.23^{b}
V	360.90^{b}	5.07^{c}	35.50^{b}	179.50^{b}	157.00^{b}	6.07^{b}	2.90^{b}	18.11^{c}	13.29^{a}	430.80^{c}	3.12^{b}	2.32^{c}	1.92^{cd}
VI	317.00^{e}	10.04^{a}	46.33^{a}	197.30^{a}	176.00^{a}	5.33^{c}	2.64^{b}	20.33^{a}	12.71^{a}	507.00^{a}	3.30^{ab}	2.34^{c}	1.70^{d}

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table 8. Time taken to reach each physiological stage

Planting No	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
I	46	76	120	166	180	210	322
II	46	76	120	166	180	210	324
III	30	60	106	196	226	270	400
IV	30	46	90	180	210	256	350
V	30	60	120	226	256	286	361
VI	30	60	90	180	210	240	317

Fig. 2. Days to reach different stages in the six bimonthly plantings



4.1.2.2 Number of fingers

Maximum number of fingers was observed in August planting which was only slightly higher than June planting. The February and December plantings recorded significantly lower number of finger counts.

4.1.2.3 Length of fingers

The length of the D-finger was the maximum in June followed by that of August and April and the results were also statistically significant.

4.1.2.4 Girth

Finger girth was the maximum in April planting followed by February and June plantings. The least finger girth was observed in August planting.

4.1.2.5 Curvature Index

The Curvature Index (CI) was highest in August followed by June planting revealing that maximum straightness of the finger was in these plantings. The other plantings showed more or less same values.

4.1.2.6 D-finger weight

The D-finger weight at harvest and at ripening was highest in June planting which was significantly superior to other plantings. This was followed by February, April and August plantings.

4.1.2.7 Days to maturity / harvest

The number of days to maturity / harvest was least in June followed by August and October plantings which were also significant. The October planting followed by April and February took maximum time.

4.1.2.8 Days to ripening from harvest

The June planting followed by April and August took least time to ripening. Maximum time was taken by October and December plantings.

4.1.2.9 Shelf life

October planting recorded maximum shelf life followed by April. On the other hand, October planting was the earliest to senesce

4.1.2.10 Pedicel Index

Maximum Pedicel Index (PI) at fruit/pedicel junction was in the case of February planting followed by August planting. The other plantings registered almost same values The PI at pedicel/ hand union was highest in August planting followed by February, the ranking on the upper side showing opposite trends.

The high variations in these characters reveal the vulnerability of the fruit to shedding

4.1.3 Time phase study on corm growth and development

The study on corm growth as a function of time or age after planting is presented in Table 9. The distinct character of an increase in corm size of the planting material which is treated prior to planting is observed evenly in all the six plantings. The planted corm swells and enlarges upto a defined period of time. This enlargement is observed with a concomitant increase in wet weight and dry weight. The bulking of the planted corm ceases at a particular stage after which a distinct growth is observed over the primary corm with an interphase or separation marked anatomically and morphologically by a constriction. Thereafter growth is centered over the newly emerging corm over the primary corm which we shall in all further studies refer to as the ***Secondary Corm.***

Growth of the planted corm or primary corm ceases the moment the constriction appears. In short, the planted corm grows only for a while (fig 3). Thereafter the corm remains live even upto the stage of harvesting but progressively senesces from the exterior with only the interior part remaining live towards harvest (plates 33a to 37).

Plate – 33a

Plate – 33b

Table 9. Time phase studies on corm growth and development

Primary Corm	I		II		III		IV		V		VI	
	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
Initial	1250.00	201.35	1200.00	168.56	1250.00	210.00	1250.00	224.31	1200.00	212.47	1200.00	219.36
EVS	1550.00	209.27	1500.00	192.23	1450.00	212.25	1350.00	233.55	1250.00	222.35	1220.00	227.56
AVS	1500.00	211.15	1550.00	194.96	1550.00	223.10	1450.00	260.00	1320.00	228.56	1290.00	234.89
SCI	1250.00	197.43	1060.00	140.00	1450.00	206.00	1600.00	272.44	1250.00	225.30	1250.00	225.45
FBI	825.00	98.30	550.00	94.87	1000.00	152.79	1050.00	195.23	650.00	152.20	800.00	153.59
FBD	700.00	65.34	500.00	90.11	860.00	145.82	900.00	188.00	520.00	121.84	570.00	116.78
Shooting	550.00	41.75	500.00	89.27	600.00	102.71	750.00	152.96	400.00	89.67	520.00	105.96
Harvest	100.00	22.67	100.00	39.21	400.00	85.46	460.00	98.50	150.00	23.99	200.00	56.58

Secondary Corm	I		II		III		IV		V		VI	
	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
Initial	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SCI	100.00	3.45	200.00	5.68	80.00	2.33	150.00	2.56	150.00	8.55	150.00	5.23
FBI	1050.00	96.65	1000.00	71.93	250.00	34.57	700.00	43.57	1550.00	138.94	1140.00	118.76
FBD	1550.00	131.61	1420.00	107.30	800.00	61.22	1100.00	58.22	1860.00	173.25	1600.00	155.20
Shooting	1800.00	196.50	1850.00	134.54	1200.00	100.81	1320.00	85.20	2580.00	197.55	2000.00	198.11
Harvest	2000.00	195.68	1960.00	182.71	1300.00	107.70	1400.00	118.90	2450.00	185.10	2150.00	198.17

Total Corm	I		II		III		IV		V		VI	
	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.	Wet wt.	Dry wt.
Initial	1250.00	201.35	1200.00	168.56	1250.00	210.00	1250.00	224.31	1200.00	212.47	1200.00	219.36
EVS	1550.00	209.27	1500.00	192.23	1450.00	212.25	1350.00	233.55	1250.00	222.35	1220.00	227.56
AVS	1500.00	211.15	1550.00	194.96	1550.00	223.10	1450.00	260.00	1320.00	228.56	1290.00	234.89
SCI	1350.00	200.88	1260.00	145.68	1530.00	208.33	1750.00	275.00	1400.00	233.85	1400.00	230.68
FBI	1875.00	194.95	1550.00	166.79	1250.00	187.36	1750.00	238.80	2200.00	291.14	1940.00	272.35
FBD	2250.00	196.95	1920.00	197.41	1660.00	207.04	2000.00	246.22	2380.00	295.09	2170.00	271.98
Shooting	2350.00	238.25	2350.00	223.81	1800.00	203.52	2070.00	238.16	2980.00	287.22	2520.00	304.07
Harvest	2100.00	218.35	2060.00	221.92	1700.00	193.16	1860.00	217.40	2600.00	209.09	2350.00	254.75

Fig. 3 Changes in growth of primary corm with different stages

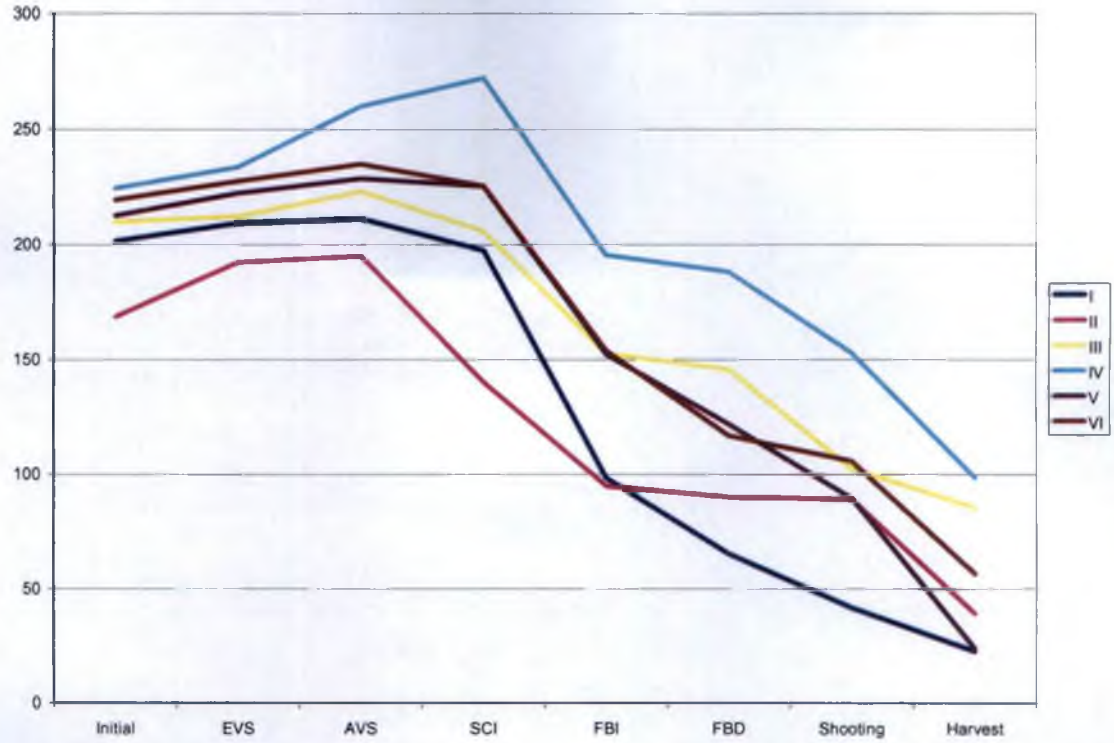


Fig. 4 Changes in growth of secondary corm with different stages

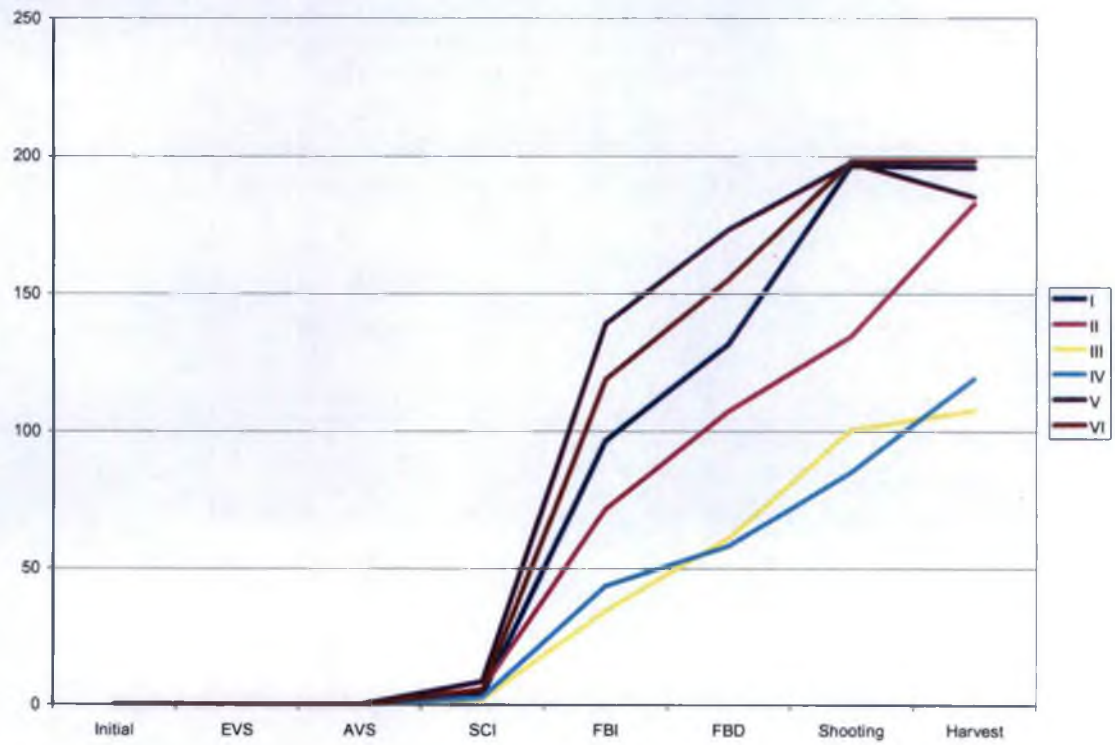


Plate – 34

Plate – 35

Plate - 36

Plate - 37

The secondary corm on the other hand starts more or less after the early vegetative phase that is visualized as an upward elongation of growth of the corm. The growth of the secondary corm initially is straight upward upto FBI and then a gradual increase upto harvest wherein expansion is observed in all directions. In terms of growth curve, it can be visualized as a double sigmoid curve (fig 4).

Thus, the total corm weight which is an addition of both the primary and secondary corm shows two distinct phases of increment

1) at the initial stage – due to the growth of the primary corm

2) from SCI to shooting – due to the secondary corm

The total corm weight shows a distinct decrease in corm weight after shooting in all the six bimonthly plantings (fig 5 & 6).

4.1.3.1 Corm Growth Rate

The Corm Growth Rate of individual plants showed the actual pattern of growth rate and was more a representative trend of dry weight (Table 10, 11 and 12 and fig 7, 8 and 9). In the case of Primary corm, growth is confined upto SCI except in Oct. planting where it is observed only upto AVS. In all plantings, the growth rate after SCI stage is negative, the rates peaking differently. If in the first planting and fourth planting it is FBI stage, in the second it is SCI, the third and fifth it is shooting and in the sixth it is FBD.

The CGR of the Secondary corm showed increments upto harvest in October, December and February planting, upto shooting in case of June, August and April planting with the latter showing negative growth from shooting to harvest.

When the whole corm was considered, the CGR was negative at SCI in October planting, at SCI and FBI in August and December planting and FBI in February planting. Invariably it was negative or zero at harvesting stage with April planting showing the accounting for the maximum negative values. The CGR peaked at shooting in June and

Table 10. Corm Growth Rate – Primary Corm

CGR - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.04	0.13	0.02	0.08	0.08	0.07
AVS	0.02	0.02	0.09	0.41	0.05	0.06
SCI	-0.08	-0.31	-0.09	0.07	-0.01	-0.08
FBI	-0.54	-0.25	-0.15	-0.21	-0.17	-0.20
FBD	-0.59	-0.08	-0.06	-0.06	-0.25	-0.31
Sh	-0.20	-0.01	-0.24	-0.19	-0.27	-0.09
Har	-0.04	-0.11	-0.03	-0.15	-0.22	-0.16

Table 11. Corm Growth Rate – Secondary Corm

CGR - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	0.02	0.03	0.01	0.01	0.04	0.04
FBI	0.51	0.36	0.09	0.11	0.31	0.32
FBD	0.62	0.63	0.22	0.12	0.29	0.30
Sh	0.54	0.23	0.22	0.15	0.20	0.36
Har	0.00	0.11	0.01	0.09	-0.04	0.00

Table 12. Corm Growth Rate – Whole Corm

CGR - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.04	0.13	0.02	0.08	0.08	0.07
AVS	0.02	0.02	0.09	0.41	0.05	0.06
SCI	-0.06	-0.28	-0.08	0.09	0.02	0.00
FBI	-0.03	0.11	-0.06	-0.10	0.00	0.12
FBD	0.04	0.55	0.16	0.00	0.03	0.00
Sh	0.34	0.22	0.00	-0.04	-0.07	0.27
Har	-0.04	0.00	-0.02	-0.06	-0.26	-0.16

Fig. 5 Changes in growth of whole corm with different stages

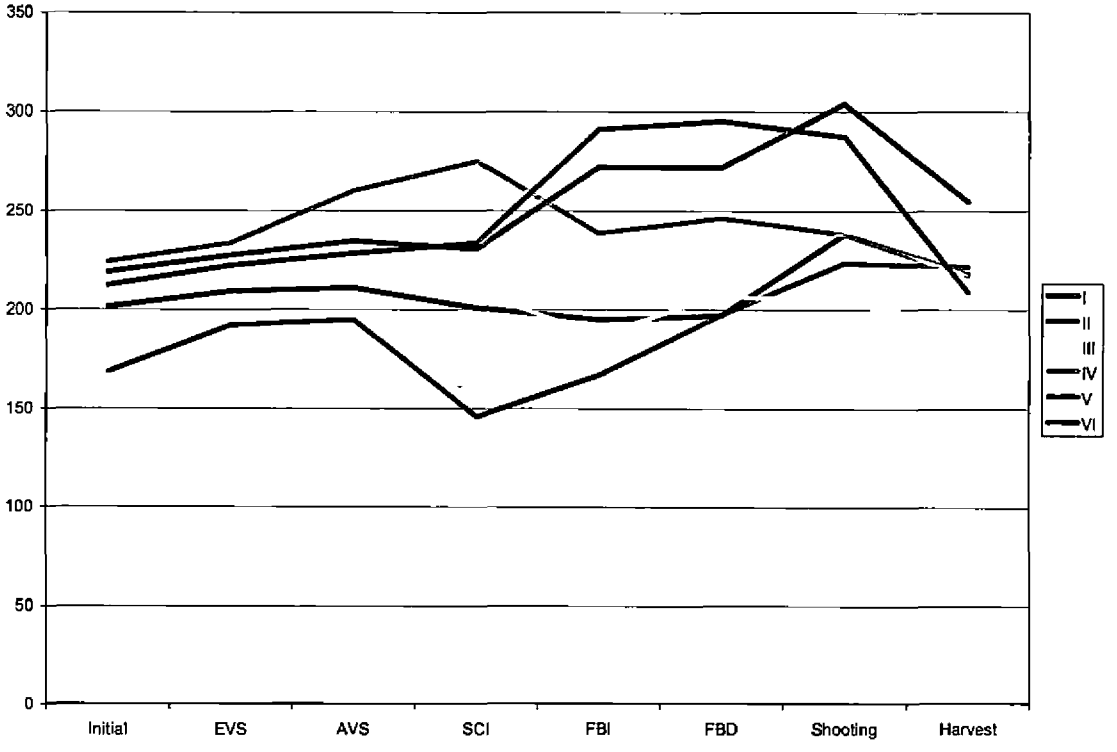


Fig. 6 General trend in growth of primary, secondary and total corm with different stages

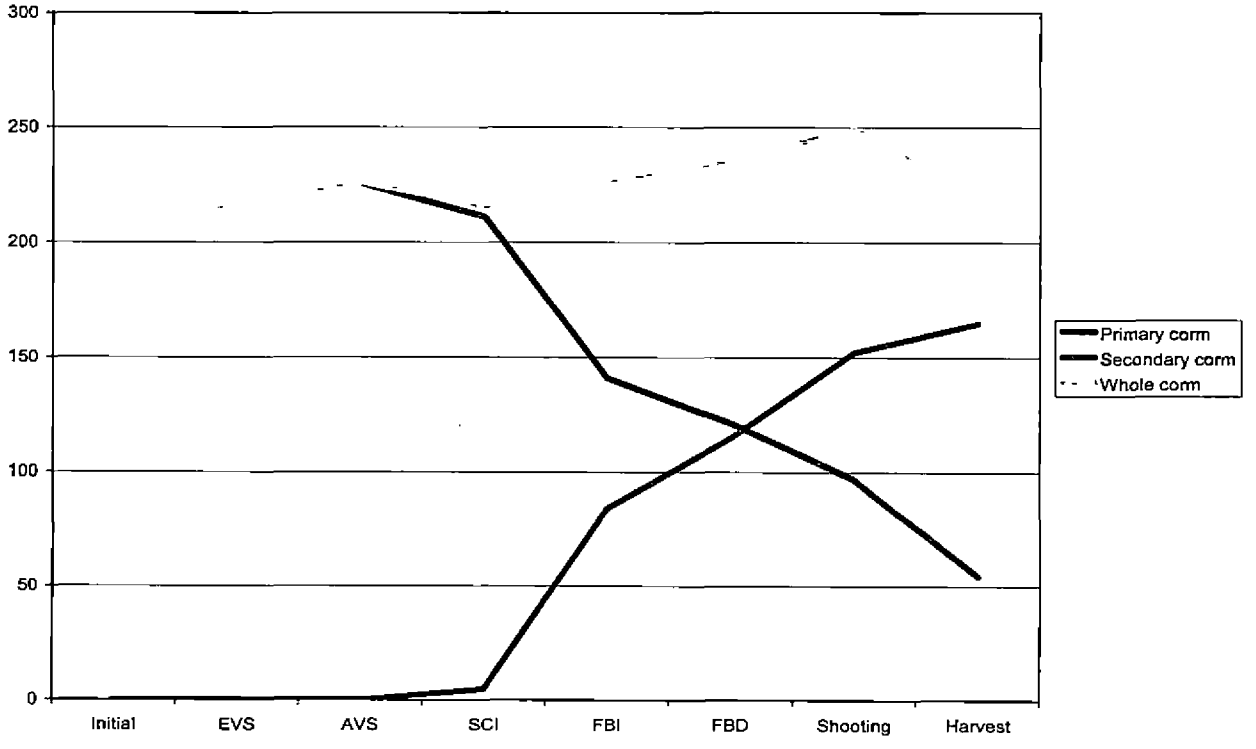


Fig – 7 Corm Growth Rate – Primary Corm

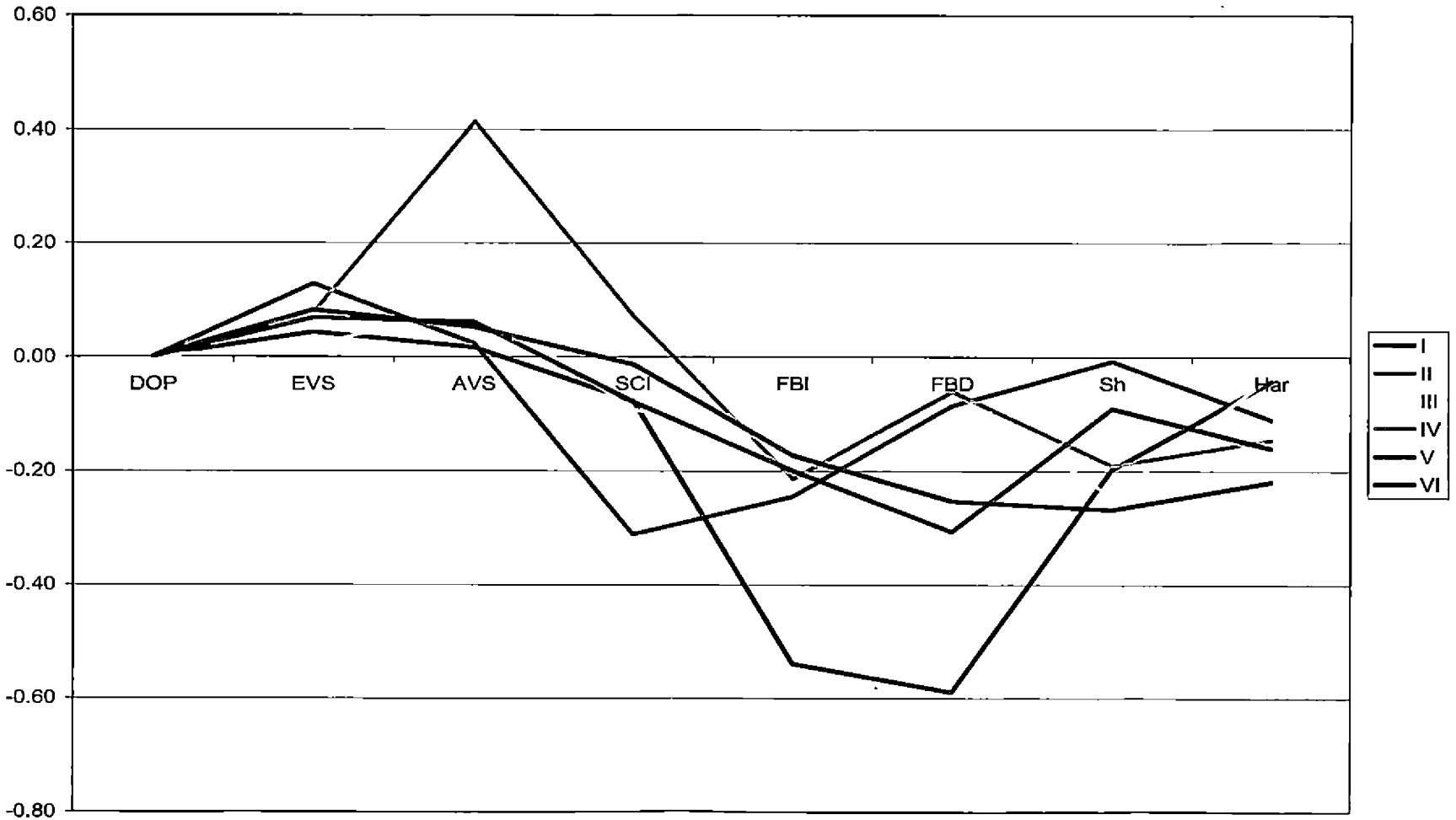


Fig 8. Corm Growth Rate – Secondary Corm

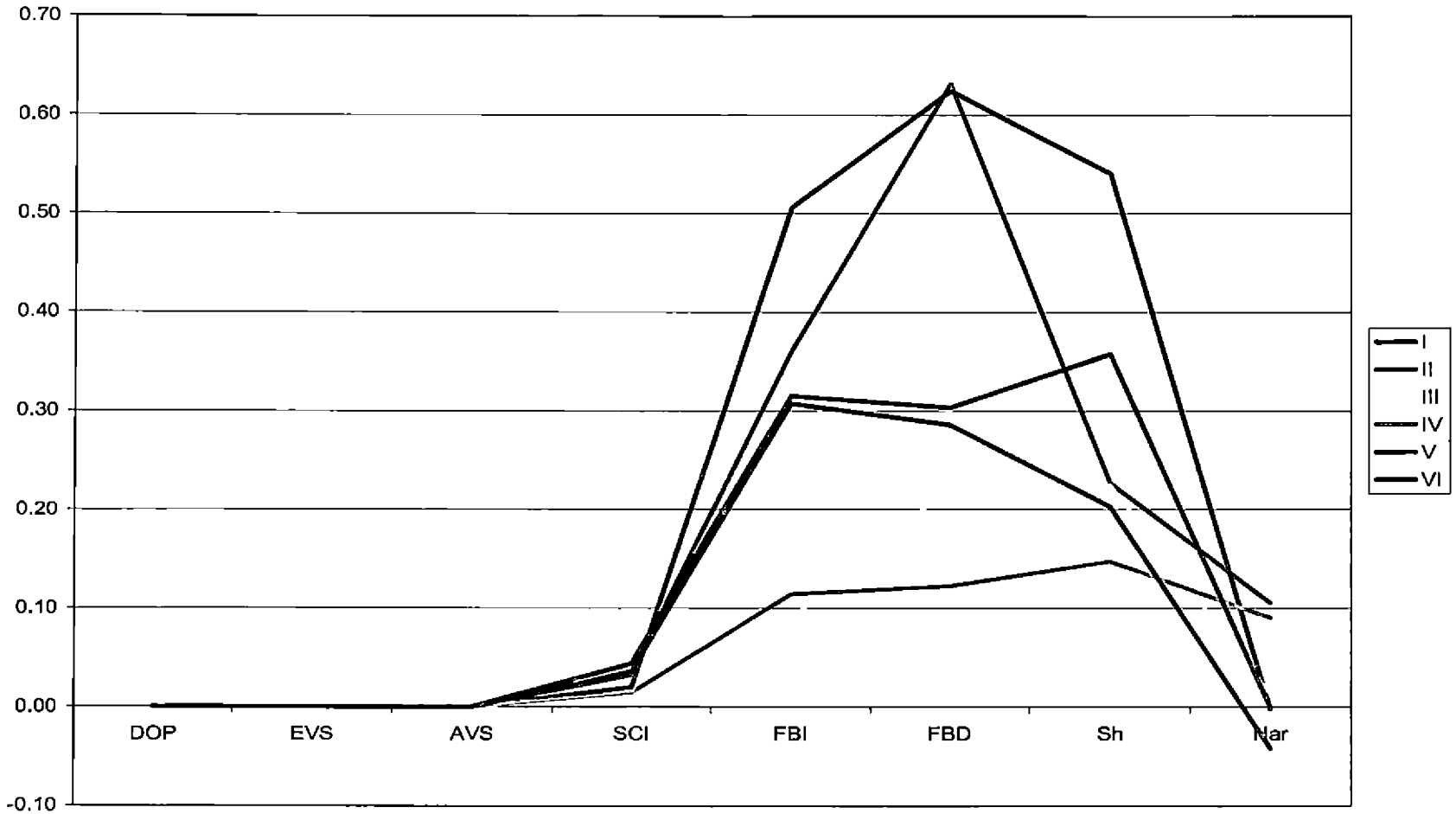
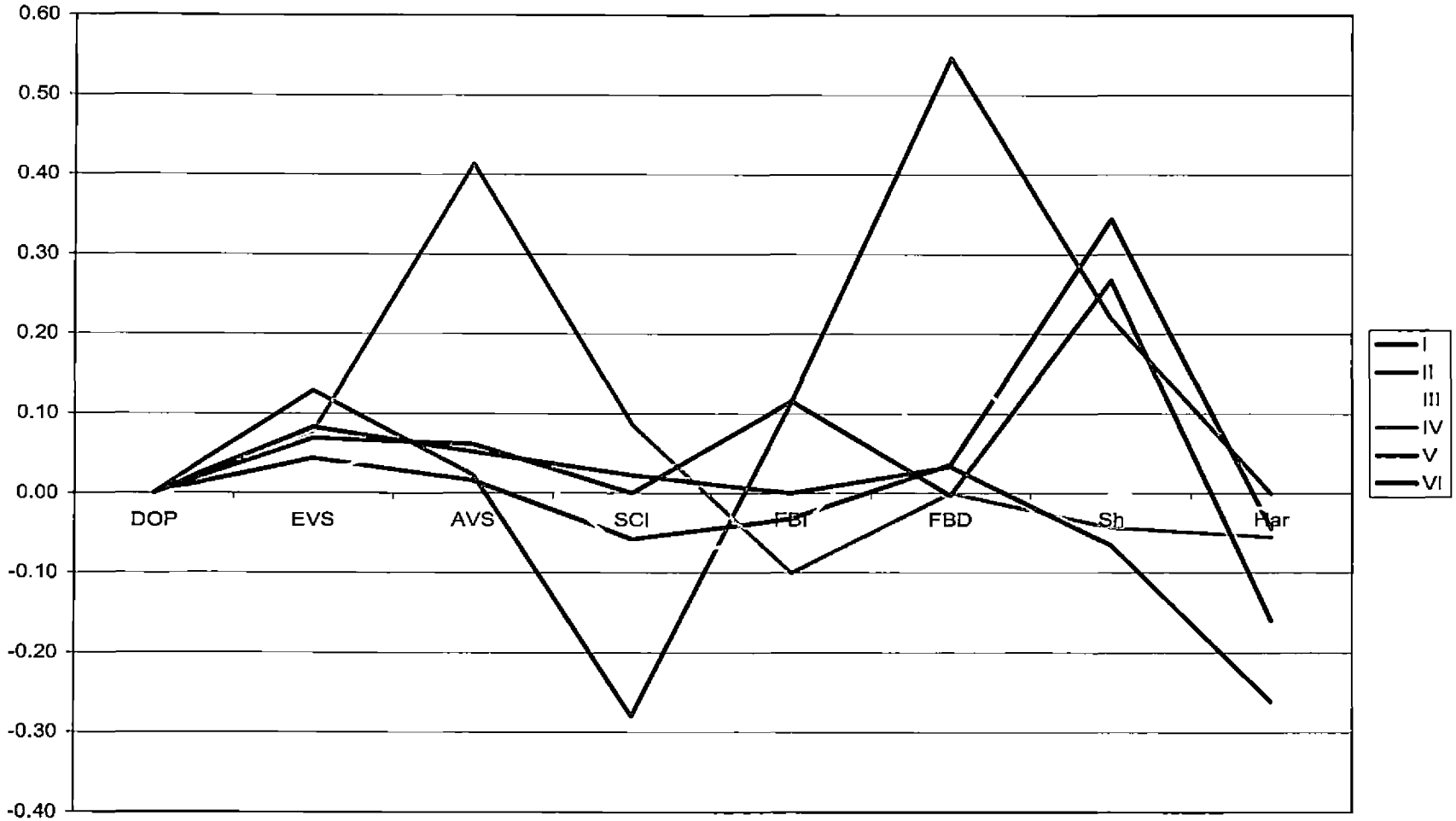


Fig 9. Corm Growth Rate – Whole Corm



August planting, at FBD in December planting, at SCI in February and AVS in April planting. The shifts imply indirectly the growth of secondary or primary corm.

4.1.3.2. Corm Weight Ratio

The corm weight ratio (CWR) presented in tables 13, 14 and15 and fig. 10, 11 and 12 is an actual ratio of the corm weight to the whole plant weight. At planting, the planted corm represents the full weight whereas at EVS it is less than half and by SCI it is less than one third. Thereafter, the Primary corm progressively reduces to reach the lowest of 0.01 and 0.02 by harvest in the first and second crop. In comparison, the reduction in the case of third and fourth crop is gradual or steadily decreasing with each biotic phase. The fifth and sixth crop gave a different picture with early reduction in corm weight upto SCI comparable with the third and fourth crop but thereafter the reduction revealed a trend similar to the first and second crop.

On the other hand, the secondary corm individually is just a fragment at 0.01 and increases progressively to reach maximum by shooting stage. At this stage, the increment is 16 times and by harvest the CWR is 0.1, the increase in ratio from start being ten times. This trend is observed in the first, second, fifth and sixth crop, whereas the secondary corm formed a more important fraction of the whole plant weight at harvest by 0.14 and 0.15 in case of February and April plantings.

Table 13. Corm Weight Ratio – Primary Corm

CWR - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	1.00	1.00	1.00	1.00	1.00	1.00
EVS	0.45	0.49	0.81	0.74	0.75	0.76
AVS	0.42	0.47	0.77	0.74	0.67	0.64
SCI	0.31	0.26	0.69	0.72	0.33	0.41
FBI	0.09	0.13	0.37	0.38	0.11	0.12
FBD	0.05	0.10	0.32	0.36	0.08	0.09
Sh	0.03	0.08	0.23	0.26	0.05	0.08
Har	0.01	0.02	0.11	0.12	0.01	0.03

Table 14. Corm Weight Ratio – Secondary Corm

CWR - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	0.01	0.01	0.01	0.01	0.01	0.01
FBI	0.08	0.10	0.08	0.08	0.10	0.10
FBD	0.11	0.12	0.14	0.11	0.11	0.12
Sh	0.16	0.11	0.22	0.14	0.12	0.15
Har	0.10	0.11	0.14	0.15	0.10	0.10

Table 15. Corm Weight Ratio – Whole Corm

CWR - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	1.00	1.00	1.00	1.00	1.00	1.00
EVS	0.45	0.49	0.81	0.74	0.75	0.76
AVS	0.42	0.47	0.77	0.74	0.67	0.64
SCI	0.32	0.27	0.70	0.73	0.34	0.42
FBI	0.17	0.22	0.46	0.46	0.21	0.22
FBD	0.16	0.21	0.46	0.47	0.19	0.20
Sh	0.19	0.19	0.45	0.40	0.18	0.22
Har	0.11	0.13	0.26	0.27	0.12	0.12

Fig 10. Corm Weight Ratio – Primary Corm

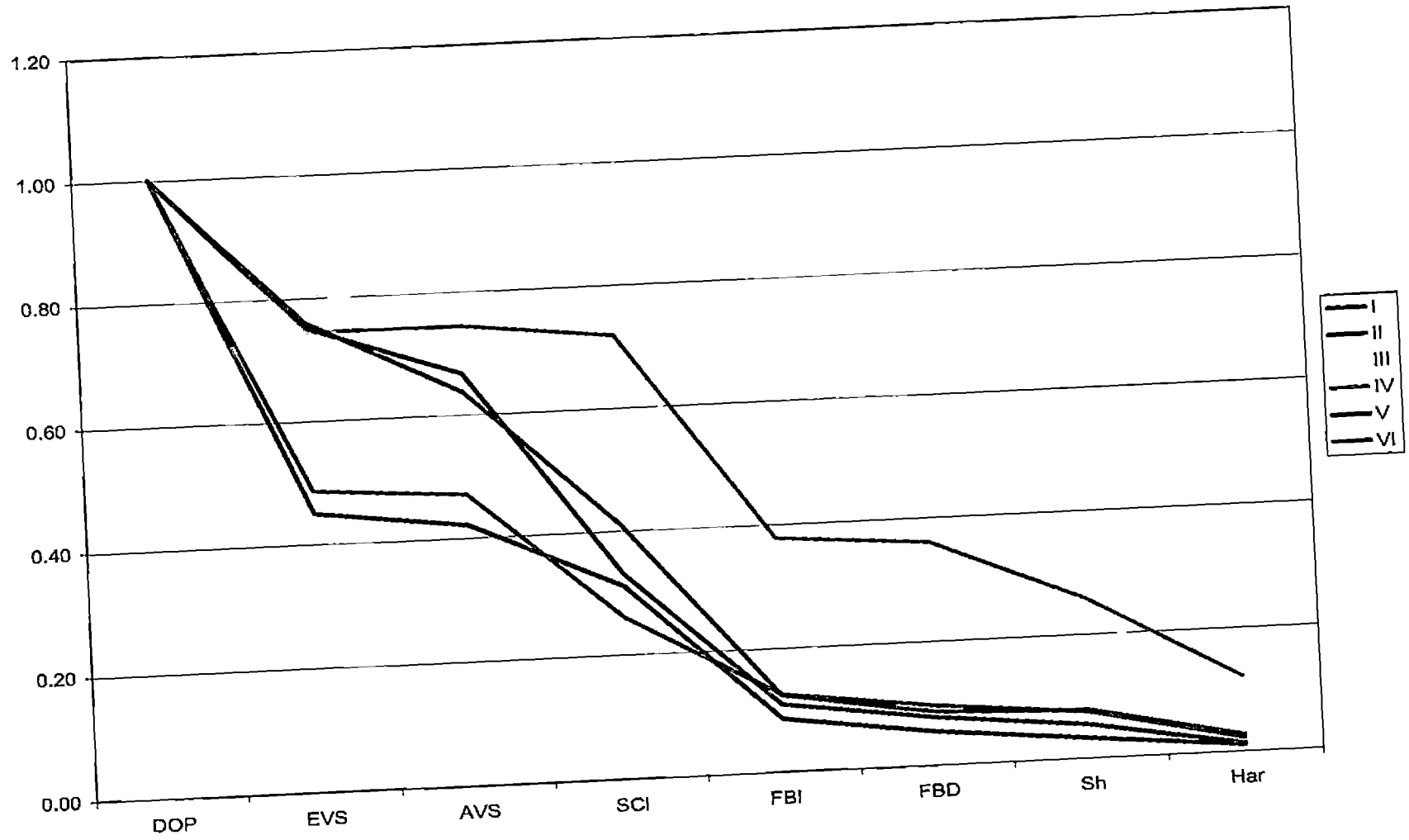


Fig 11. Corm Weight Ratio – Secondary Corm

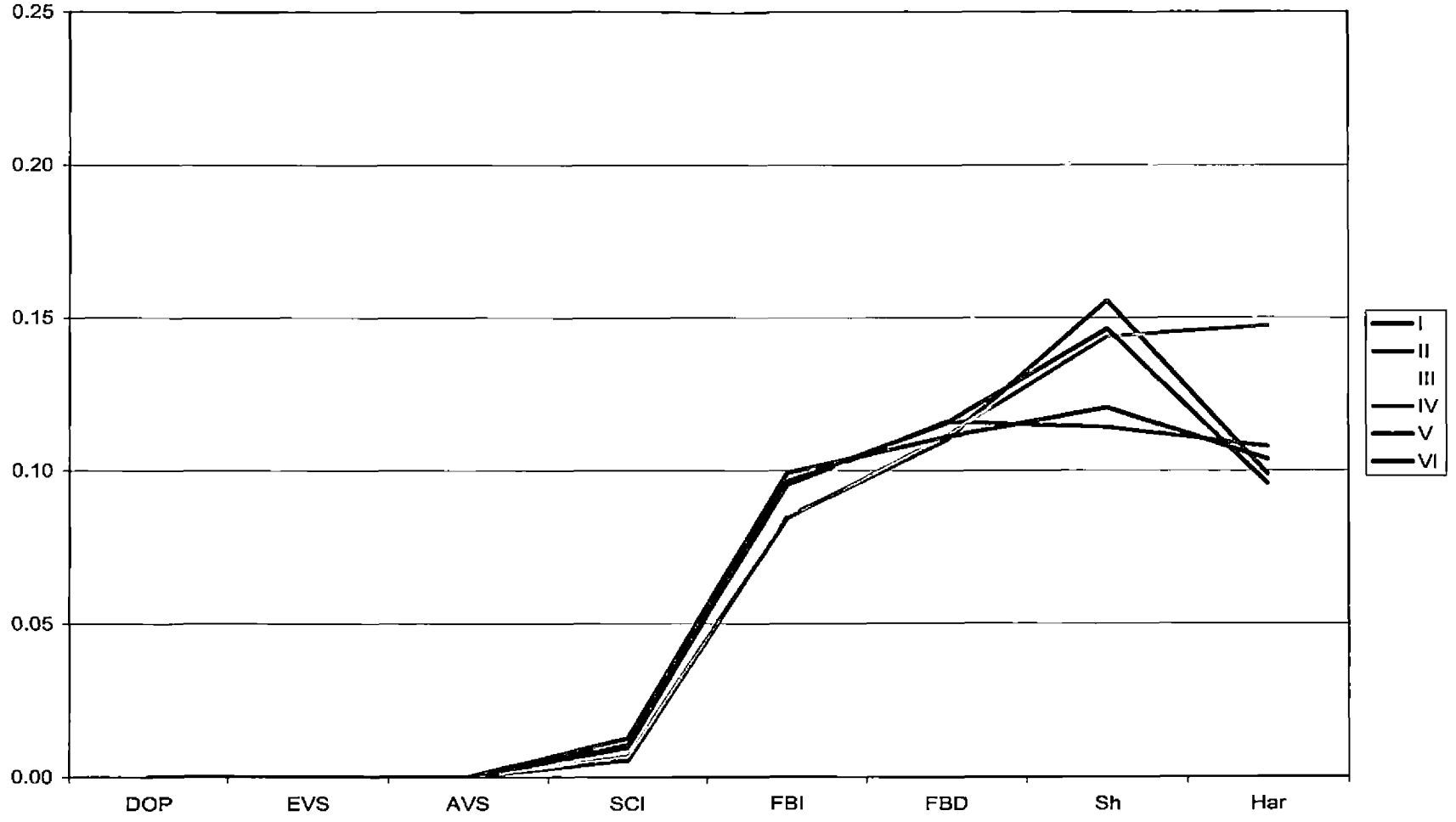
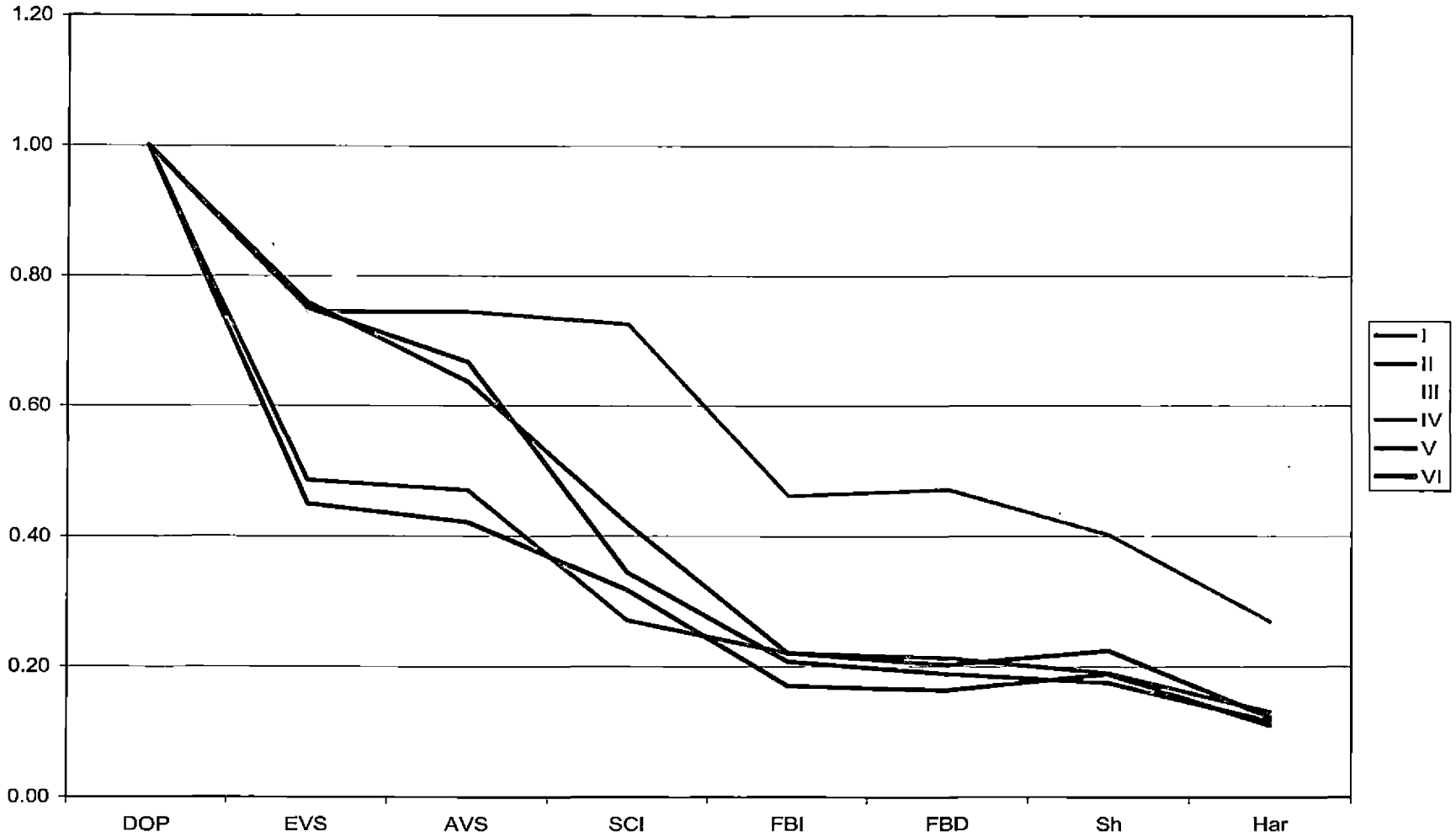


Fig 12. Corm Weight Ratio – Whole Corm



In the case of whole corm (primary and secondary), the reduction in corm weight ratio is drastic from planting to EVS and AVS in case of August and October planting. Thereafter the reduction is gradual. On the contrary, the reduction in December and February plantings is steady and gradual upto harvest. Whereas in April and June, it is gradual and steady upto SCI. Thereafter the reduction is sharp with almost identical values as in the case of August and October planting towards the later biotic phases.

4.1.3.3. Specific Corm Area

The Specific Corm Area (SCA) which is a measure of the corm area in relation to its dry weight is presented in tables 16, 17 and 18. The SCA of Primary corm shows a progressive reduction from EVS to shooting and then an increase at harvesting stage in August, October April and June planting, whereas in December and February plantings it is a gradual and progressive reduction upto harvest (fig. 13).

The SCA of Secondary corm starts only from SCI stage. Here again, there is a progressive reduction from SCI to shooting stage in April, June and August plantings whereas there is a progressive reduction from SCI to harvest in October, December and February plantings (fig. 14).

The SCA of the whole corm showed exactly the same trend as that of the Secondary corm (fig 15).

Table 16. Specific Corm Area – Primary Corm

SCA - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	4.43	4.18	3.79	3.63	2.84	4.27
AVS	4.25	3.91	4.61	3.52	2.77	3.86
SCI	3.10	4.26	3.25	2.84	2.34	3.34
FBI	3.28	4.45	3.45	3.26	3.11	2.34
FBD	2.89	2.70	2.48	2.85	2.53	1.98
Sh	2.26	1.80	2.14	2.36	2.56	0.96
Har	4.16	3.84	1.76	2.52	8.38	1.11

Table 17. Specific Corm Area – Secondary Corm

SCA - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	49.15	15.92	27.49	25.02	10.28	27.02
FBI	11.70	7.44	8.43	5.95	2.85	11.90
FBD	10.50	7.13	6.67	6.02	4.05	11.75
Sh	7.35	6.23	4.73	4.79	3.86	9.92
Har	7.25	4.54	4.43	3.78	4.13	10.12

Table 18. Specific Corm Area – Whole Corm

SCA - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	4.43	4.18	3.79	3.63	2.84	4.27
AVS	4.25	3.91	4.61	3.52	2.77	3.86
SCI	3.89	4.71	3.52	3.04	2.63	3.88
FBI	7.45	5.74	4.37	3.75	2.99	6.51
FBD	7.97	5.11	3.72	3.60	3.42	7.56
Sh	6.46	4.46	3.42	3.23	3.46	6.79
Har	6.93	4.41	3.25	3.21	4.62	8.12

Fig 13. Specific Corm Area – Primary Corm

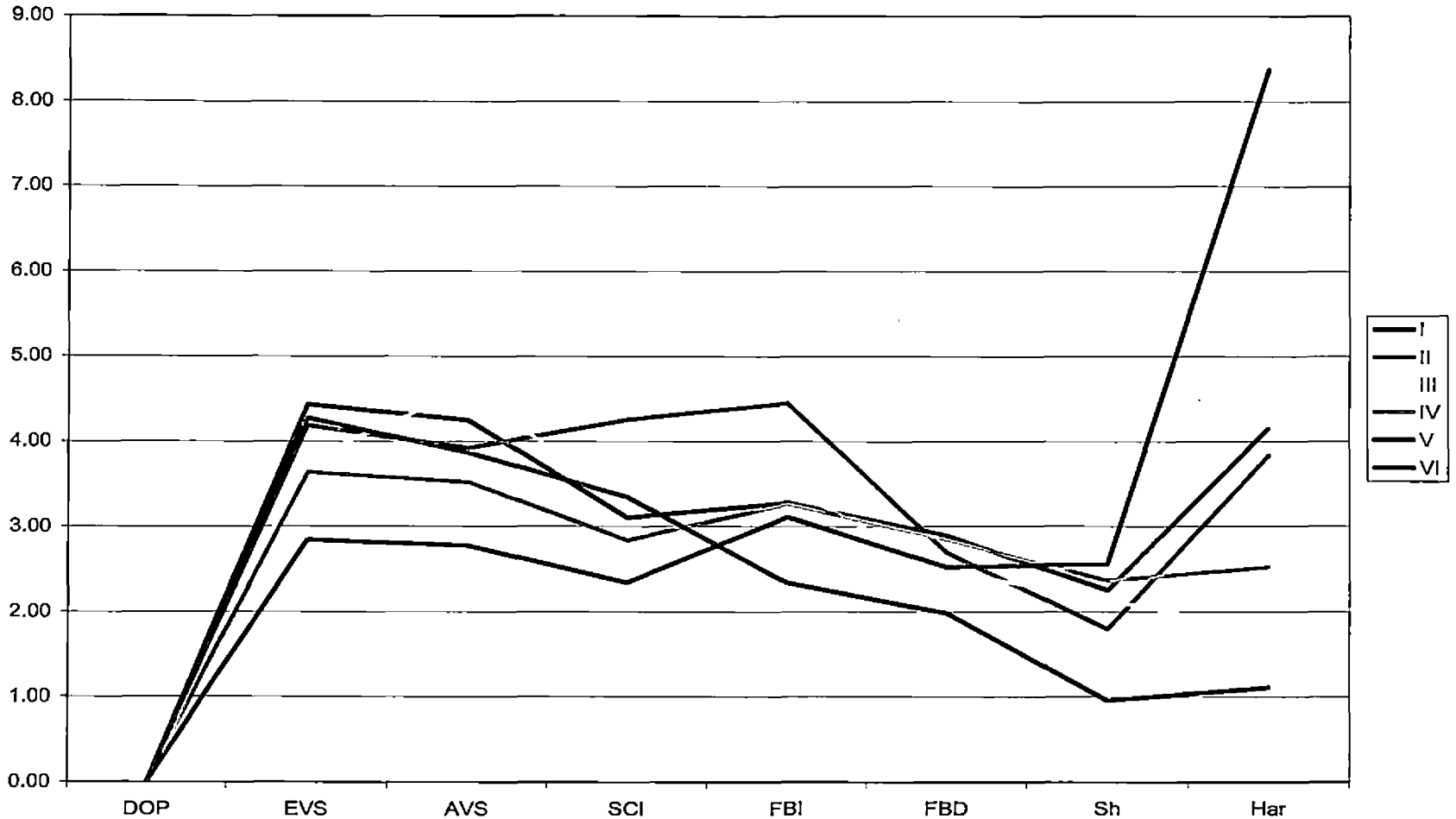


Fig – 14 Specific Corm Area – Secondary Corm

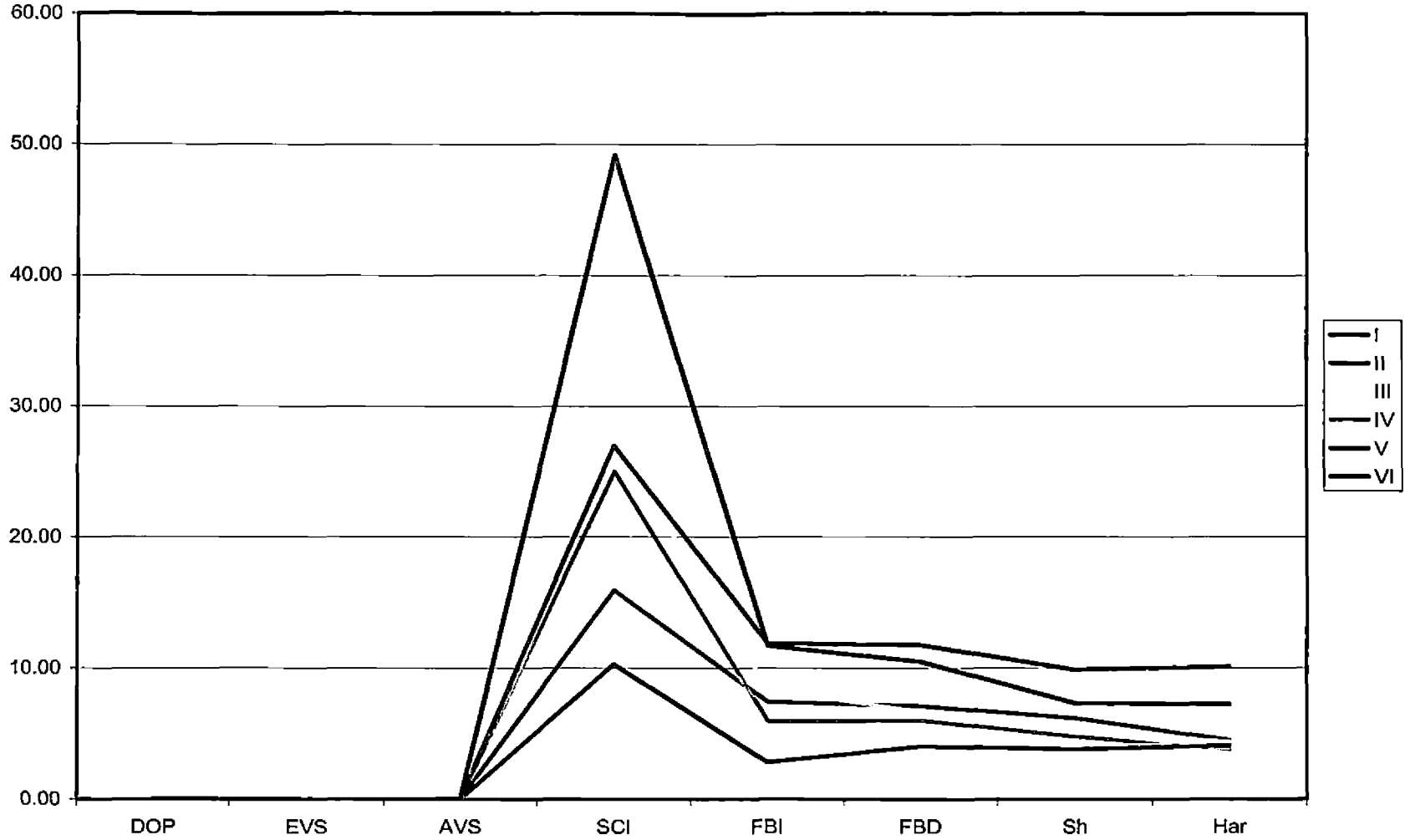
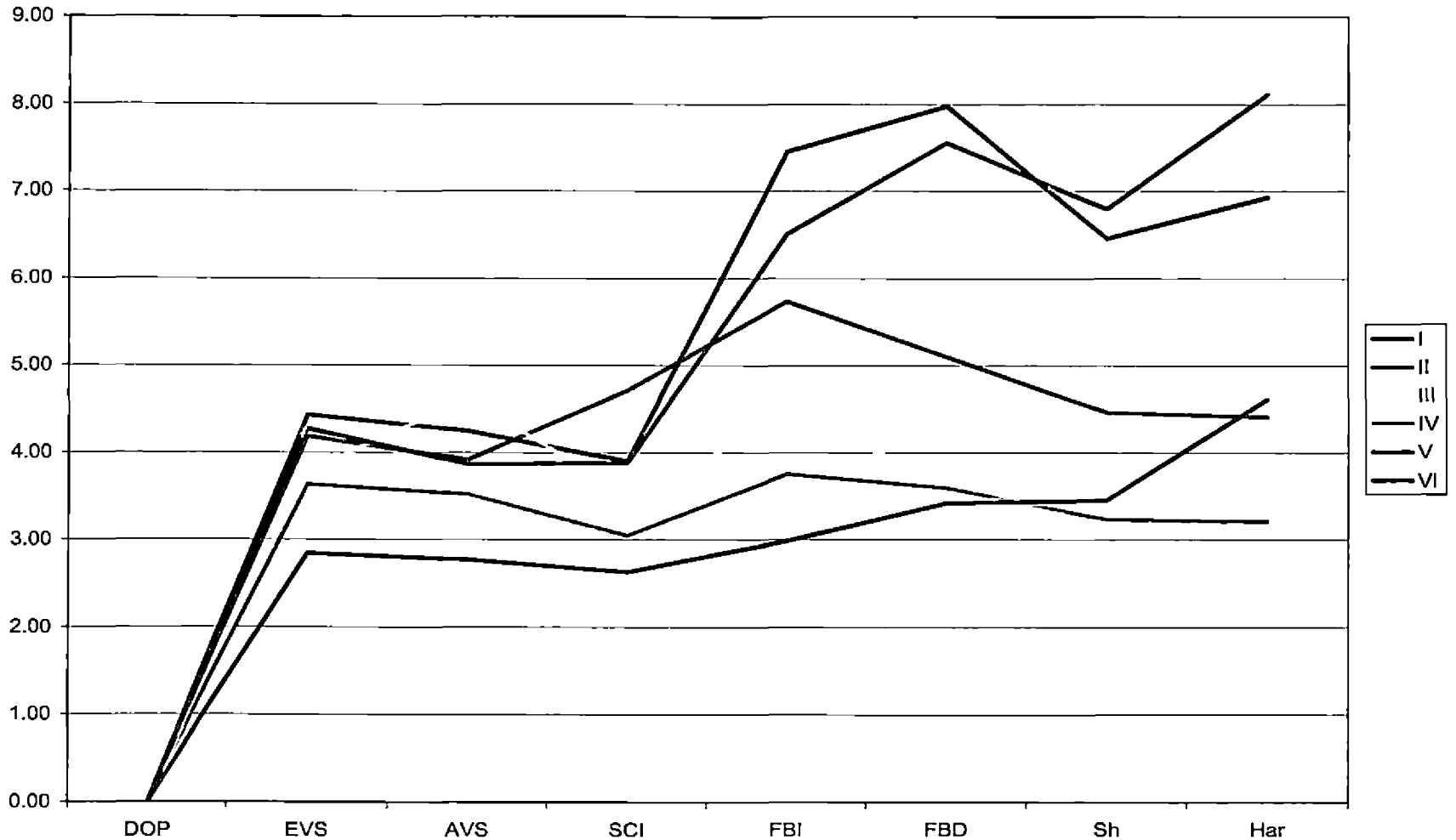


Fig – 15 Specific Corm Area – Whole Corm



4.1.3.4. Corm Area Ratio

The Corm Area Ratio (CAR) which is the corm area as a function of the whole plant dry weight presented in tables 19, 20, and 21.

In the case of Primary corm, all the six crops showed the same trend ie. a reduction from the EVS to harvest (fig. 16).

The trend was just the reverse in the case of the Secondary corm with progressive increase upto shooting in June, December, April and February plantings whereas almost the same values in FBD and shooting in August planting. On the contrary, the October planting the crop at FBD stage registered the highest values (fig. 17).

When the whole corm was considered, highest values were observed manifested as two peaks in the graph, 1) at EVS stage in all the six crops and the second at FBD stage. In the June crop, which was the best from the point of yield, FBD and shooting stage gave the same values (fig. 18).

4.1.3.5. Specific Corm Weight

Specific Corm Weight (SCW), a measure of corm weight per unit area is presented in tables 22, 23 and 24.

Table 19. Corm Area Ratio – Primary Corm

CAR - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	1.99	2.03	3.06	2.70	2.13	3.24
AVS	1.79	1.84	3.54	2.62	1.85	2.46
SCI	0.97	1.11	2.25	2.04	0.78	1.37
FBI	0.28	0.56	1.29	1.23	0.34	0.29
FBD	0.16	0.26	0.80	1.03	0.20	0.17
Sh	0.07	0.14	0.48	0.61	0.14	0.08
Har	0.05	0.09	0.20	0.31	0.11	0.03

Table 20. Corm Area Ratio – Secondary Corm

CAR - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	0.27	0.17	0.22	0.17	0.13	0.26
FBI	0.99	0.71	0.71	0.50	0.28	1.15
FBD	1.15	0.83	0.91	0.67	0.45	1.36
Sh	1.14	0.71	1.04	0.69	0.47	1.45
Har	0.72	0.49	0.64	0.56	0.43	0.97

Table 21. Corm Area Ratio – Whole Corm

CAR - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	1.99	2.03	3.06	2.70	2.13	3.24
AVS	1.79	1.84	3.54	2.62	1.85	2.46
SCI	1.23	1.28	2.46	2.21	0.91	1.63
FBI	1.27	1.27	2.00	1.73	0.62	1.44
FBD	1.31	1.09	1.71	1.70	0.65	1.53
Sh	1.22	0.85	1.53	1.30	0.61	1.53
Har	0.77	0.58	0.84	0.86	0.54	1.00

Fig 16. Corm Area Ratio – Primary Corm

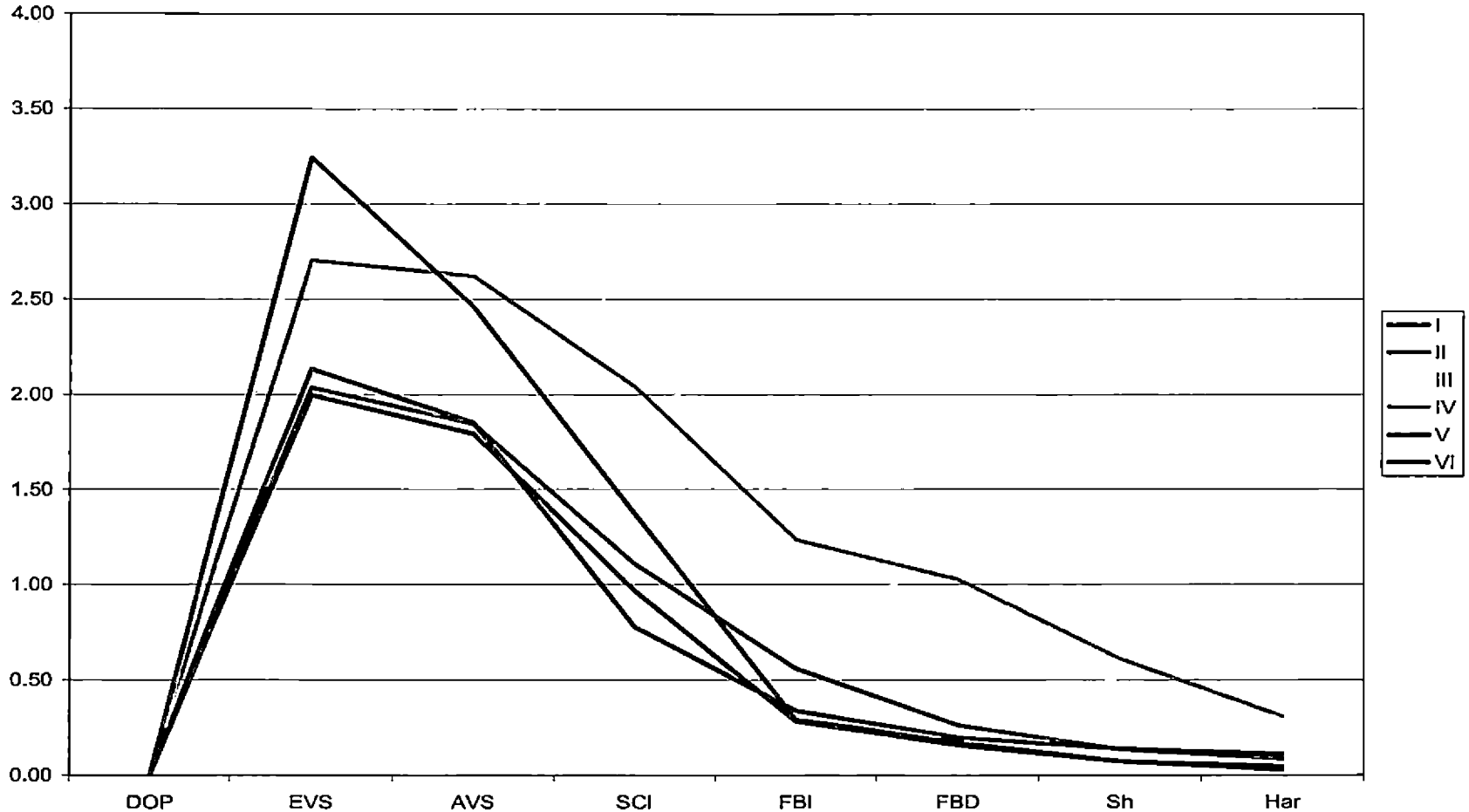


Fig 17. Corm Area Ratio – Secondary Corm

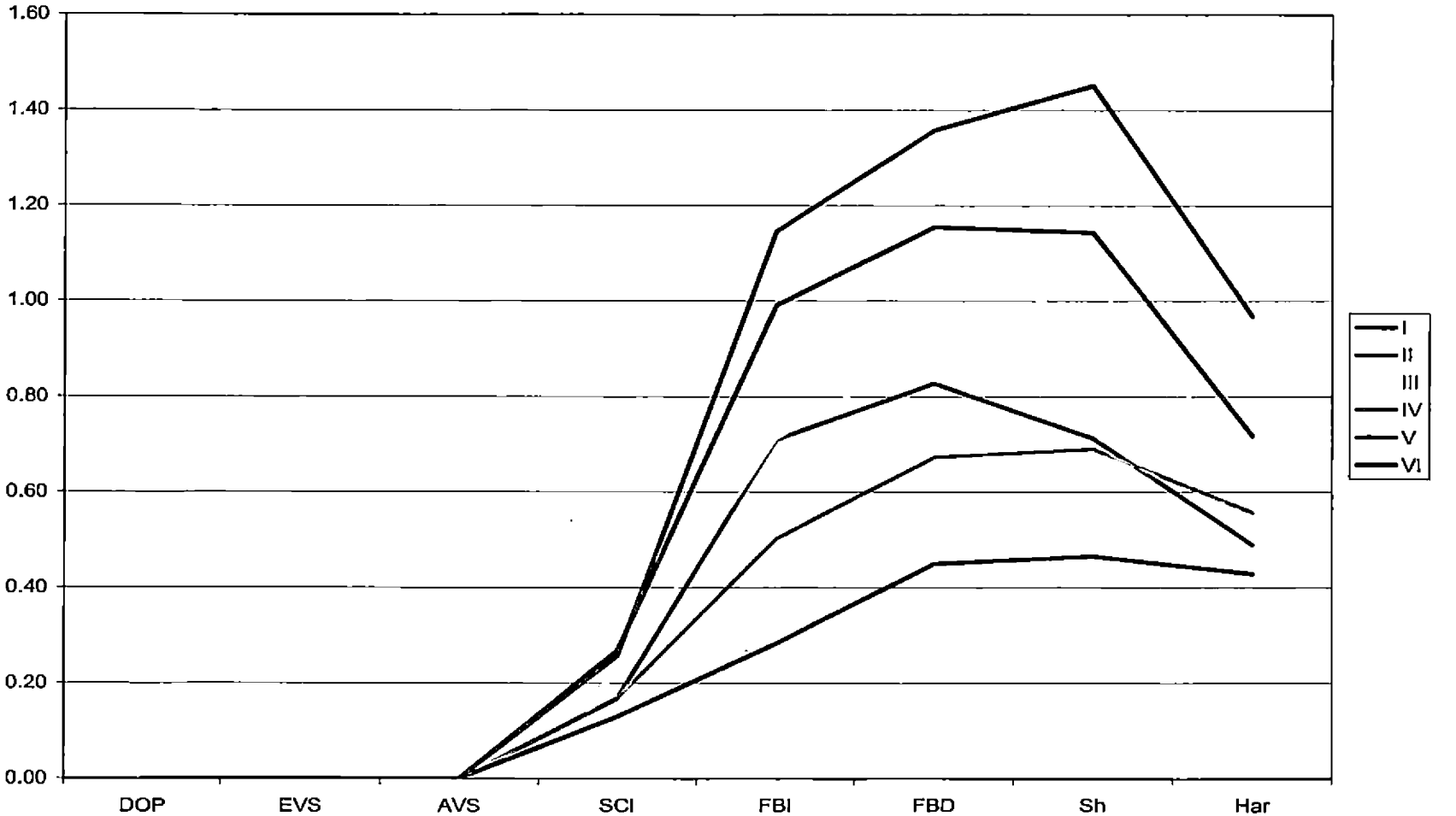


Fig 18. Corm Area Ratio – Whole Corm

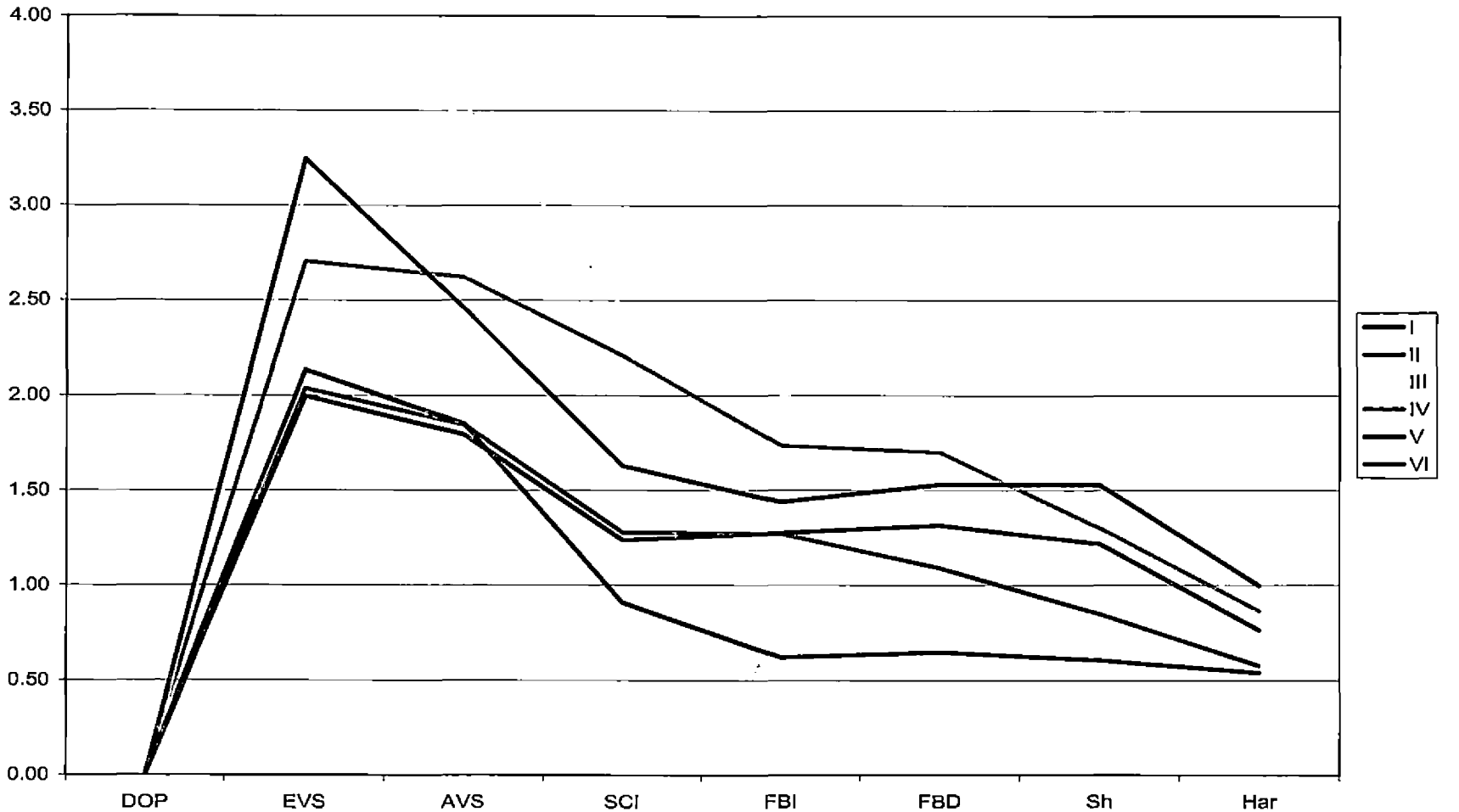


Table 22. Specific Corm Weight – Primary Corm

SCW - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.23	0.24	0.26	0.28	0.35	0.23
AVS	0.24	0.26	0.22	0.28	0.36	0.26
SCI	0.32	0.23	0.31	0.35	0.43	0.30
FBI	0.31	0.22	0.29	0.31	0.32	0.43
FBD	0.35	0.37	0.40	0.35	0.40	0.50
Sh	0.44	0.56	0.47	0.42	0.39	1.04
Har	0.24	0.26	0.57	0.40	0.12	0.90

Table 23. Specific Corm Weight – Secondary Corm

SCW - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	0.02	0.06	0.04	0.04	0.10	0.04
FBI	0.09	0.13	0.12	0.17	0.35	0.08
FBD	0.10	0.14	0.15	0.17	0.25	0.09
Sh	0.14	0.16	0.21	0.21	0.26	0.10
Har	0.14	0.22	0.23	0.26	0.24	0.10

Table 24. Specific Corm Weight – Whole Corm

SCW - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.23	0.24	0.26	0.28	0.35	0.23
AVS	0.24	0.26	0.22	0.28	0.36	0.26
SCI	0.26	0.21	0.28	0.33	0.38	0.26
FBI	0.13	0.17	0.23	0.27	0.33	0.15
FBD	0.13	0.20	0.27	0.28	0.29	0.13
Sh	0.15	0.22	0.29	0.31	0.29	0.15
Har	0.14	0.23	0.31	0.31	0.22	0.12

The SCW of the Primary corm is found to increase from EVS to shooting followed by a reduction at harvest in June and August plantings. In February and April planting, intermediary reduction is seen at FBI stage with gradual increase upto harvesting stage. In contrast, the October and December plantings, after showing a reduction in FBI stage, shows progressive increment only upto shooting and thereafter reduces (fig 19).

The SCW of the Secondary corm on the other hand showed a different trend. In the case of the best crops in June and August and also in April, a progressive is seen upto shooting and thereafter it remains the same. Whereas in October, December and February, there is an increase upto harvest stage (fig 20).

The SCW of the whole corm on the other hand reveals two peaks, first upto SCI in all the six crops and second which varies with crops. The August, June and April crops showed a second peak at shooting stage whereas in October, December and February plantings, it was the maximum at harvesting stage (fig. 21).

4.1.3.6. Absolute Growth Rate

The data of corm AGR are given in tables 25, 26 and 27. The values were the highest in the EVS in August, October, April and June plantings whereas in December and February plantings it was highest at AVS stage. Negative AGR values were observed from SCI stage except in February planting where negative growth values were recorded only from FBI (fig 22).

Table 25. Absolute Growth Rate – Primary Corm

AGR - PRIMARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.17	0.51	0.08	0.31	0.33	0.27
AVS	0.06	0.09	0.36	1.65	0.21	0.24
SCI	-0.31	-1.25	-0.37	0.28	-0.05	-0.31
FBI	-2.16	-0.98	-0.59	-0.86	-0.69	-0.80
FBD	-2.35	-0.34	-0.23	-0.24	-1.01	-1.23
Sh	-0.79	-0.03	-0.98	-0.76	-1.07	-0.36
Har	-0.17	-0.44	-0.13	-0.58	-0.88	-0.64

Table 26. Absolute Growth Rate – Secondary Corm

AGR - SECONDARY CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.00	0.00	0.00	0.00	0.00	0.00
AVS	0.00	0.00	0.00	0.00	0.00	0.00
SCI	0.08	0.13	0.05	0.06	0.14	0.17
FBI	2.03	1.44	0.36	0.46	1.23	1.26
FBD	2.50	2.53	0.89	0.49	1.14	1.21
Sh	2.16	0.91	0.90	0.59	0.81	1.43
Har	-0.01	0.42	0.05	0.36	-0.17	0.00

Table 27. Absolute Growth Rate – Whole Corm

AGR - WHOLE CORM						
	I	II	III	IV	V	VI
DOP	0.00	0.00	0.00	0.00	0.00	0.00
EVS	0.17	0.51	0.08	0.31	0.33	0.27
AVS	0.06	0.09	0.36	1.65	0.21	0.24
SCI	-0.23	-1.12	-0.32	0.34	0.09	-0.14
FBI	-0.13	0.46	-0.23	-0.40	0.54	0.46
FBD	0.14	2.19	0.66	0.25	0.13	-0.01
Sh	1.38	0.88	-0.08	-0.18	-0.26	1.07
Har	-0.18	-0.02	-0.08	-0.22	-1.04	-0.64

Fig 19. Specific Corm Weight – Primary Corm

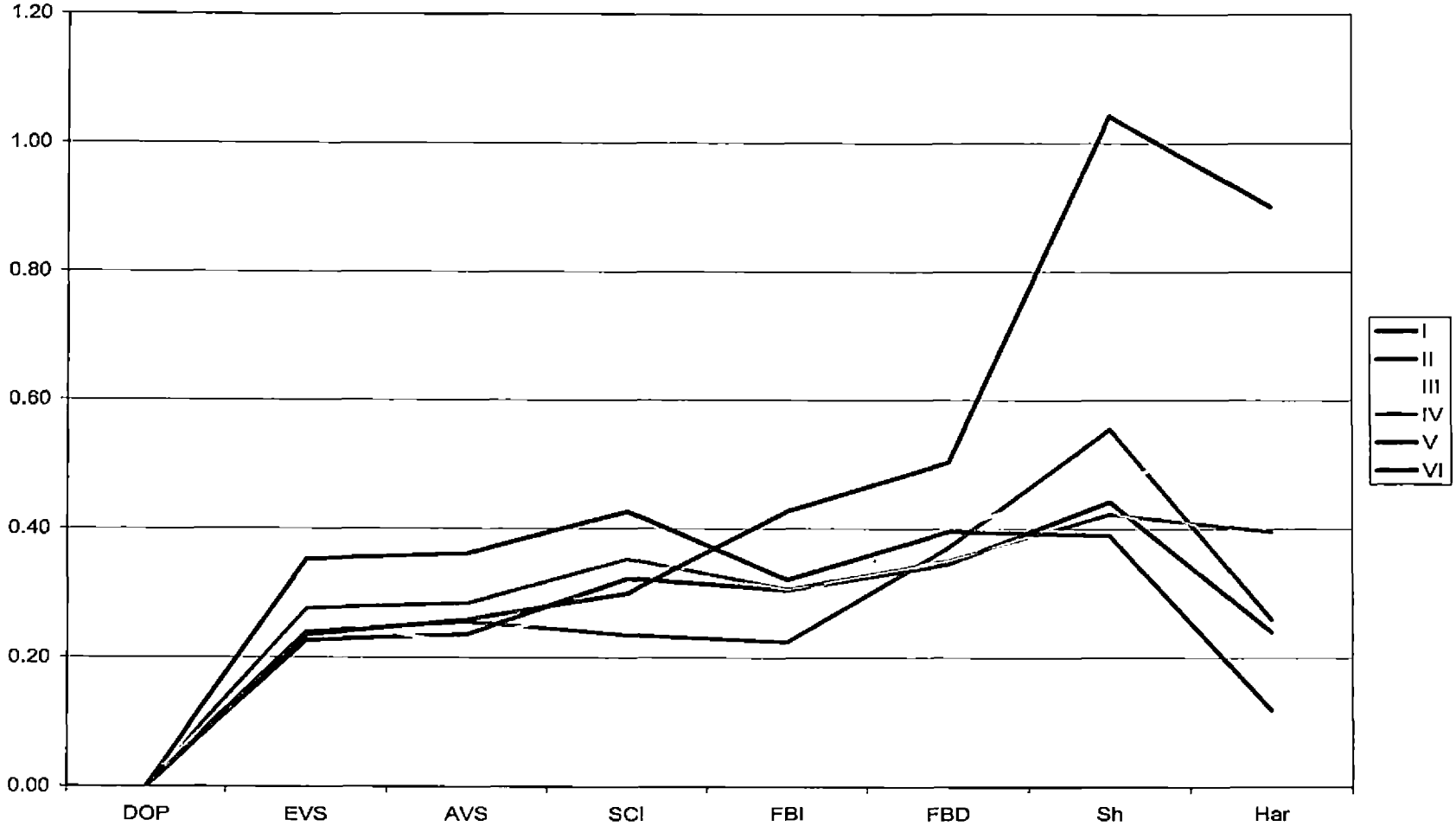


Fig 20. Specific Corm Weight – Secondary Corm

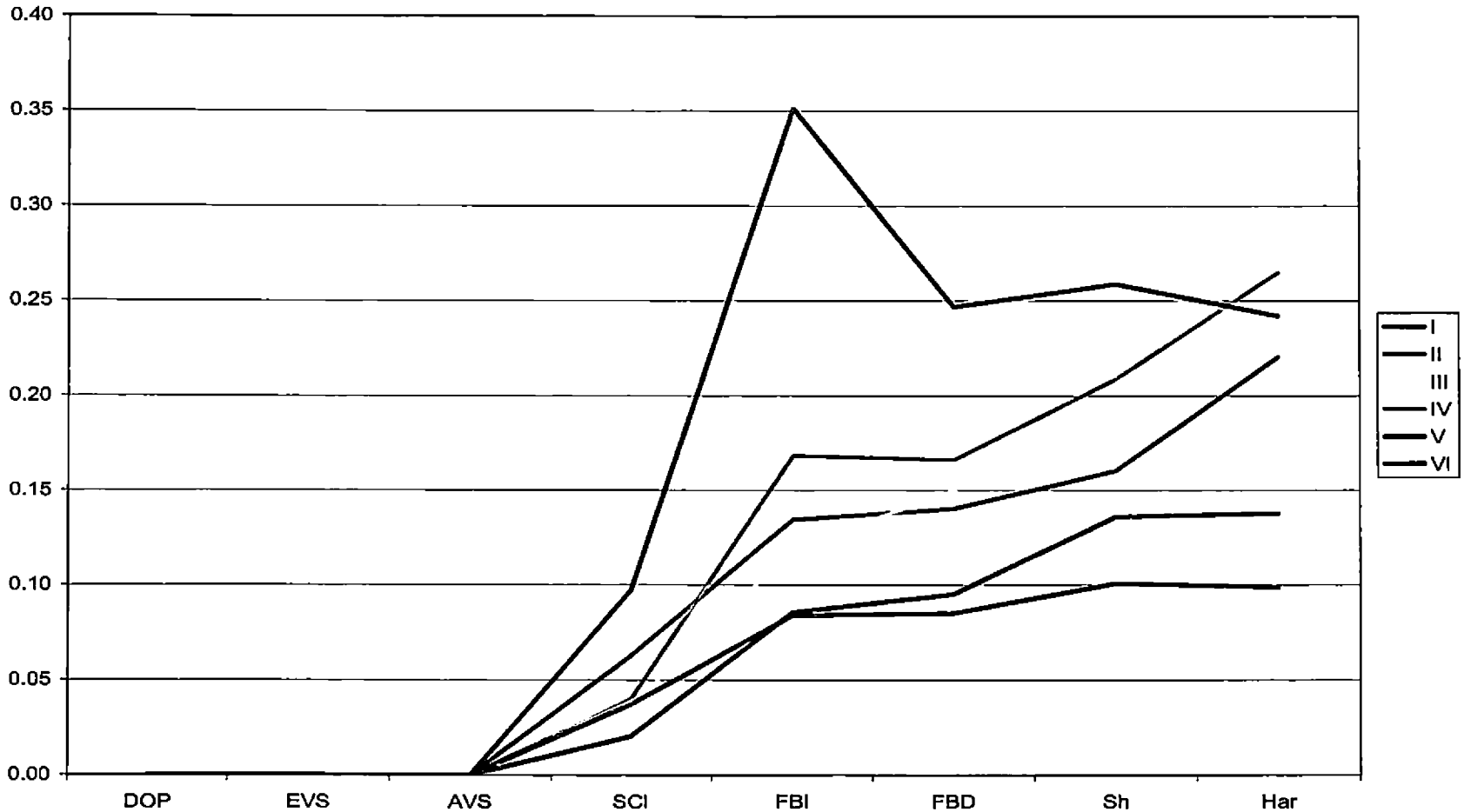


Fig 21. Specific Corm Weight – Whole Corm

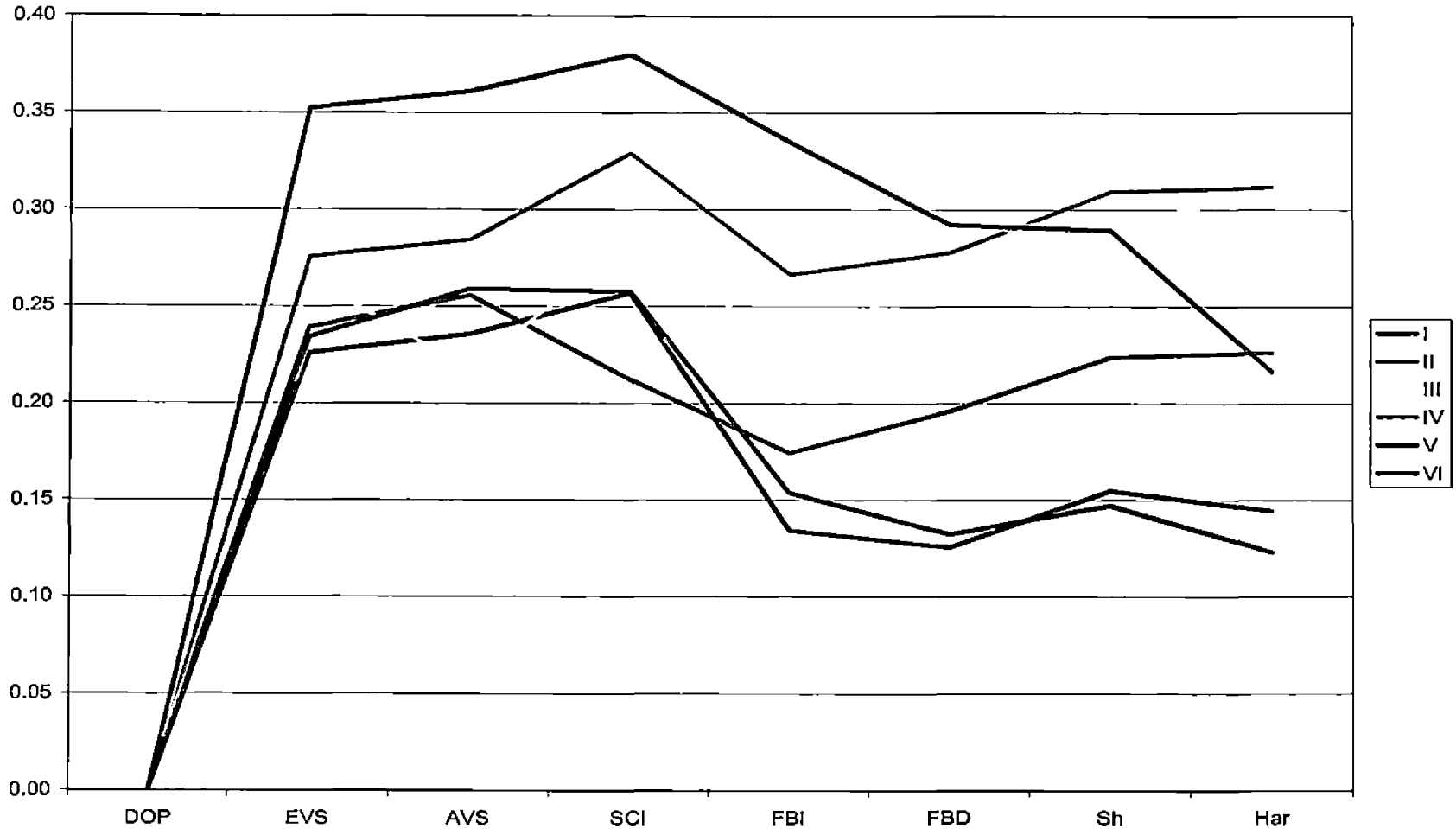
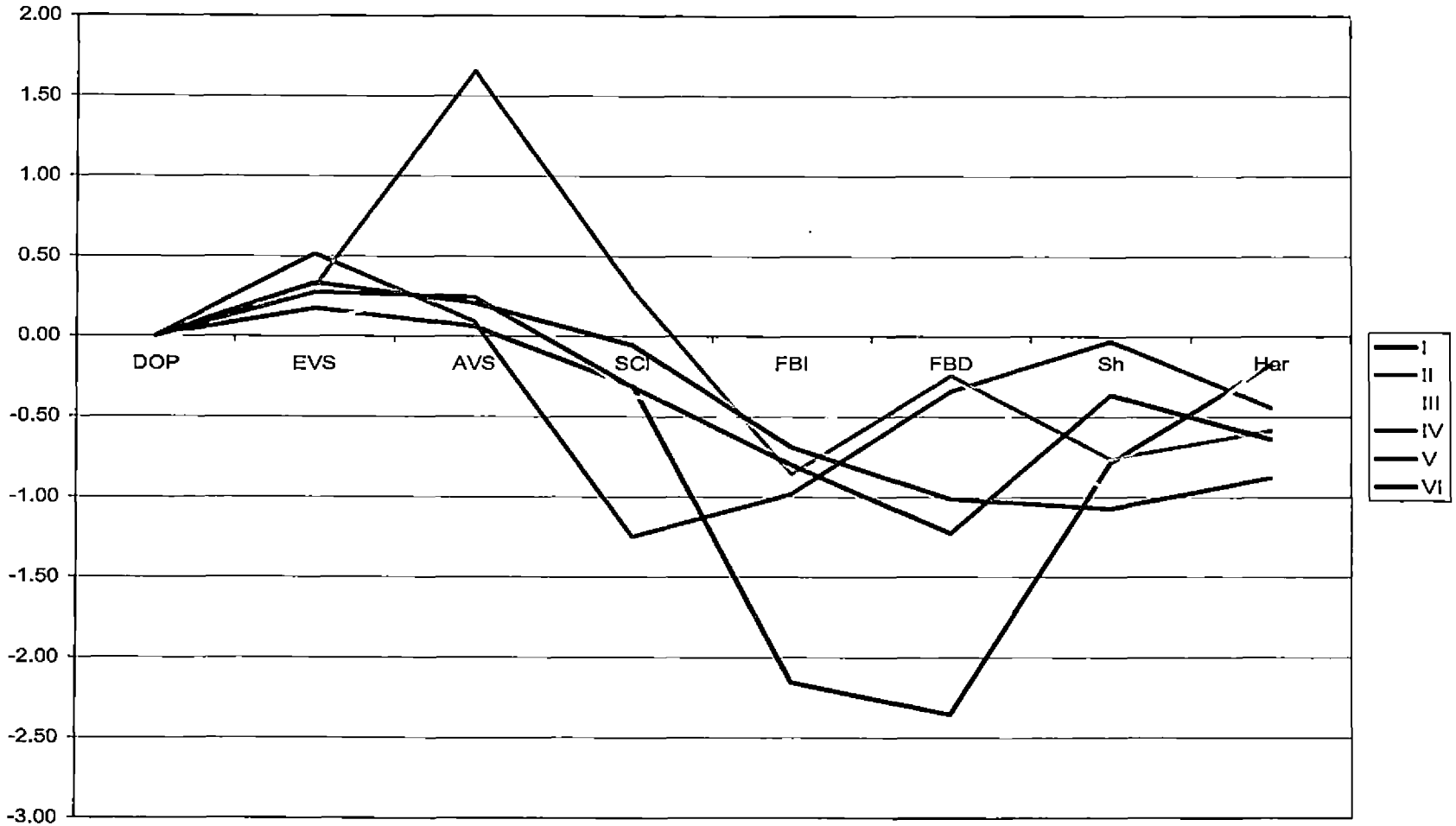


Fig 22. Absolute Growth Rate – Primary Corm



In the case of Secondary corm growth, the maximum AGR was recorded at FBD in August and October planting, at shooting in December, February and June plantings with not much difference in the December planting with FBD stage and FBI stage in April planting (fig 23).

In case of whole corm, AGR maximum values were observed at shooting stage in August and June planting, at FBD stage in October and December planting, at FBI stage in the case of April planting and at AVS in the case of February planting (fig 24).

4.1.3.7. Net Assimilation Ratio

The Net Assimilation Ratio (NAR) data is presented in tables 28, 29 and 30.

The NAR of the Primary corm shows almost the same trend for all the six crops. From SCI the NAR is negative except in February where Primary corm growth is observed upto SCI (fig 25).

In the case of Secondary corm maximum growth is observed at FBI and FBD. In the February, April and August plantings, negative values were observed at shooting (fig 26).

When the whole corm was considered, negative values were recorded at SCI and FBI in August; SCI, FBI, shooting and harvest in October; SCI and harvest in October; SCI, FBD and harvest in June; SCI, FBI, shooting and harvest in December (fig 27).

Table 28. Net Assimilation Ratio – Primary Corm

NAR - Primary Corm							
	EVS	AVS	SCI	FBI	FBD	Sh	Har
I	0.0004	9.14454E-06	-1.39911E-05	-4.1E-05	-3.7E-05	-1.3E-05	0
II	0.0021	1.62553E-05	-7.03548E-05	-2.7E-05	-5.7E-06	-5E-07	-1.2E-05
III	0.0015	0.00039051	-7.13272E-05	-3.5E-05	-7.8E-06	-3.1E-05	-6E-06
IV	0.0064	0.001154333	4.36415E-05	-6E-05	-1.1E-05	-2.9E-05	-2.9E-05
V	0.0041	0.000109172	-4.09676E-06	-1.8E-05	-2E-05	-2.5E-05	-2.7E-05
VI	0.0138	7.25397E-05	-8.87167E-06	-0.00001	-7.3E-06	-2.1E-06	-5.3E-06

Table 29. Net Assimilation Ratio – Secondary Corm

NAR - Secondary Corm							
	EVS	AVS	SCI	FBI	FBD	Sh	Har
I	0.0000	0	3.52E-06	3.89E-05	3.88E-05	3.54E-05	-1.5E-07
II	0.0000	0	7.27E-06	4.01E-05	4.27E-05	1.63E-05	1.19E-05
III	0.0000	0	9.72E-06	2.14E-05	2.97E-05	2.88E-05	2.39E-06
IV	0.0000	0	8.64E-06	7.45E-06	1.21E-05	-0.00014	0
V	0.0000	0	1.07E-05	3.15E-05	2.24E-05	1.87E-05	-5.1E-06
VI	0.0000	0	4.92E-06	0.00001	7.2E-06	8.43E-06	6.44E-09

Table 30. Absolute Growth Rate – Whole Corm

NAR - Whole Corm							
	EVS	AVS	SCI	FBI	FBD	Sh	Har
I	0.0004	9.14454E-06	-1.04729E-05	-2.5E-06	2.22E-06	2.25E-05	0
II	0.0021	1.62553E-05	-6.30837E-05	1.28E-05	3.7E-05	1.58E-05	-4.7E-07
III	0.0015	0.00039051	-6.16084E-05	-1.4E-05	2.2E-05	-2.6E-06	-3.6E-06
IV	0.0064	0.001154333	5.26224E-05	-2.8E-05	1.09E-05	-6.7E-06	-1.1E-05
V	0.0041	0.000109172	6.64781E-06	1.39E-05	2.57E-06	-6E-06	-3.2E-05
VI	0.0138	7.25397E-05	-3.95654E-06	0.00000	-7.3E-08	6.3E-06	-5.3E-06

Fig 23. Absolute Growth Rate – Secondary Corm

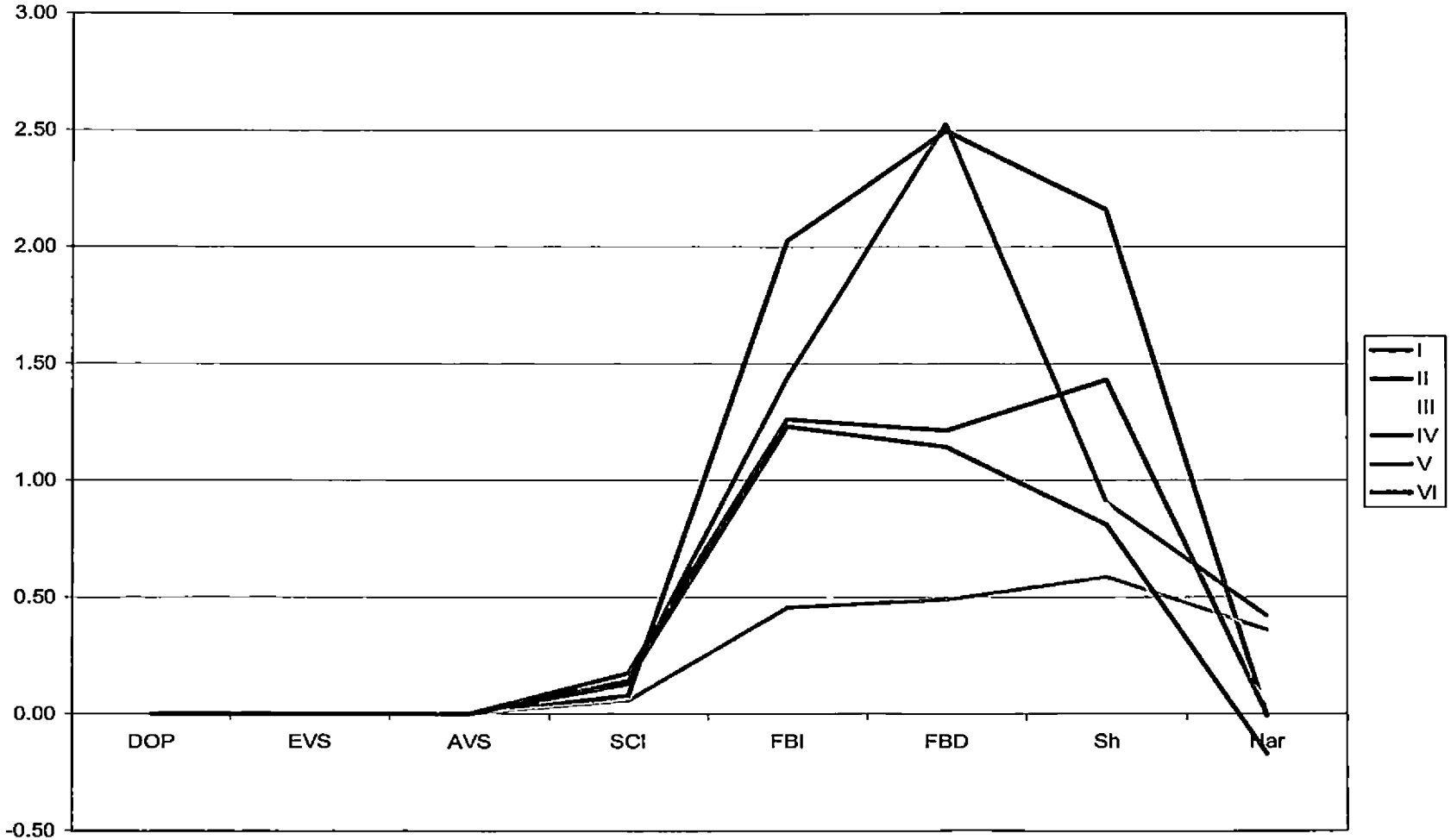


Fig 24. Absolute Growth Rate – Whole Corm

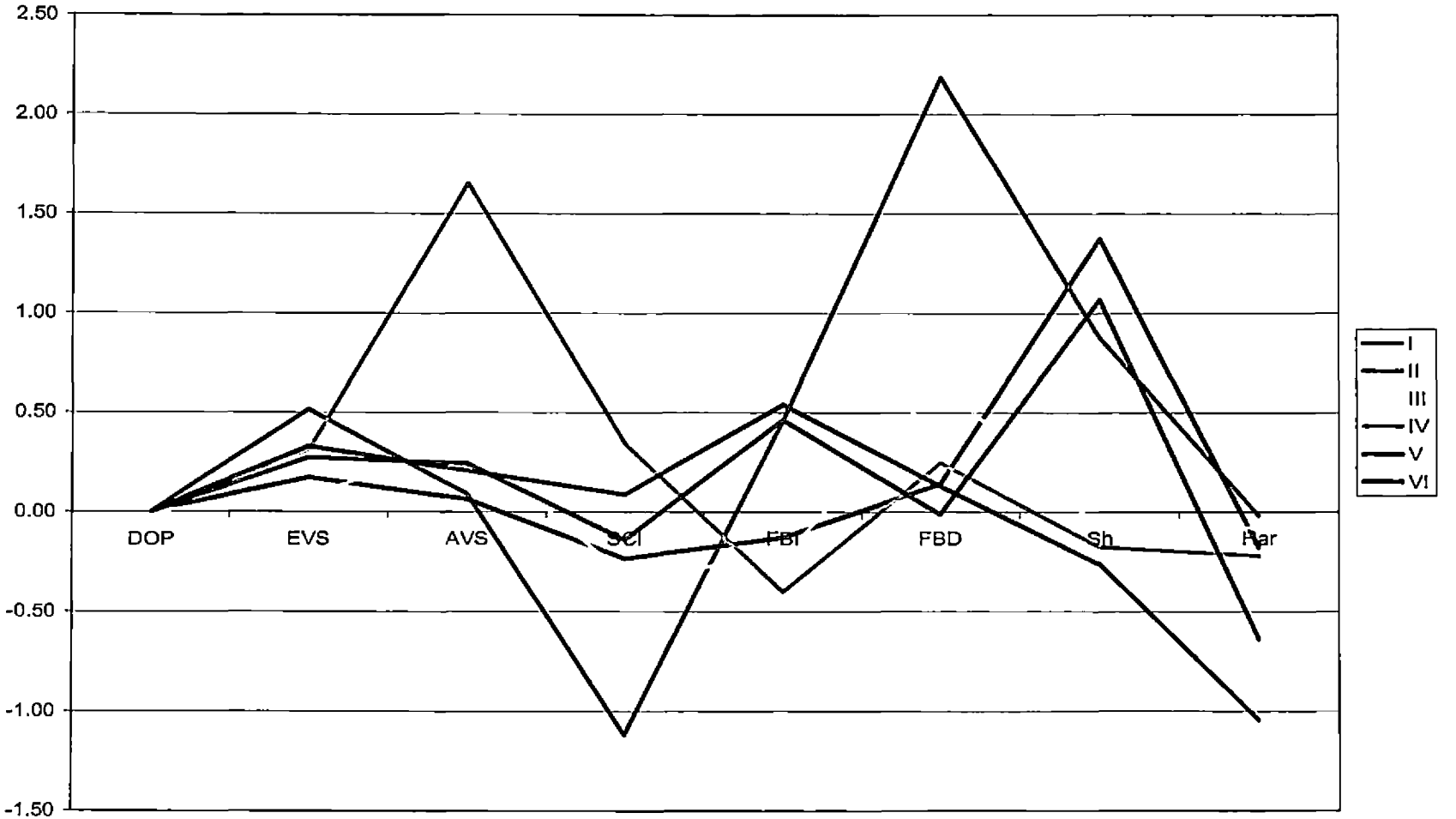


Fig 25. Net Assimilation Rate – Primary Corm

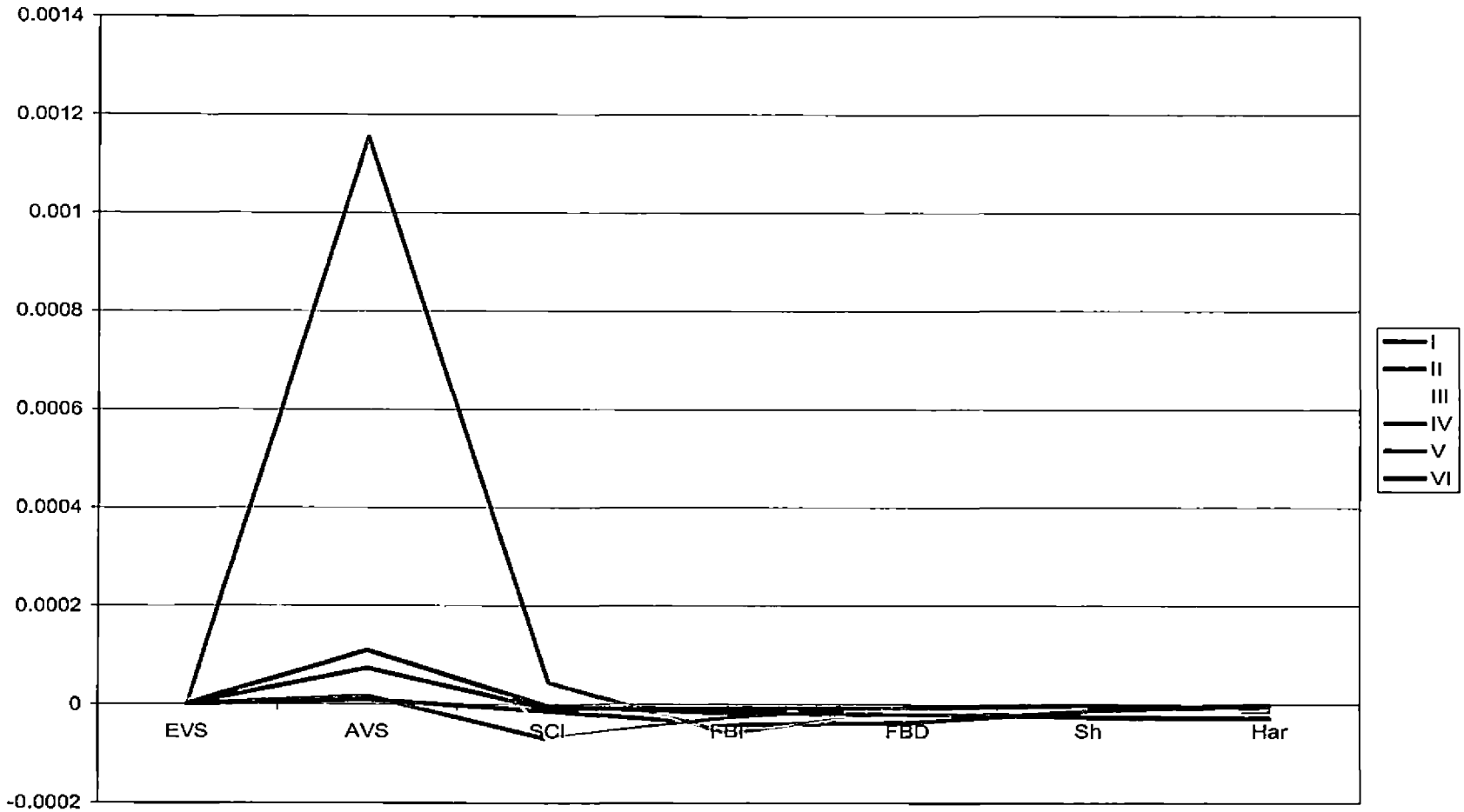


Fig 26. Net Assimilation Rate – Secondary Corm

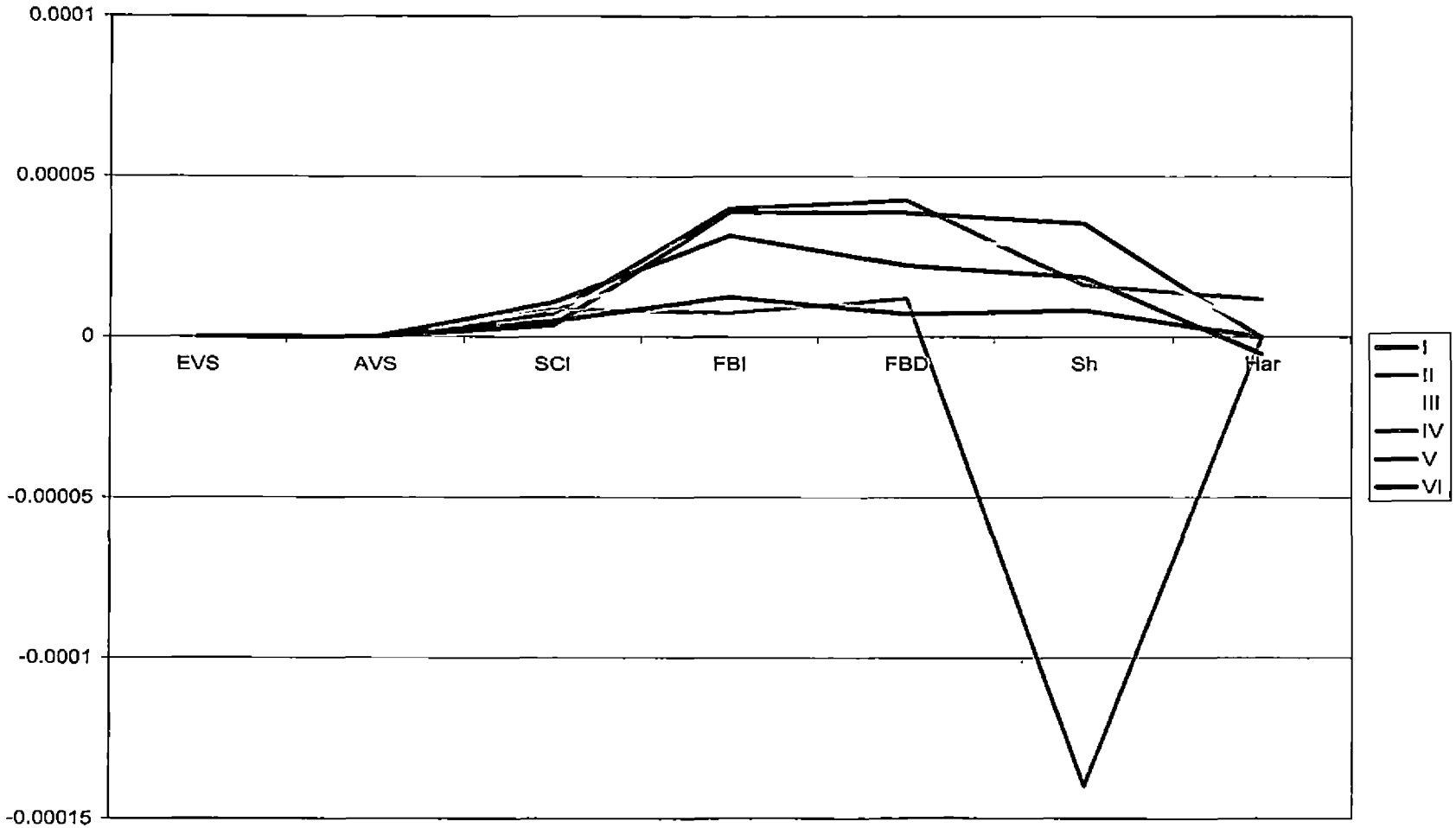
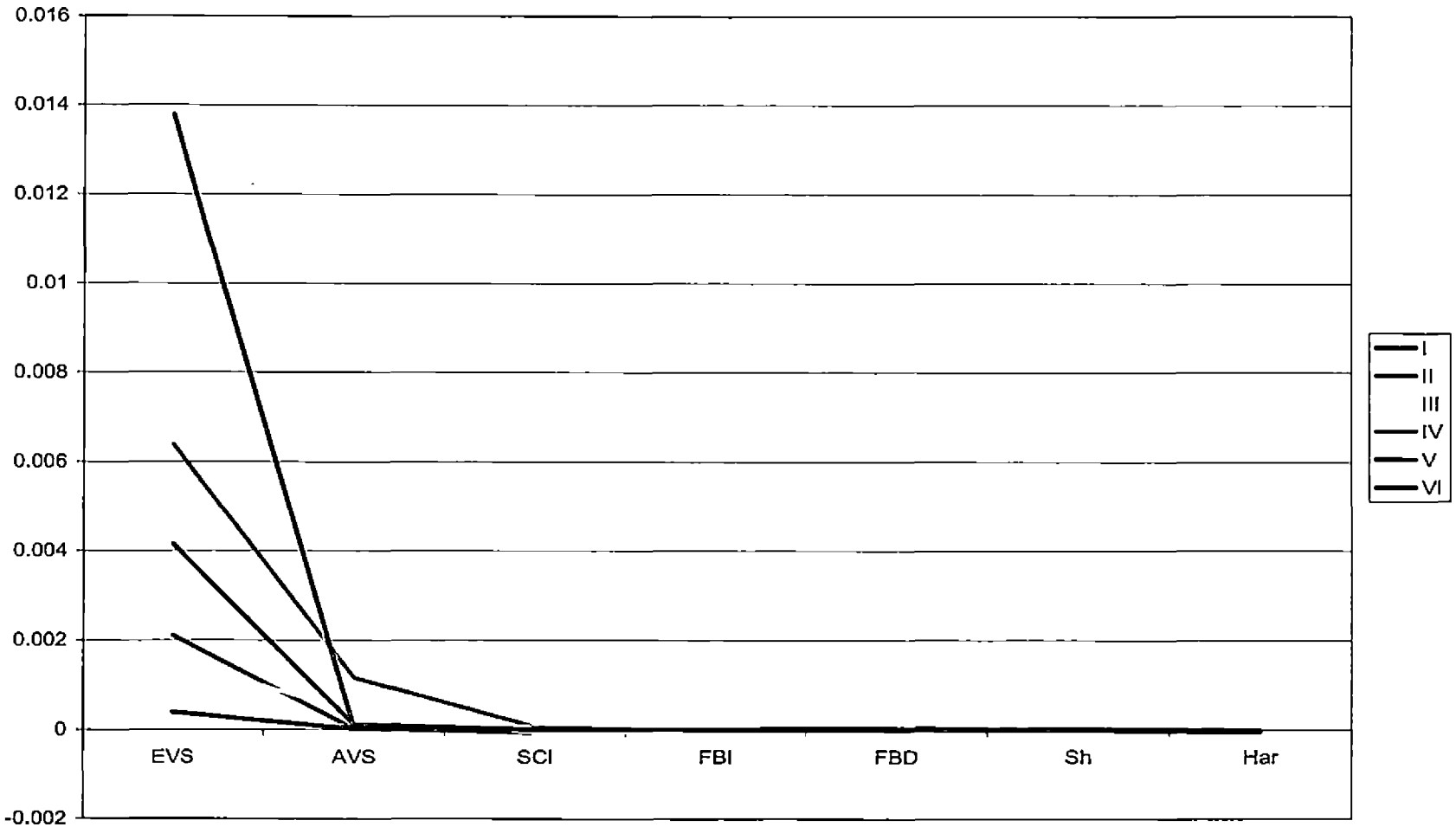


Fig 27. Net Assimilation Rate – Whole Corm



In the case of whole plant, at all stages, positive values were observed in June, August and April plantings with peak NAR values at EVS stage in all six crops. Negative values were recorded at shooting in February, from FBI onwards in October planting and at early and late two stages in December planting.

4.1.4 Heat Unit Requirements of Banana Plant

4.1.4.1 Base temperature studies

Studies to identify and standardize the base temperature at which growth starts in banana cv. Nendran and the effect of defined regimes of temperature were also taken up during this period. Differences were observed with age of leaf with older leaves showing distinct susceptibility to low temperatures. A comparison of the characters of the second fully opened leaf in all the temperature regimes under study revealed that the leaf lamina was most susceptible to low temperature. The petiole remained more inclined or showed a highly acute angle to the pseudostem upto 13^0C. On the contrary, at and above 14^0C, the petiole was less inclined nearing to 45^0. The leaf lamina gets unevenly distorted within 24 hours at temperatures of 10-12^0C, with characteristic yellowing and wilting. At 13^0C, lamina is partially distorted, partial yellowing and wilting was observed but at 4 days showed full wilting. Plants subjected to 14^0C not only survived but began growing. Further field studies also revealed that at low temperatures, leaf area was affected. This effect is dependent on the biotic phase of the crop and is more pronounced when the plant is in its active vegetative stage of growth.

Plate 38. TC plantlets kept at 10^0C

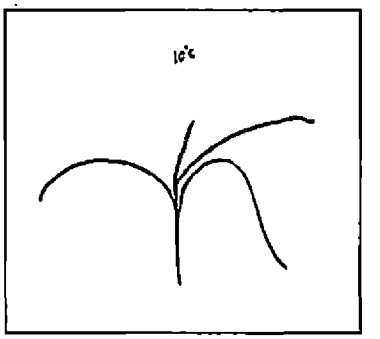


Fig 28. Leaf orientation at 10^0C

Plate 39. TC plantlets kept at 11^0C

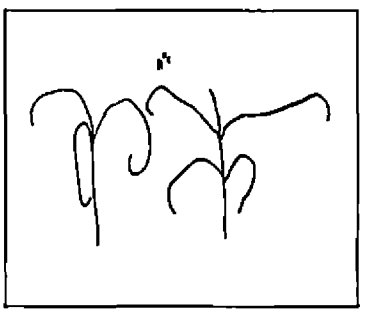


Fig 29. Leaf orientation at 11^0C

Plate 40. TC plantlets kept at 12^0C

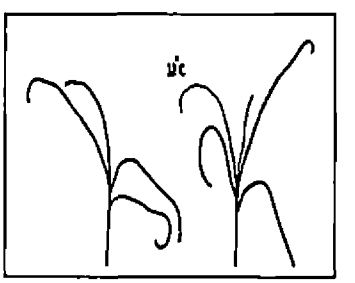


Fig 30. Leaf orientation at 12^0C

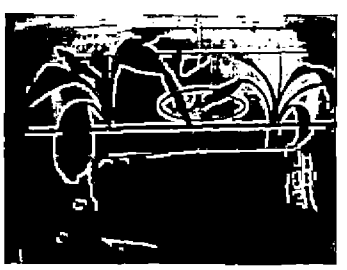


Plate 41. TC plantlets kept at 13^0C

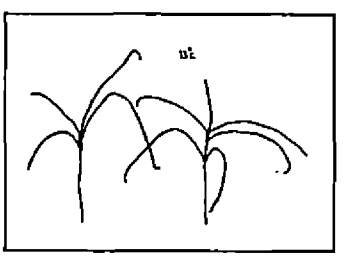


Fig 31. Leaf orientation at 13^0C

Plate 42. TC plantlets kept at 14^0C

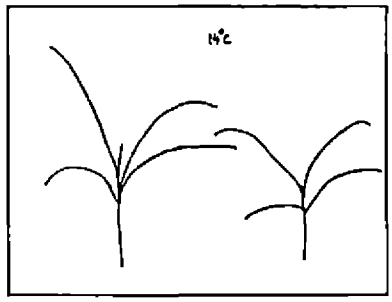


Fig 32. Leaf orientation at 14^0C

Plate 43. TC plantlets kept at 15^0C

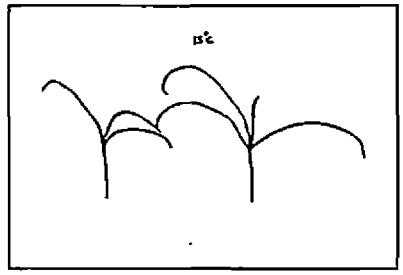


Fig 33. Leaf orientation at 15^0C

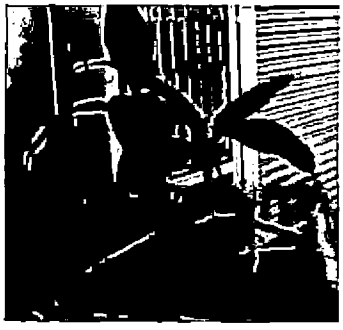


Plate 44. TC plantlets kept at 16^0C

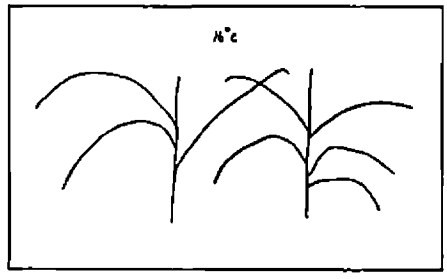


Fig 34. Leaf orientation at 16^0C

Plate 45. Growth of 14^0C maintained plants after 2 months of open conditions

4.1.4.2 Heat Unit Requirement for Various Physiological Phases

The photoperiodic responses in terms of GDD, photothermal units and heliothermal units from planting to various stages and from SCI to harvest are presented in tables 31 and 32.

In the six plantings, one of the major findings is that the planting to secondary corm initiation took a definite time, which is a factor to be reckoned with. The lowest value was 1168 degree days and the highest 1619 degree days in different plantings. Though calculations were made on all the three aspects, no definite trends were observed.

One of the major finding resulting from the study was on the ratio of the realized thermal units (ITU) to the potential thermal units (PTU). The ratios were in accordance with the realized yields. Hence it should be confirmed that it is the efficiency of the realized thermal units (realized *vs.* potential) that influences crop productivity and not just the realized or the potential that is important in influencing crop productivity. From the present study, it can be inferred that higher the values, higher is the realized yield and it goes a long way in explaining yields.

4.1.4.3 Duration of biotic phases with planting

The duration of biotic phases (Table 33) with planting revealed a very interesting trend. The EVS and AVS duration of the minimum and maximum crop duration planting were the same revealing that it is factors from SCI to harvest which will determine the duration.

Table 31. Photoperiodic responses in terms of GDD, PTU and ITU from planting to different stages

Planting No	Plt – 2^0 Corm			Plt – FBI			Plt – FBD		
	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU
I	1619.60	19701.56	8023.08	2249.76	27251.00	12257.60	2433.36	29277.95	13667.05
II	1612.81	19121.57	9070.81	2280.06	27123.19	14536.26	2502.81	29876.38	16353.33
III	1494.66	17741.81	11204.97	2792.01	34092.32	18369.56	3198.51	39357.55	19927.92
IV	1338.85	16388.80	10087.19	2489.46	31101.24	14808.47	2912.61	36391.45	16715.51
V	1614.56	20554.77	7525.06	3198.16	39841.83	14996.87	3615.56	44850.63	17728.83
VI	1168.16	14833.61	4684.27	2516.51	31091.53	11423.83	2930.56	36060.13	14251.52

Planting No	Plt – Shoot				Plt – Harv			
	GDD	PTU	ITU	ITU/PTU	GDD	PTU	ITU	ITU/PTU
I	2840.11	34059.8	16968.6	0.4982	2764.71	33751.6	18204.3	0.54
II	2954.26	35567	19153	0.5385	2552.55	31925.4	15163.8	0.47
III	3806.11	46987.8	23344.1	0.4968	3889.45	48259.7	20485.4	0.42
IV	3674.36	45708.6	20153.5	0.4409	3569.39	44018.5	17645.5	0.40
V	4020.34	49695.5	20449.2	0.4115	3495.03	42114.7	21519.4	0.51
VI	3342.29	40804.7	17076.2	0.4185	3312.53	39812	21435.9	0.54

Table 32. Photoperiodic responses in terms of GDD, PTU and ITU from SCI to different stages

Planting No	SCI - FBI			SCI - FBD			SCI - Shoot			SCI- Harvest			
	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU	ITU/PTU
I	630.16	7549.44	4234.52	813.76	9576.39	5643.97	1220.51	14358.2	8945.48	4384.31	53453.2	26227.3	0.491
II	667.25	8001.62	5465.45	890	10754.8	7282.52	1341.45	16445.4	10082.2	4165.36	51047	24234.6	0.475
III	1297.35	16350.5	7164.59	1703.85	21615.7	8722.95	2311.45	29246	12139.1	5384.11	66001.5	31690.4	0.480
IV	1150.61	14712.4	4721.28	1573.76	20002.7	6628.32	2335.51	29319.8	10066.3	4908.24	60407.3	27732.6	0.459
V	1583.6	19287.1	7471.81	2001	24295.9	10203.8	2405.78	29140.7	12924.2	5109.59	62669.5	29044.5	0.463
VI	1348.35	16257.9	6739.56	1762.4	21226.5	9567.25	2174.13	25971.1	12392	4480.69	54645.6	26120.2	0.478

Table 33. Duration of biotic phases with planting (days)

Planting No	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
I	46[a]	76[a]	120[a]	166[d]	180[d]	210[e]	322[e]
II	46[a]	76[a]	120[a]	166[d]	180[d]	210[e]	324[d]
III	30[b]	60[b]	106[b]	196[b]	226[b]	270[b]	400[a]
IV	30[b]	46[c]	90[c]	180[c]	210[c]	256[c]	350[c]
V	30[b]	60[b]	120[a]	226[a]	256[a]	286[a]	361[b]
VI	30[b]	60[b]	90[c]	180[c]	210[c]	240[d]	317[f]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

In the present study, the lowest duration to SCI and harvest was taken by June planting but considering from FBI to shooting, the least duration was in June and October planting. The trend of duration of the bunch from shooting to harvest in different plantings is presented in fig. 35. The maximum duration from shooting to harvest was in December planting and the least in April planting.

4.2. Anatomy, developmental physiology of the corm and basic study of root habits

4.2.1 Morphological characters

4.2.1.1 Plant height

The plant height followed a definite trend from planting to shooting (table 34, fig. 36) with large corms producing plants of maximum tall structure followed by the small corms and then medium size plants. From shooting onwards, the small sized corms produced plants of maximum height followed by the plants of large and medium size.

4.2.1.2 Collar girth

The plants from the large corm size were of maximum collar girth from the date of planting to harvest which was glaringly explicit (table 35, fig. 37). Except for the EVS the collar girth of small size corms were slightly higher than that of plants from medium size corms. At harvest the values were almost the same.

Table - 34 . Plant height (cm) at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	35.15[a]	50.70[a]	82.63[a]	169.12[a]	186.95[a]	197.95[a]	200.50[a]
Medium	16.80[b]	31.80[b]	55.35[c]	133.80[b]	169.75[b]	180.96[b]	182.50[b]
Small	19.97[b]	45.57[a]	64.70[b]	157.55[a]	174.69[ab]	209.80[a]	212.45[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table - 35. Collar Girth (cm) at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	4.83[a]	8.85[b]	22.90[a]	42.70[a]	52.80[a]	63.90[a]	60.52[a]
Medium	3.80[b]	6.83[c]	17.95[b]	39.71[b]	47.56[ab]	57.60[ab]	55.20[a]
Small	3.77[b]	15.30[a]	22.05[a]	40.63[ab]	48.02[b]	57.85[b]	55.86[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table - 36. Total Number of Leaves at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	2.50[a]	5.47[b]	8.27[b]	12.37[b]	12.73[a]	12.33[a]	6.53[a]
Medium	1.63[b]	5.47[b]	8.40[b]	12.53[b]	12.33[a]	10.83[c]	4.86[c]
Small	1.50[b]	9.07[a]	11.37[a]	12.97[a]	11.67[b]	11.40[b]	5.65[b]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig. 35. Duration of the bunch from shooting to harvest in the six bimonthly plantings

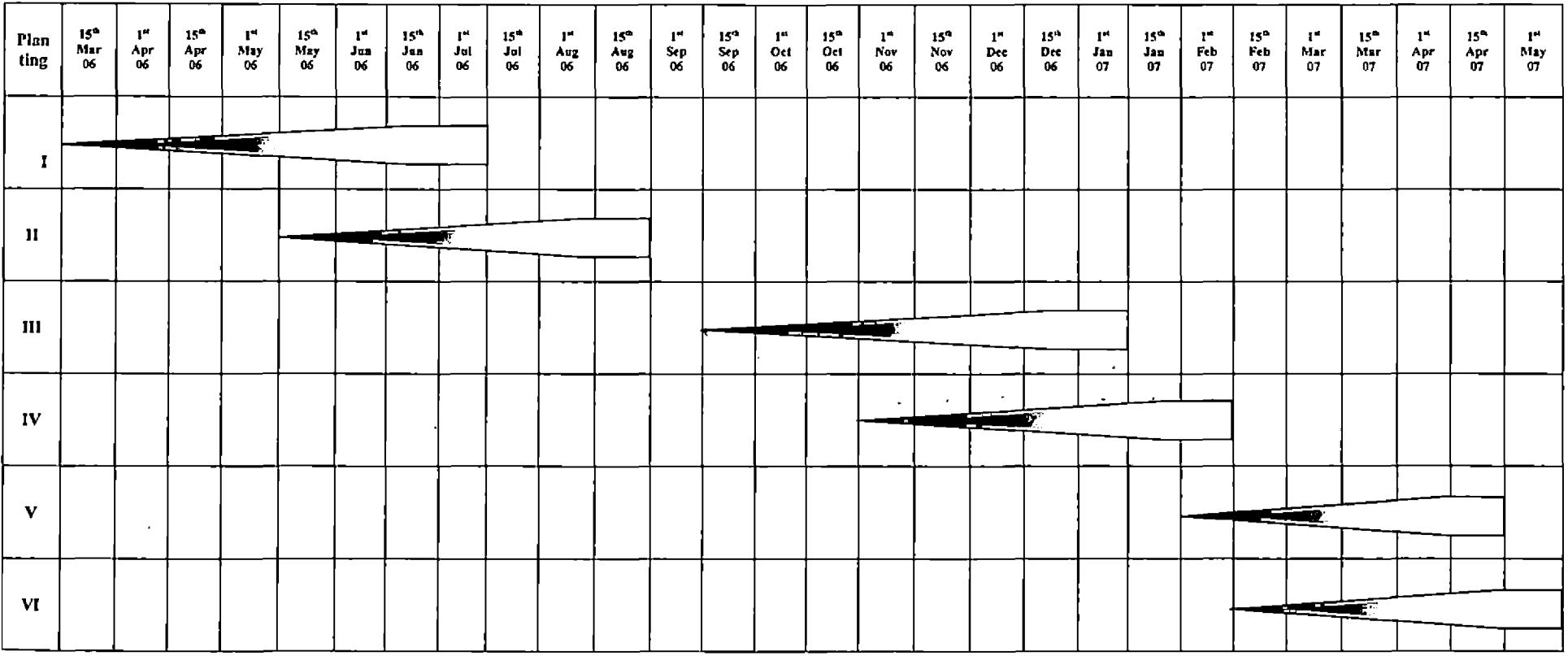


Fig 36. Plant height (cm) at different stages of corm size planting

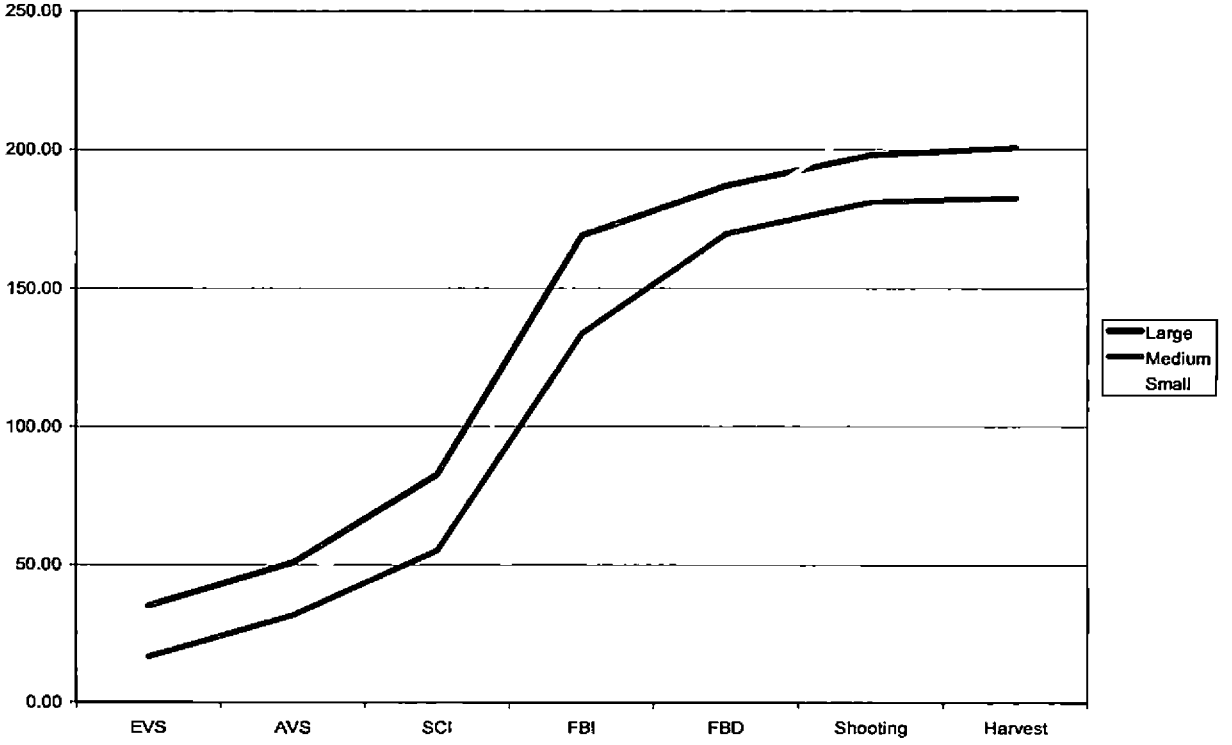
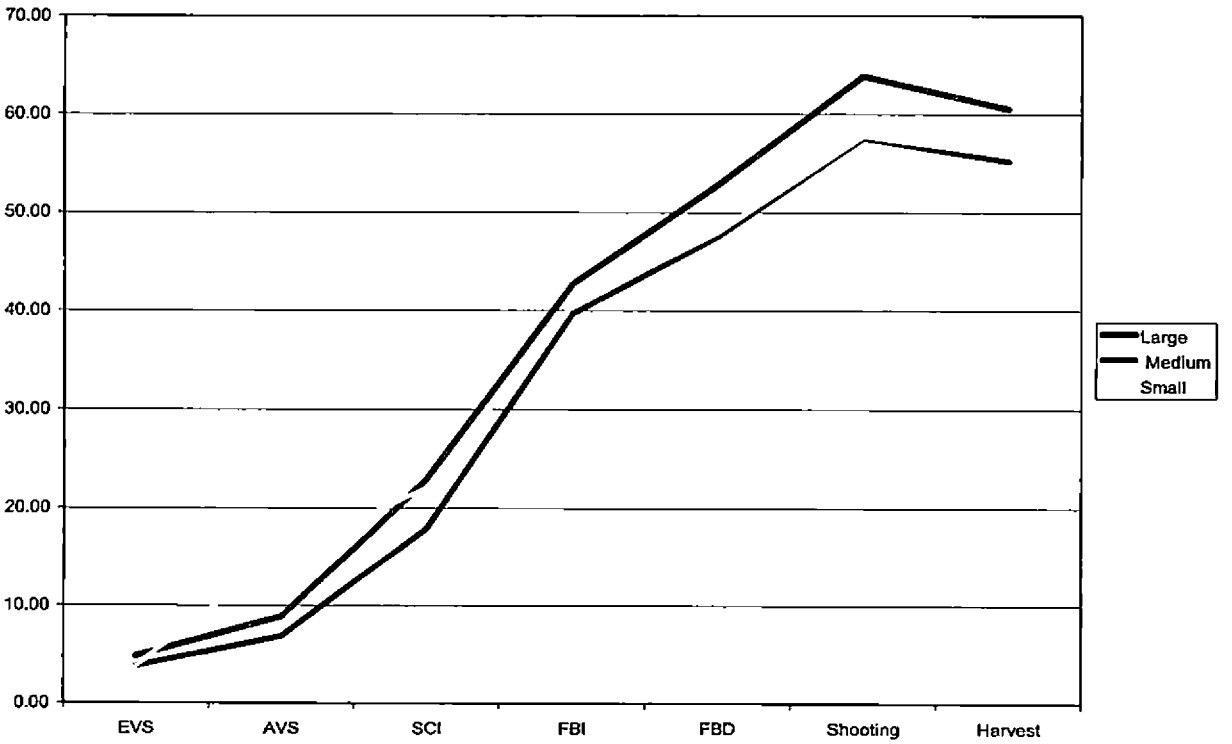


Fig 37. Collar girth (cm) at different stages of corm size planting



4.2.1.3 Total number of leaf retention at different stages

The total number of leaves retained on the plant followed another trend. In the initial EVS to FBI, the plants from the smallest corm size reported the highest values but thereafter it was from plants of maximum corm size (table 36, fig. 38).

4.2.1.4 New leaves produced at different biotic phases

From the EVS to FBI, maximum number of leaves was produced by corm of smallest size (table 37). From the FBD stage onwards, the intermediary corm reported more leaf production. At all the stages the leaves produced by large corm size was the least. The number of leaves produced is almost like a normal deviate curve but skewed towards FBI and FBD phases. The figures reveal the maximum or log phase of new leaf production is from SCI to FBI (fig. 39)

4.2.1.5 Leaf area

The leaf area of "D leaf" (diagnostic leaf) was the maximum in the early stages in large corm size (EVS to SCI). From FBI stage, it was the small corm size that gave maximum D leaf area (table 38a). The increase in leaf area follows a double sigmoid curve (fig. 40).

4.2.1.6 Canopy area

The canopy area was highest at EVS in maximum corm size plantings but from AVS to FBI, the small corm size planting produced maximum canopy area. At FBD, it

Table - 37. New leaves produced at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	2.90[a]	5.10[b]	7.90[c]	16.40[c]	21.03[c]	22.23[b]	0.00
Medium	1.60[b]	4.23[c]	8.97[b]	21.73[b]	26.53[a]	27.77[a]	0.00
Small	1.50[b]	6.43[a]	10.50[a]	23.47[a]	25.73[b]	27.03[a]	0.00

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table – 38a. D-Leaf area (cm^2) at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	185.69[a]	1259.35[a]	1607.68[a]	4733.09[b]	4881.27[b]	5819.54[a]	5819.54[a]
Medium	42.93[b]	657.88[c]	1007.64[b]	4845.44[b]	6252.72[a]	5961.86[a]	5961.86[a]
Small	34.14[b]	1078.32[b]	1216.74[b]	5996.52[a]	6259.17[a]	6085.49[a]	6085.49[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table – 38b. Canopy area (cm^2) at different stages of corm size plantings

	EVS	AVS	SCI	FBI	FBD	Shooting	Harvest
Large	464.21[a]	6884.43[b]	13290.15[a]	58532.49[b]	62154.82[c]	71774.35[a]	38001.61[a]
Medium	70.12[b]	3596.40[c]	8464.21[b]	60729.51[b]	77116.93[a]	64586.81[a]	28974.64[b]
Small	51.21[b]	9776.78[a]	13830.23[a]	77754.82[a]	73023.61[a]	69374.62[a]	34383.04[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 38. Total leaves produced at different stages of corm size planting

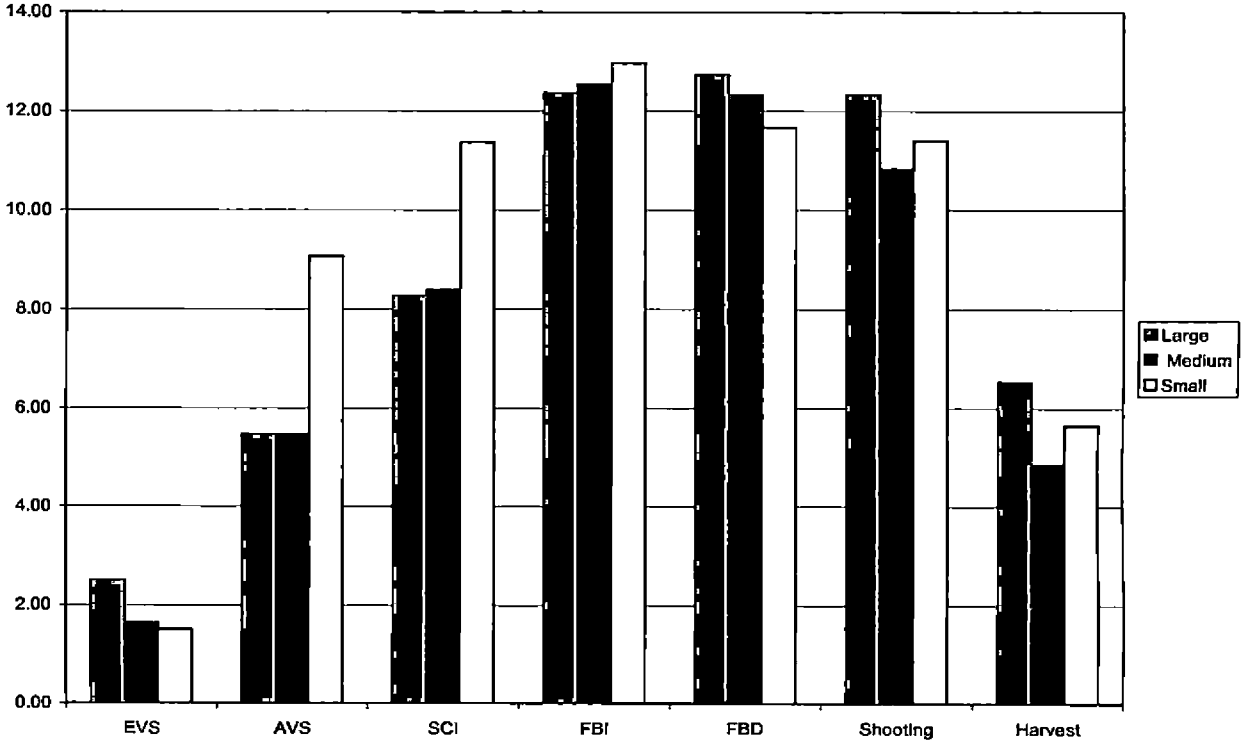


Fig 39. New leaves produced at different stages of corm size planting

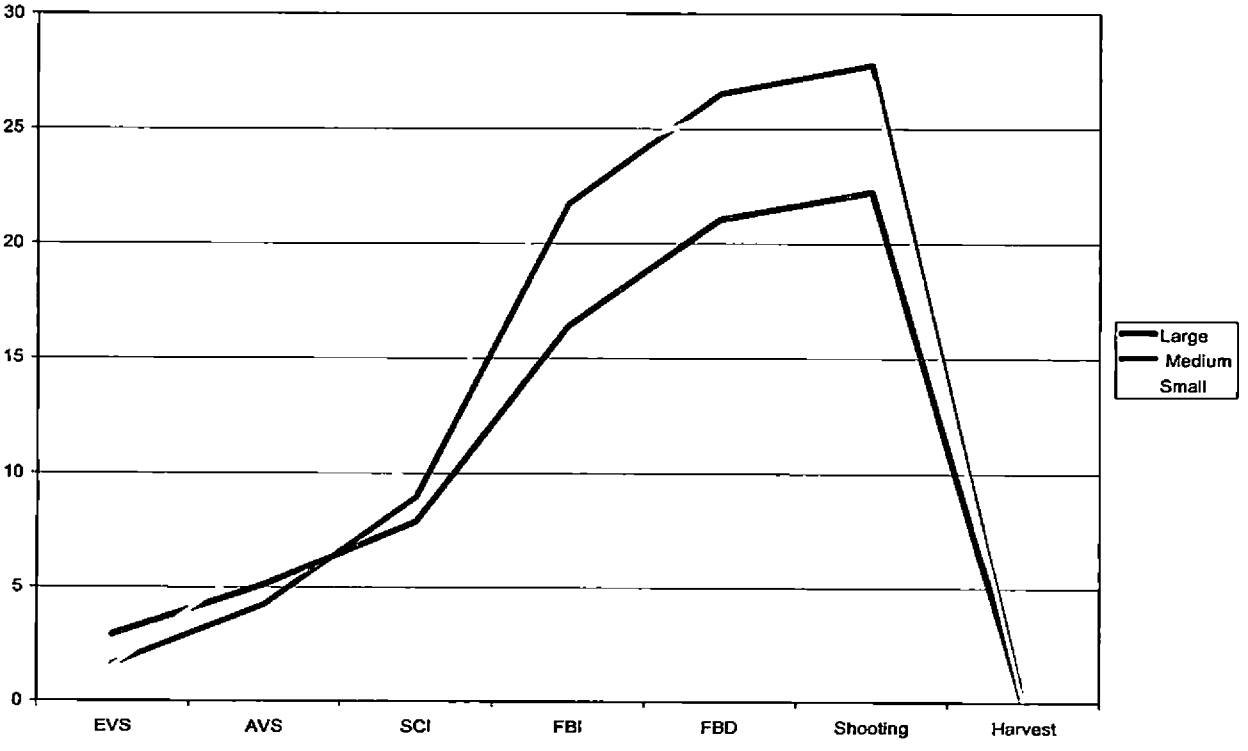


Fig 40. D-Leaf area (cm^2) at different stages of corm size planting

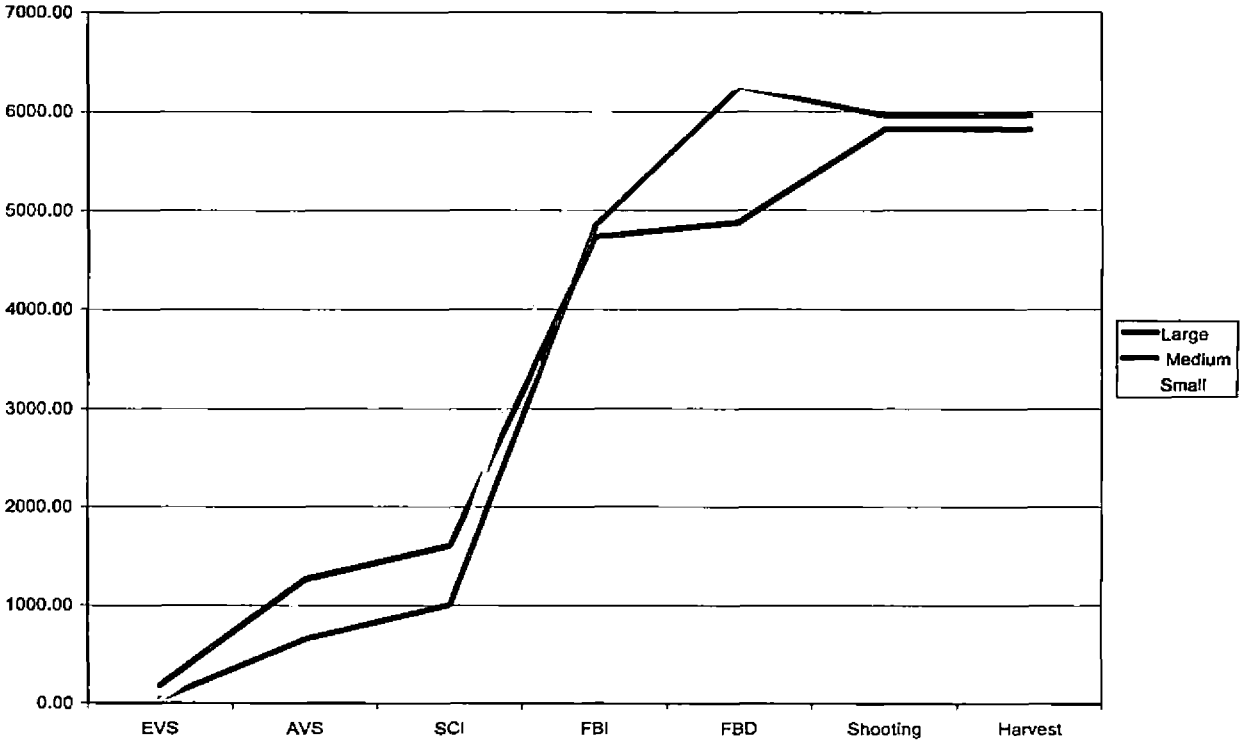
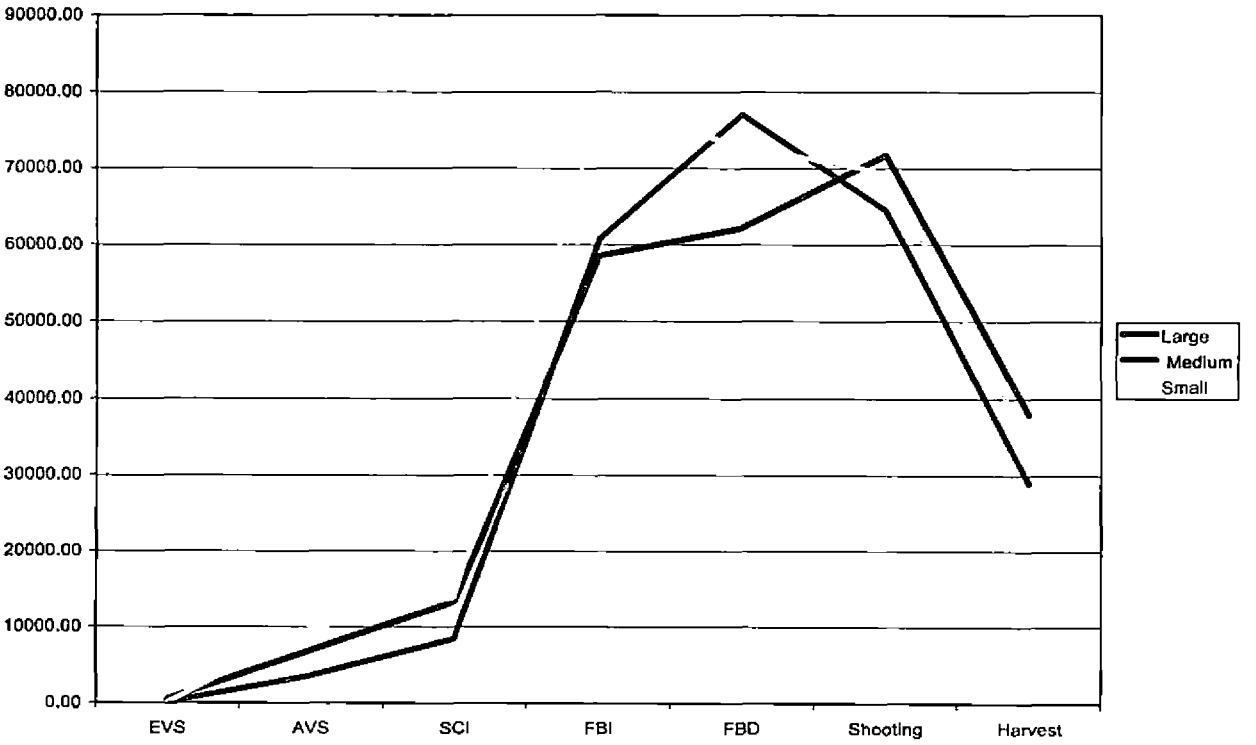


Fig 41. Canopy area (cm^2) at different stages of corm size planting



was the intermediary stage and at shooting and harvest it was the crop from maximum corm size that gave maximum canopy area (table 38b). This would probably explain the yield parameters. The increase in canopy area is closely a single sigmoid curve (fig. 41). Again it confirms that the maximum leaf area increases from SCI to FBI.

4.2.1.7 Root Characters

The root characters of the large, medium and small corm size plantings are represented in table 39.

4.2.1.7.1 Total number of roots produced

In the case of first flush of roots, the highest number was recorded in the large corm size followed by medium corm size and small corm size. A similar trend was observed in the second flush, third flush and the fourth flush. In the fifth flush, the maximum number was recorded in the large corm size whereas the small and medium sizes recorded same values.

4.2.1.7.2 Length of roots

The trend was similar as above in the case of first flush. In the case of the second flush, the large and medium registered almost the same length whereas the small corm size recorded the least. When it came to the third flush, values were almost equal in all the three corm sizes. In the fourth and fifth flushes, the maximum length recorded was in the increasing order of size of corms. A comparison between the various flushes revealed that the fourth flush followed by the second, in all the three cases gave the longest roots.

Table 39. Root characters of corm size plantings

Flush of Roots	1st flush			2nd flush			3rd flush			4th flush			5th flush		
Crops	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
Total no of roots	45	35	29	100	80	50	44	30	26	102	65	50	65	45	46
Max Length of roots	40.6	30	29.8	58.4	58.69	45.6	32.2	32.4	32	86.8	72.6	52	42.6	34.5	26
Time to reach max length	30	30	60	60	45	60	60	45	45	60	60	90	60	60	60
prox.dia	0.32	0.38	0.32	0.48	0.45	0.42	1.08	0.89	0.82	0.52	0.46	0.44	1.28	1.25	0.84
Mid dia	0.35	0.36	0.32	0.48	0.43	0.43	0.86	0.86	0.83	0.5	0.48	0.46	0.88	0.98	0.84
Apical dia	0.26	0.24	0.28	0.53	0.48	0.5	0.56	0.54	0.48	0.54	0.46	0.48	0.46	0.5	0.56
LAUZ	0	0	0	0	0	0	20	14.2	12.2	32.8	20.5	16.6	0	0	0
No.of branches	0	0	0	0	0	0	7.4	6.33	6.2	8.6	8	6	0	0	0
Av. Leng. of branched roots	0	0	0	0	0	0	8.07	7.25	8.56	27.75	25.2	12.08	0	0	0
root hairs per cm	0	14.5	10.8	0	0	0	0	0	0	10	18.5	12	34	35.5	28
RBZ	10.5	7.8	6.2	12.5	10.3	6	8.5	7	5.6	18.6	11.5	9.8	11.5	10.2	7.8
length of flush	45	45	60	105	75	90	105	75	60	135	135	150	105	90	90

4.2.1.7.3 Time taken to reach the maximum length

In the first flush the large and medium took a month's time whereas the small corm size took two month's time to reach maximum length. In the case of second flush, the large and small corm size took 60 days to reach maximum length whereas it was 45 days in medium corm size.

In the third flush, maximum length was attained in 60 days in large and 45 days in small and medium corm sizes. In the fourth flush, the maximum length was attained in 60 days in large and medium corm sizes and 90 days in small corm size. In the case of the fifth flush, maximum length was obtained in 60 days in all the three corm sizes.

4.2.1.7.4 Root thickness

The root thickness in the first flush was almost the same. Whereas in the second case, the large size corms showed higher values. The third flush higher values were observed again with size of corms. In the case of the fourth flush the largest corm size again recorded higher values and in all the three cases the values increased from the proximal diameter to the distal diameter.

In the fifth flush again the bigger size corm yielded roots of better thickness but the values decreased for the proximal to distal.

On the whole, the diameter of the fifth flush of roots and the third flush of roots could be considered as thick roots.

4.2.1.7.5 Length of Apical Unbranched Zone (LAUZ)

The LAUZ of the first and second flush was zero as it was unbranched. On the contrary, maximum LAUZ increased with increasing corm size in the third and fourth flush. Again in the fifth flush, the roots were unbranched.

4.2.1.7.6 Number of root branches

The number of root branches in the first and second flushes was zero in all the three cases. In the third and fourth flush, the number of branches increased with size of the corms. In the fifth flush, the roots were unbranched in all the three cases.

4.2.1.7.7 Average length of branches

The average length of root branches was the highest in largest corm size in the case of third flush. Whereas in the fourth flush, it was the maximum branched. The length of branches were conspicuously higher in large and medium corms.

4.2.1.7.8 Root hairs per centimeter

The second and third flush of roots showed no root hairs at all. In the first flush, the root hair per cm length was almost the same. In the fourth and fifth flush, the medium sized corms showed the highest density of root hairs. A comparison between

flushes revealed that the maximum root hair density was in the fifth flush, which was a characteristic feature of the flush.

4.2.1.7.9 Length of the flush

The large and medium sized corms took 45 days for the completion of the first flush. Whereas it took another fortnight more in the case of the small size. In the case of the second flush, the large corm size continued upto 105 days, the small upto 90 days and the medium upto 75 days. The trend and duration was similar in the third flush but the small corms took only 60 days. In the fourth flush, comparatively the longest of the flushes, took 135 days in the large and medium, whereas it took 150 days in the case of small corm size. The fifth flush took 105 days in the case of the large corm size. But in the medium and large, took only 90 days' duration for completion of the flush.

4.2.2 Yield components

4.2.2.1 Bunch Yield

The bunch yield followed a definite trend with the large corm size giving highest yields. The bunch superiority was in the increasing order of planting corm size (table 40).

4.2.2.2 Number of hands

The number of hands was again a reflection of planting corm size with larger corms yielding more number of hands.

Table 40. Bunch Characters of corm size plantings

Planting No.	Days to Harvest	Bunch Wt.	No. of Hands	No. of fingers	D-finger wt.		Days to Ripen	Shelf Life	Length (cm)	Girth (cm)	Curvature Index	Pedicel Length	Pedicel Index	
					Green	Ripe							Prox	Distal
Small	301.77[a]	5.83[b]	4.63[c]	39.63[b]	141.50[a]	112.83[b]	16.27[a]	5.27[b]	17.90[a]	9.08[c]	499.67[b]	3.93[a]	2.66[a]	2.51[a]
Medium	276.00[b]	6.11[b]	5.07[b]	40.43[b]	147.17[a]	125.83[a]	20.30[a]	3.27[c]	18.17[a]	10.29[b]	541.14[a]	3.23[b]	2.65[a]	2.46[a]
Large	259.00[c]	7.08[a]	5.40[a]	48.87[a]	143.83[a]	123.00[a]	20.10[a]	9.40[a]	18.25[a]	12.08[a]	546.38[a]	3.33[b]	2.67[a]	2.51[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

4.2.2.3 Number of fingers

The number of fingers was again a reflection of the graded size of planted corm size with maximum being produced in largest corm size.

4.2.2.4 Length and girth of fingers

The length and girth of fingers were the maximum in large corm size planting and the gradation was with the size of planted corms.

4.2.2.5 Curvature index

The index was again highest in large corm size planting in the graded order revealing the maximum straight fingers were produced when corm size was big.

4.2.2.6 Pedicel index

The pedicel index was highest in large corm size followed by the smallest corm size and the least in intermediary corm size.

4.2.3 Dry weight

4.2.3.1 Primary corm

Irrespective of the corm size, a general trend was observed wherein there was an initial increase in the weight of the planted corm which gradually declines with the development of various other physiological phases. Though it was observed to senesce, the central part of the primary corm remained live to the time of harvest.

Table 41. Time phase studies on corm growth and development of corm size plantings

Large	Total Leaves		D Leaf		Boot Leaf		Petiole		Pseudostem		Pri corm		Sec corm		Roots		Bunch		Total	
	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt
EVS	350.00	27.35	80.00	7.35	0.00	0.00	110.00	5.65	1400.00	14.51	3400.00	580.71	0.00	0.00	200.00	29.88	0.00	0.00	5540.00	665.45
AVS	1120.00	86.15	100.00	8.50	0.00	0.00	250.00	13.50	2500.00	29.67	3420.00	582.23	0.00	0.00	280.00	33.21	0.00	0.00	7670.00	753.26
SCI	1440.00	111.62	180.00	12.25	0.00	0.00	350.00	18.50	4300.00	70.50	3320.00	576.85	120.00	8.88	450.00	81.54	0.00	0.00	10160.00	880.14
FBI	3250.00	250.55	500.00	68.31	0.00	0.00	750.00	50.24	9280.00	159.88	2290.00	305.22	1800.00	155.20	1250.00	153.80	0.00	0.00	19120.00	1143.20
FBD	4150.00	315.67	540.00	70.56	0.00	0.00	880.00	72.68	10300.00	182.65	1820.00	268.45	2120.00	195.21	1380.00	182.49	0.00	0.00	21190.00	1287.71
Shooting	4600.00	343.84	550.00	72.85	140.00	20.57	1280.00	98.25	11800.00	267.46	1250.00	222.10	2400.00	228.50	1420.00	201.25	2500.00	220.00	25940.00	1674.82
Harvest	3200.00	236.90	570.00	71.23	150.00	21.69	860.00	70.25	11600.00	235.65	420.00	90.61	2350.00	220.50	950.00	83.24	7800.00	950.00	27900.00	1980.07

Medium	Total Leaves		D Leaf		Boot Leaf		Petiole		Pseudostem		Pri corm		Sec corm		Roots		Bunch		Total	
	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt
EVS	300.00	22.44	60.00	5.51	0.00	0.00	80.00	4.11	1100.00	11.40	2300.00	392.83	0.00	0.00	150.00	22.41	0.00	0.00	3990.00	458.70
AVS	880.00	66.66	80.00	6.80	0.00	0.00	110.00	5.94	1500.00	17.80	2320.00	394.96	0.00	0.00	250.00	29.65	0.00	0.00	5140.00	521.82
SCI	1200.00	93.01	140.00	9.52	0.00	0.00	240.00	12.69	3300.00	54.10	2300.00	399.63	80.00	5.92	350.00	63.42	0.00	0.00	7610.00	638.29
FBI	2950.00	221.59	460.00	62.12	0.00	0.00	650.00	43.54	8200.00	141.27	1750.00	233.25	1250.00	107.78	1000.00	123.04	0.00	0.00	16260.00	932.59
FBD	3250.00	240.93	490.00	64.90	0.00	0.00	1120.00	85.97	9500.00	215.33	1050.00	186.56	2000.00	190.00	1200.00	170.07	1750.00	154.00	20360.00	1307.76
Shooting	3300.00	249.87	520.00	69.12	120.00	15.60	1200.00	91.80	10150.00	209.26	750.00	145.92	2250.00	212.69	1280.00	170.35	2000.00	300.00	21570.00	1464.61
Harvest	2200.00	168.86	260.00	32.50	120.00	16.25	500.00	50.84	10260.00	208.43	350.00	80.51	2175.00	201.32	800.00	75.15	6500.00	821.67	23165.00	1655.53

Small	Total Leaves		D Leaf		Boot Leaf		Petiole		Pseudostem		Pri corm		Sec corm		Roots		Bunch		Total	
	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt	Wet wt	Dry wt
EVS	250.00	18.80	80.00	8.65	0.00	0.00	40.00	1.50	500.00	18.50	1500.00	242.35	0.00	0.00	120.00	49.89	0.00	0.00	2490.00	339.69
AVS	450.00	34.40	120.00	10.55	0.00	0.00	100.00	5.50	750.00	26.83	1580.00	254.84	0.00	0.00	150.00	55.78	0.00	0.00	3150.00	387.90
SCI	1250.00	96.30	160.00	12.23	0.00	0.00	260.00	16.71	2720.00	64.19	1500.00	244.44	550.00	21.26	230.00	67.68	0.00	0.00	6670.00	522.82
FBI	2150.00	158.38	350.00	40.61	0.00	0.00	820.00	54.50	8800.00	163.31	530.00	95.52	2250.00	123.81	600.00	121.00	0.00	0.00	15500.00	757.13
FBD	2250.00	170.36	350.00	48.56	0.00	0.00	900.00	63.80	10020.00	291.35	500.00	86.35	2500.00	128.87	800.00	184.73	0.00	0.00	17320.00	974.02
Shooting	2550.00	189.86	380.00	53.85	80.00	9.87	980.00	71.50	10750.00	306.98	400.00	79.55	2750.00	135.96	1000.00	200.80	1400.00	123.5	20290.00	1171.87
Harvest	1450.00	102.15	250.00	29.33	150.00	16.98	300.00	31.50	11350.00	347.25	100.00	39.21	2650.00	112.18	850.00	192.84	5300.00	707.56	22400.00	1579.00

4.2.3.2 Secondary corm

In the case of secondary corm dry weight also, it was more or less influenced by weight of planting material and followed the same trend as observed in the experiment on bimonthly plantings (experiment-1).

4.2.3.3 Root weight

The dry weight of roots were also a reflection of corm size at planting to FBI but from FBD the smallest size corm planting produced maximum root weights.

4.2.3.4 Shoot dry weight

The total leaf dry weight, D leaf and petiole, boot leaf, bunch weight and total dry weight followed a same trend in accordance with size of planting with maximum corm size yielding maximum dry weight (table 41).

The only difference observed was in the case of pseudostem where the crops from least corm size yielded maximum pseudostem dry weights.

4.2.4 Growth analysis

The incremental values between the successive biotic phases of the plants from large, medium and small size suckers are given below.

4.2.4.1 Corm Growth Rate

The Corm Growth Rate (CGR) of the primary corm showed increments upto active vegetative stage in large and small corm size and upto SCI in medium corm size. Thereafter the deterioration resulted in negative values. Growth rate of corm was the maximum in small corm size, followed by medium and large corm size (table 42 and fig. 42).

On the contrary, the secondary corm growth rate was in tune with the corm size, the largest showing maximum corm size. In all the corm size cases, at harvest negative values were recorded. The large corm size showed maximum growth rate at shooting, in medium it was FBD and in small it was at FBI (table 43 and fig. 43).

In case of whole corm (table 44 and fig. 44), growth rate was noticed in all cases upto SCI, with the least in large corm size and both others registering same values. Maximum whole corm growth rate was at FBD in large and medium whereas in small it was at SCI.

4.2.4.2 Specific Corm Area

The Specific Corm Area (SCA) was the maximum at AVS in all the three stages (table 45-47 and fig. 45-47). On the contrary, SCA of the secondary corm was the maximum in SCI for large and medium corm size and at harvest for the small corm size planting. In both large and small corm size, there was a reduction followed by an increase at harvest whereas in small corm size an upward measure was observed.

Table 42. Corm Growth Rate – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.01	0.02	-0.04	-1.13	-0.66	-0.72	-0.35
M	0.00	0.02	0.03	0.04	-0.69	-0.39	-0.73	-0.17
S	0.00	0.02	0.07	-0.09	-0.49	-0.16	-0.06	-0.11

Table 43. Corm Growth Rate – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.00	0.00	0.07	0.61	0.71	0.52	-0.02
M	0.00	0.00	0.00	0.05	0.42	0.69	0.41	-0.03
S	0.00	0.00	0.00	0.18	0.34	0.09	0.06	-0.06

Table 44. Corm Growth Rate – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.01	0.02	0.03	-0.52	0.06	-0.20	-0.37
M	0.00	0.02	0.03	0.09	-0.27	0.30	-0.32	0.00
S	0.00	0.02	0.07	0.09	-0.15	-0.07	0.00	-0.17

Fig 42. Corm Growth Rate – Primary Corm

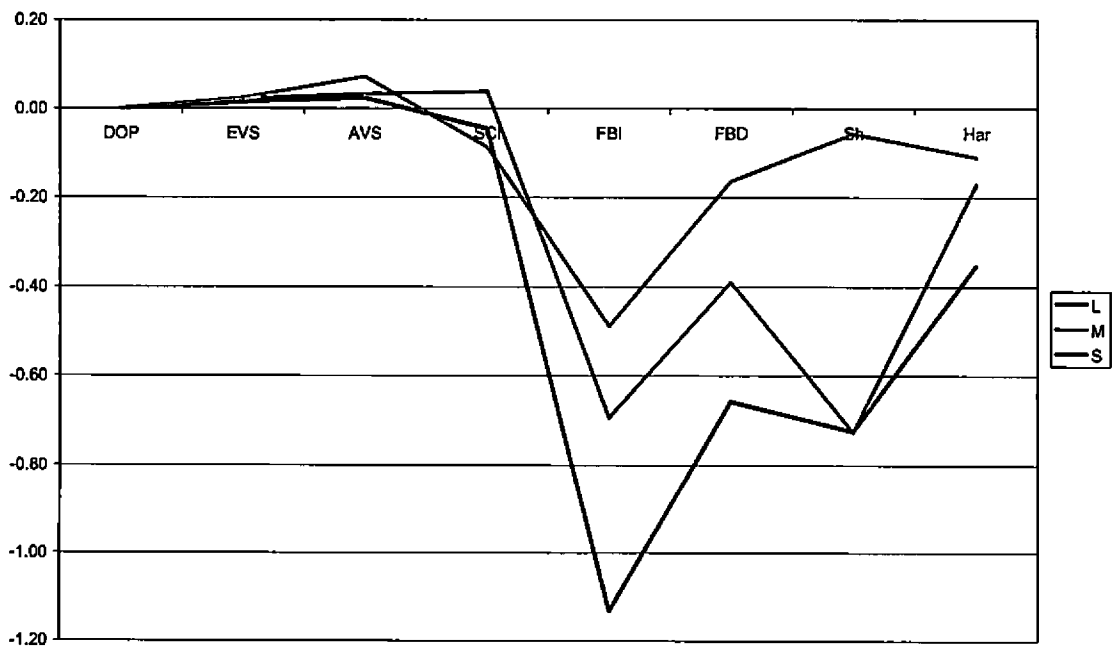


Fig 43. Corm Growth Rate – Secondary Corm

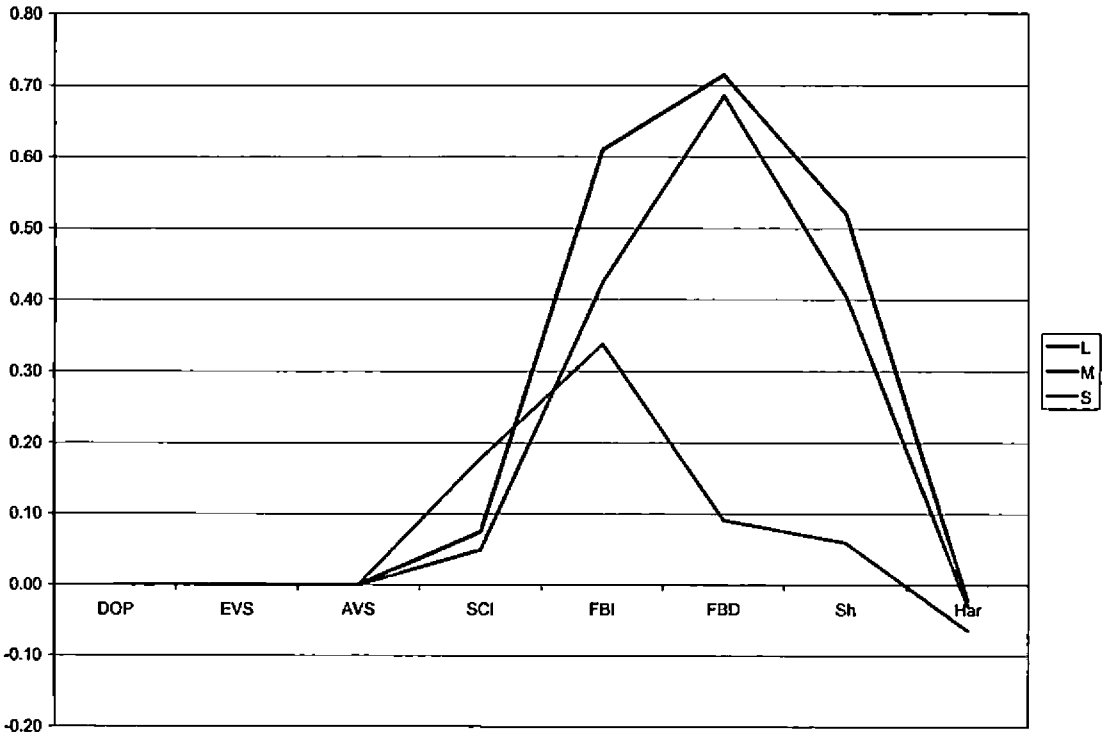


Fig 44. Corm Growth Rate – Whole Corm

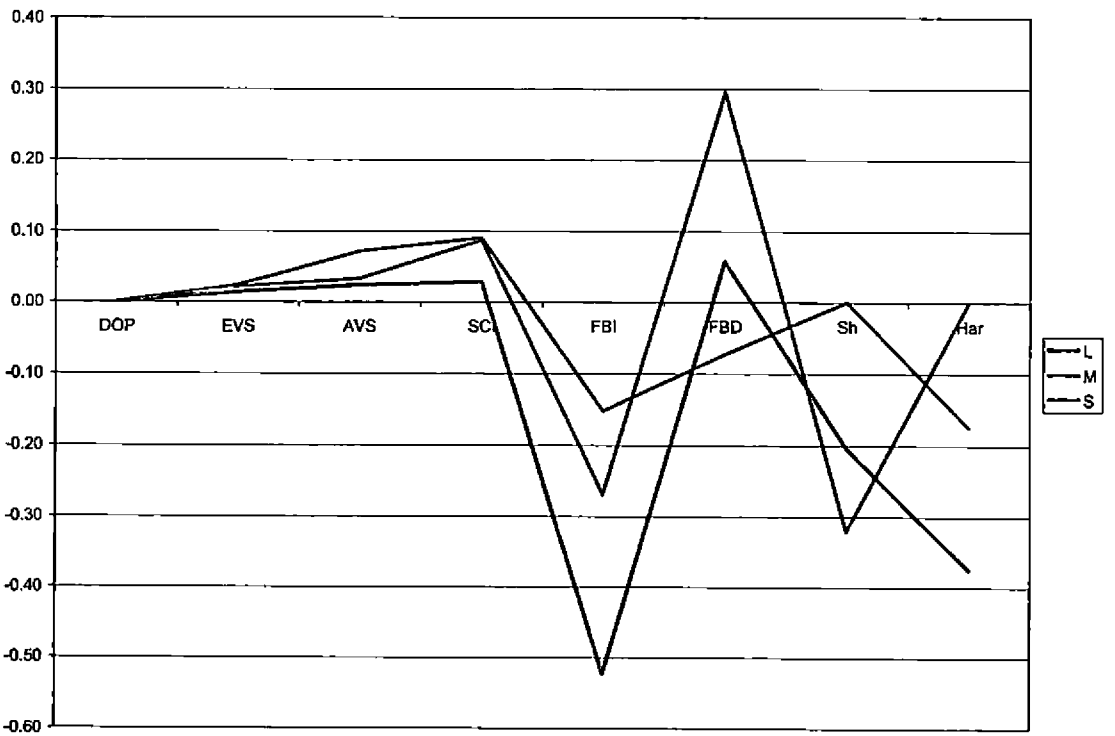


Table 45. Specific Corm Area – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0	3.23	3.15	2.68	2.69	2.55	1.98	3.47
M	0	3.19	3.18	2.61	2.53	2.24	1.99	2.81
S	0	3.32	2.99	2.44	4.42	2.81	2.02	3.84

Table 46. Specific Corm Area – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.00	0.00	36.07	8.17	8.99	8.90	10.25
M	0.00	0.00	0.00	31.82	7.43	6.37	6.23	7.42
S	0.00	0.00	0.00	4.25	4.32	5.94	6.17	7.39

Table 47. Specific Corm Area – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	3.23	3.15	3.19	4.54	5.26	5.49	8.28
M	0.00	3.19	3.18	3.04	4.08	4.32	4.50	6.11
S	0.00	3.32	2.99	2.58	4.36	4.68	4.64	6.47

Fig 45. Specific Corm Area – Primary Corm

Fig 46. Specific Corm Area – Secondary Corm

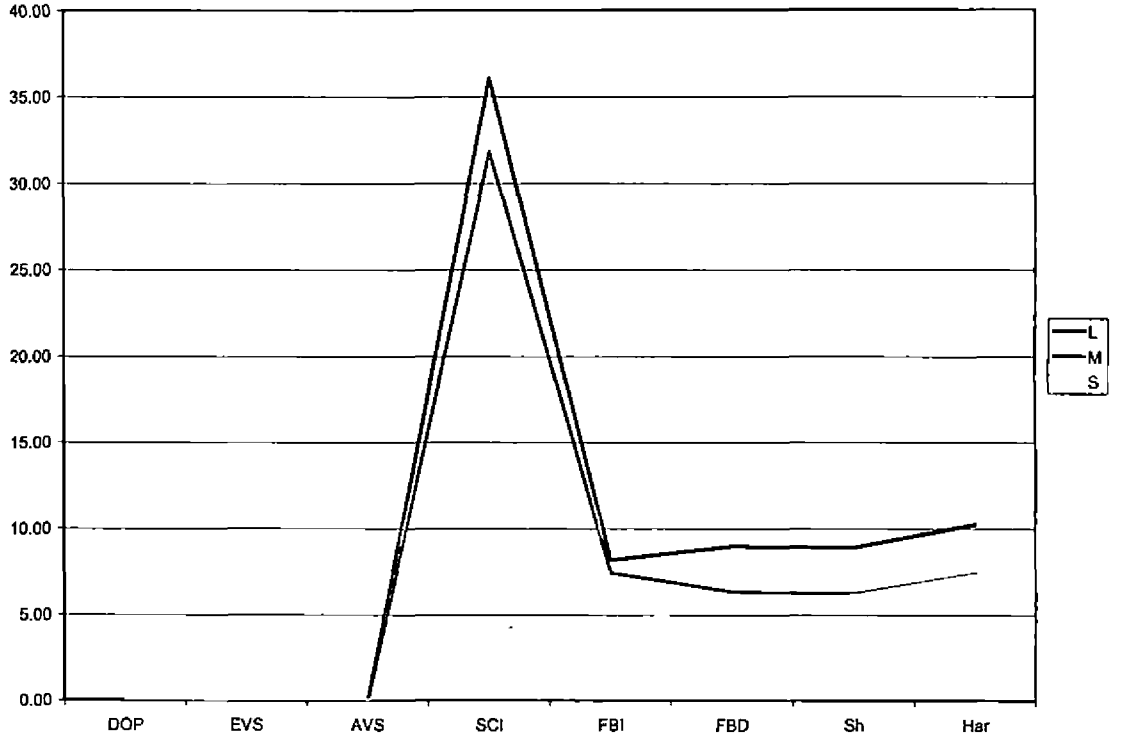
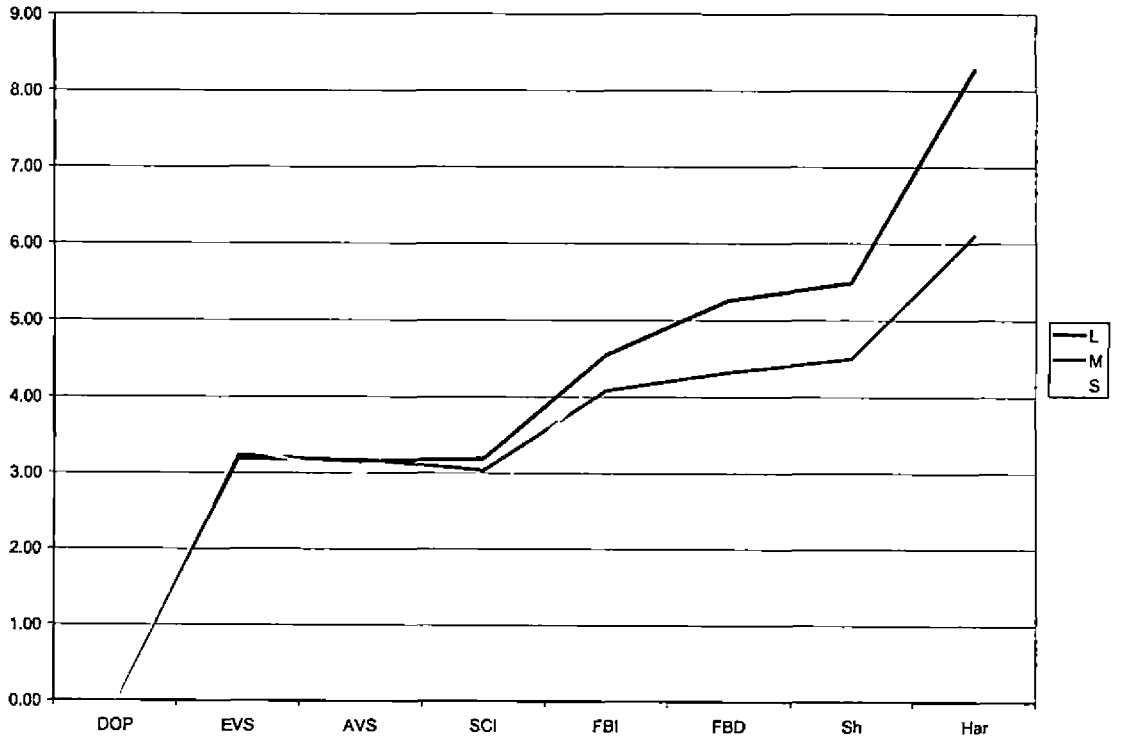


Fig 47. Specific Corm Area – Whole Corm



The SCA of the whole corm in large, medium and small corm sizes showed a small decrease at AVS and then increased gradually upto harvest, rates being the maximum in large corm size.

4.2.4.3 Corm Area Ratio

The Corm Area Ratio (CAR) of primary corm was the maximum at EVS in all the corm sizes (table 48-50 and fig. 48-50). Then it gradually reduced upto harvesting. The CAR of the secondary corm gradually increased upto FBD stage and thereafter the CAR increased but at a lower rate.

When the CAR of the whole corm was considered, peak values were observed at the EVS stage after which though there was an increase, the rates were lower.

4.2.4.4 Corm Weight Ratio

Corm Weight Ratio (CWR) of the primary corm was at its peak in the EVS stage. Thereafter the values were positive but decreased gradually upto the harvest stage, in the case of all the three corm sizes (table 51-53 and fig. 51-53).

In the case of secondary corm, the values peaked at FBD stage in large and medium corm size whereas it peaked at FBI stage in case of small corm size. When the CWR of whole corm was considered, the values were at its peak in the early stage and it showed a decreasing trend with further progress in age.

Table 48. Corm Area Ratio – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	**0.00**	2.82	2.44	1.76	0.72	0.53	0.26	0.16
M	0.00	2.73	2.41	1.64	0.63	0.32	0.20	0.14
S	0.00	2.37	1.97	1.14	0.56	0.25	0.14	0.10

Table 49. Corm Area Ratio – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.00	0.00	0.36	1.11	1.36	1.21	1.14
M	0.00	0.00	0.00	0.30	0.86	0.92	0.90	0.90
S	0.00	0.00	0.00	0.17	0.71	0.79	0.72	0.52

Table 50. Corm Area Ratio – Whole Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	2.82	2.44	2.12	1.83	1.89	1.48	1.30
M	0.00	2.73	2.41	1.93	1.49	1.24	1.10	1.04
S	0.00	2.37	1.97	1.31	1.26	1.03	0.85	0.62

Fig 48. Corm Area Ratio – Primary Corm

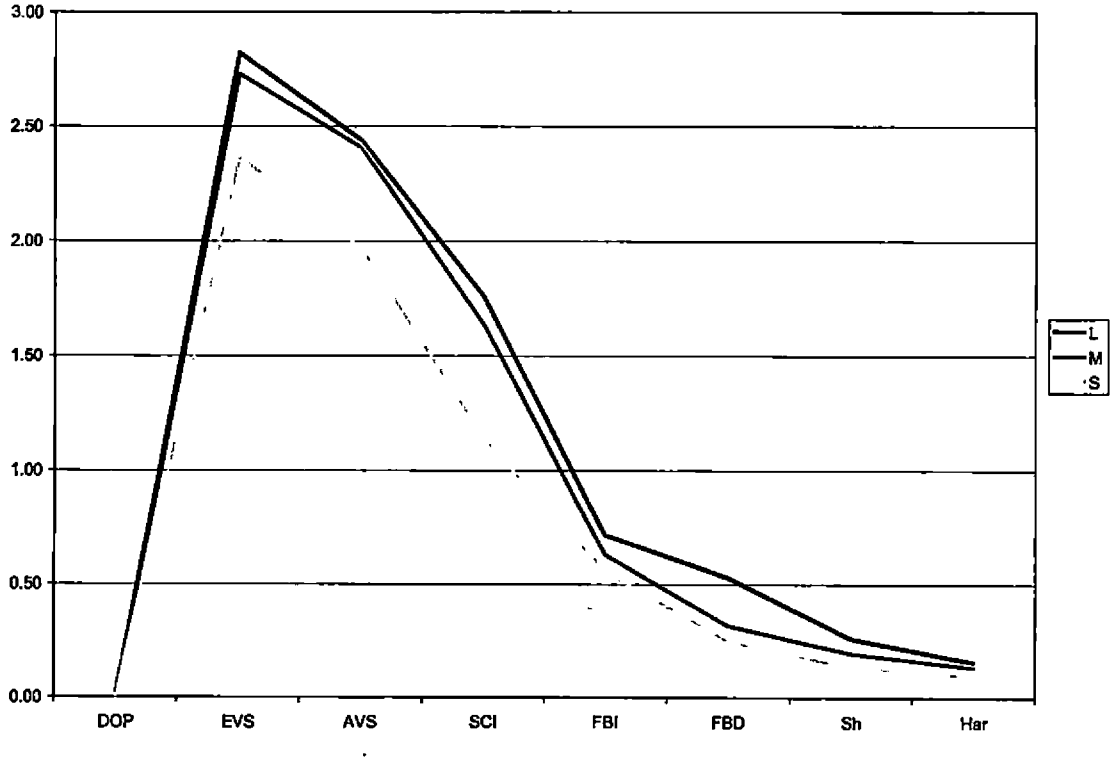


Fig 49. Corm Area Ratio – Secondary corm

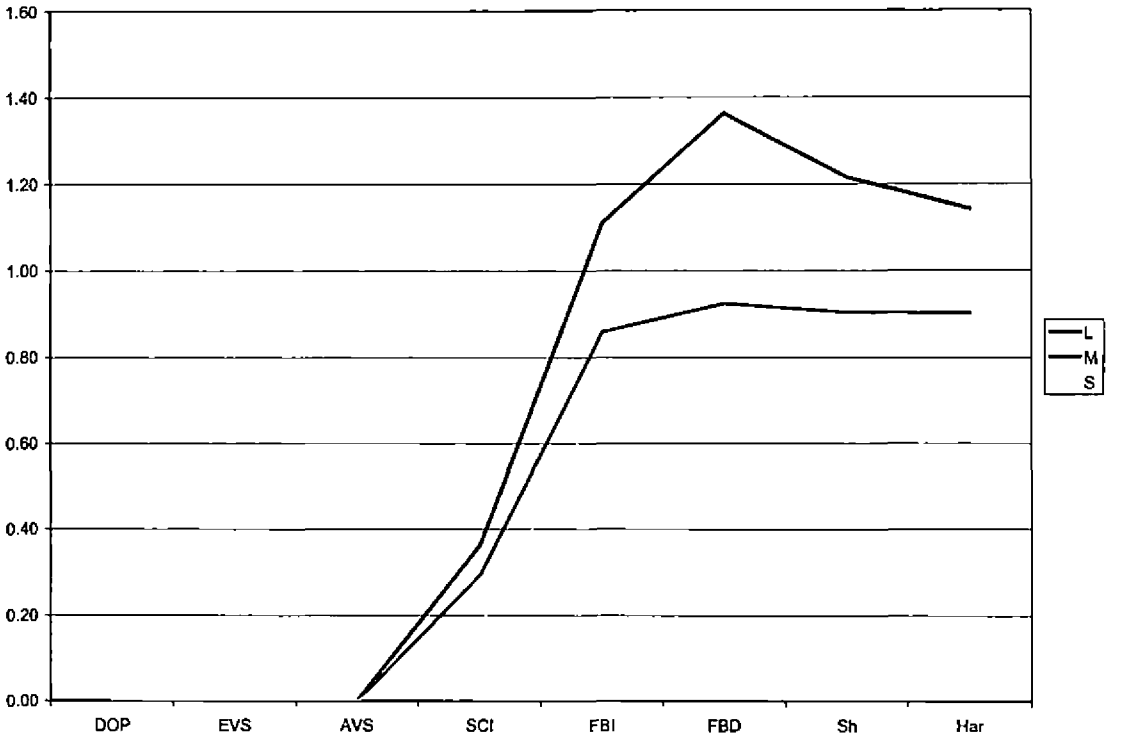


Fig 50. Corm Area Ratio – Whole corm

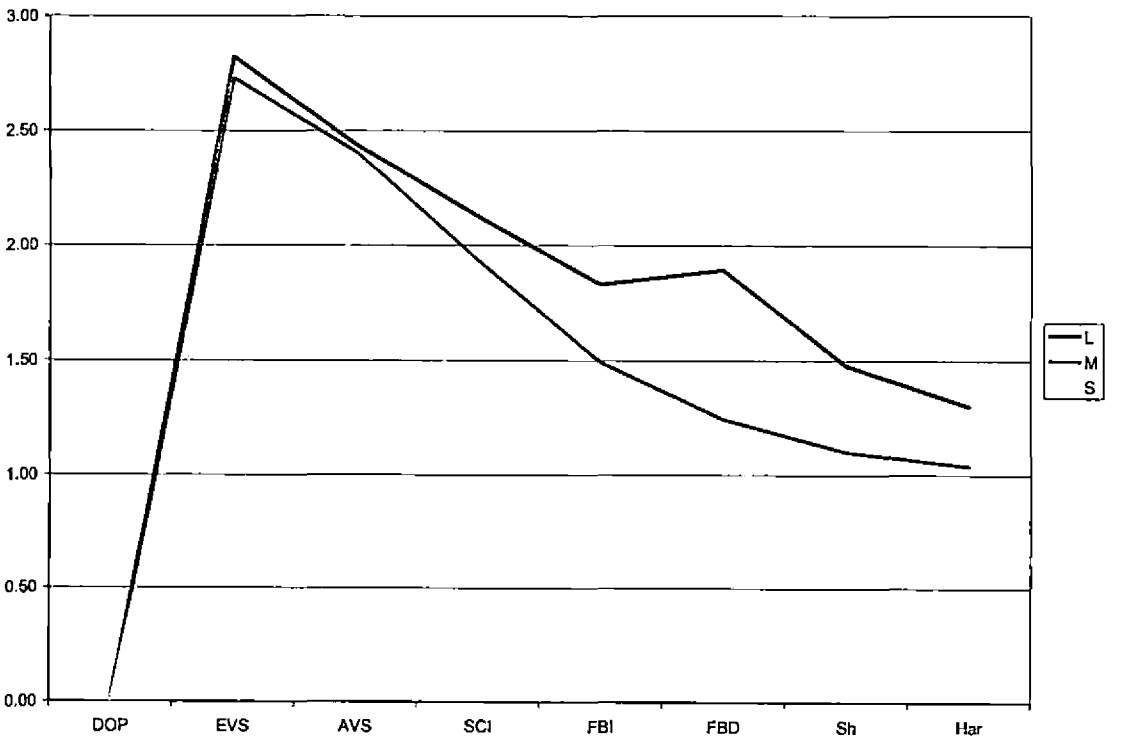


Table 51. Corm Weight Ratio – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	1.00	0.87	0.77	0.66	0.27	0.21	0.13	0.05
M	1.00	0.86	0.76	0.63	0.25	0.14	0.10	0.05
S	1.00	0.71	0.66	0.47	0.13	0.09	0.07	0.02

Table 52. Corm Weight Ratio – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.00	0.00	0.01	0.14	0.15	0.14	0.11
M	0.00	0.00	0.00	0.01	0.12	0.15	0.15	0.12
S	0.00	0.00	0.00	0.04	0.16	0.13	0.12	0.07

Table 53. Corm Weight Ratio – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	1.00	0.87	0.77	0.67	0.40	0.36	0.27	0.16
M	1.00	0.86	0.76	0.64	0.37	0.29	0.24	0.17
S	1.00	0.71	0.66	0.51	0.29	0.22	0.18	0.10

Fig 51. Corm Weight Ratio – Primary Corm

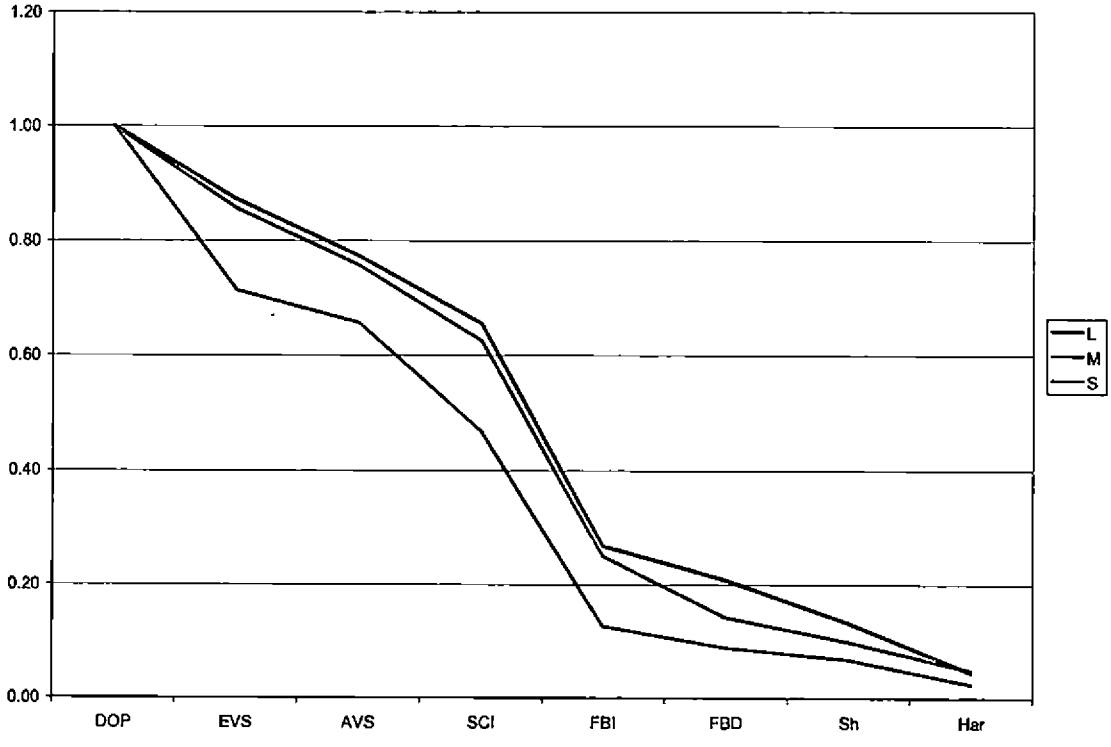


Fig 52. Corm Weight Ratio – Secondary Corm

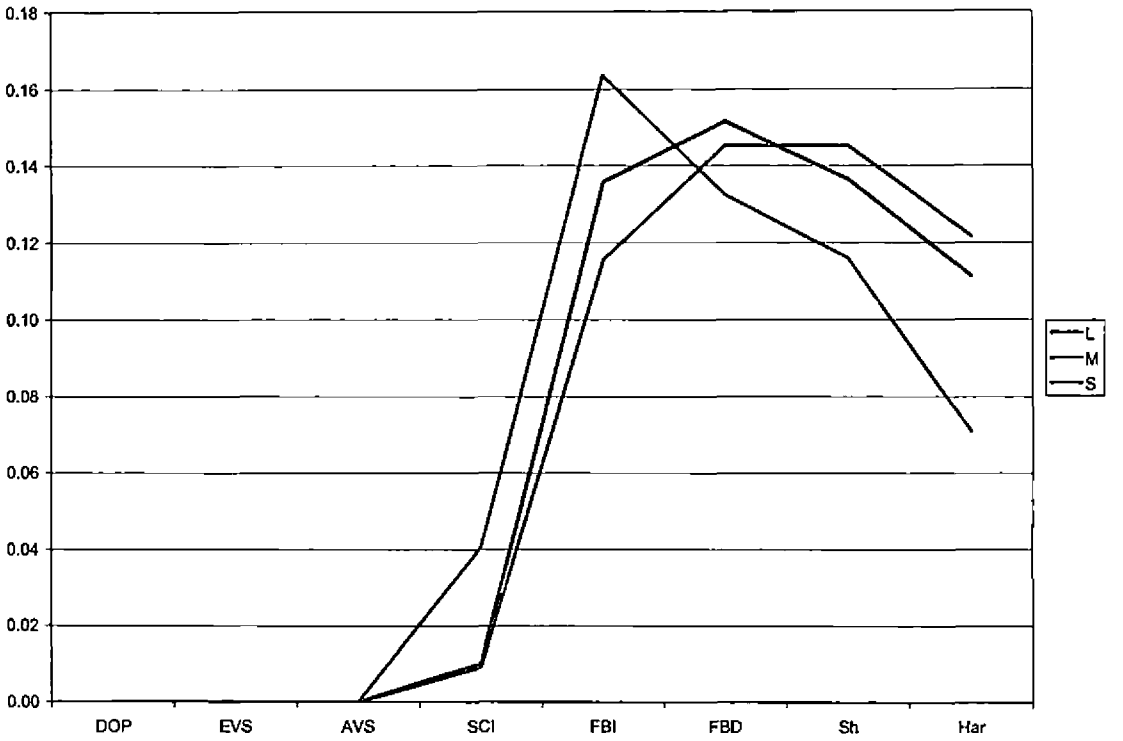
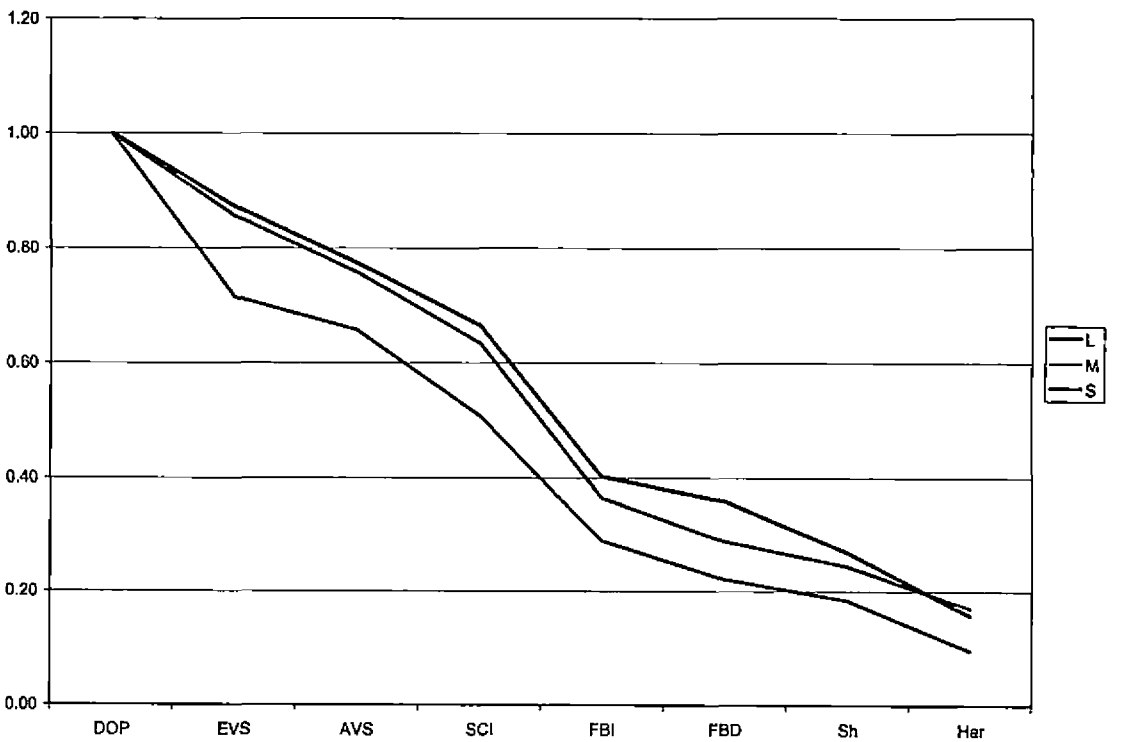


Fig 53. Corm Weight Ratio – Whole Corm



4.2.4.5 Specific Corm Weight

In the case of Specific Corm Weight (SCW), the primary corm values increased progressively upto shooting (table 54-56 and fig. 54-56) and thereafter decreased in the case of large, medium and small corm sizes.

In the case of secondary corm the values peaked at FBD stage and were almost the same at FBD and shooting. Higher values were observed in small corm size followed by medium corm size.

When the whole corm was taken into consideration, the SCW peaked at AVS stage in case of large corm size where as it was at SCI stage in the case of medium and small corm size.

4.2.4.6 Absolute Growth Rate

The Absolute Growth Rate (AGR) of the primary corm registered upward values upto AVS in large and small corm size and upto SCI stage in medium size, thereafter the values were negative (table 57-59 and fig. 57-59). On the contrary, the AGR values of the secondary corm peaked upto FBD in large and medium corm sizes and upto FBI in small size. The values were positive upto shooting but the increase was comparatively on the downward stage. At harvest the values were negative in all the corm sizes.

When the whole corm was considered, maximum AGR was observed at FBD stage in large and medium corm sizes and at SCI in small corm size.

Table 54. Specific Corm weight – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.31	0.32	0.37	0.37	0.39	0.51	0.29
M	0.00	0.31	0.31	0.38	0.40	0.45	0.50	0.36
S	0.00	0.30	0.33	0.41	0.23	0.36	0.49	0.26

Table 55. Specific Corm weight – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.00	0.00	0.03	0.12	0.11	0.11	0.10
M	0.00	0.00	0.00	0.03	0.13	0.16	0.16	0.13
S	0.00	0.00	0.00	0.24	0.23	0.17	0.16	0.14

Table 56. Specific Corm weight – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.00	0.31	0.32	0.31	0.22	0.19	0.18	0.12
M	0.00	0.31	0.31	0.33	0.25	0.23	0.22	0.16
S	0.00	0.30	0.33	0.39	0.23	0.21	0.22	0.15

Fig 54. Specific Corm weight – Primary Corm

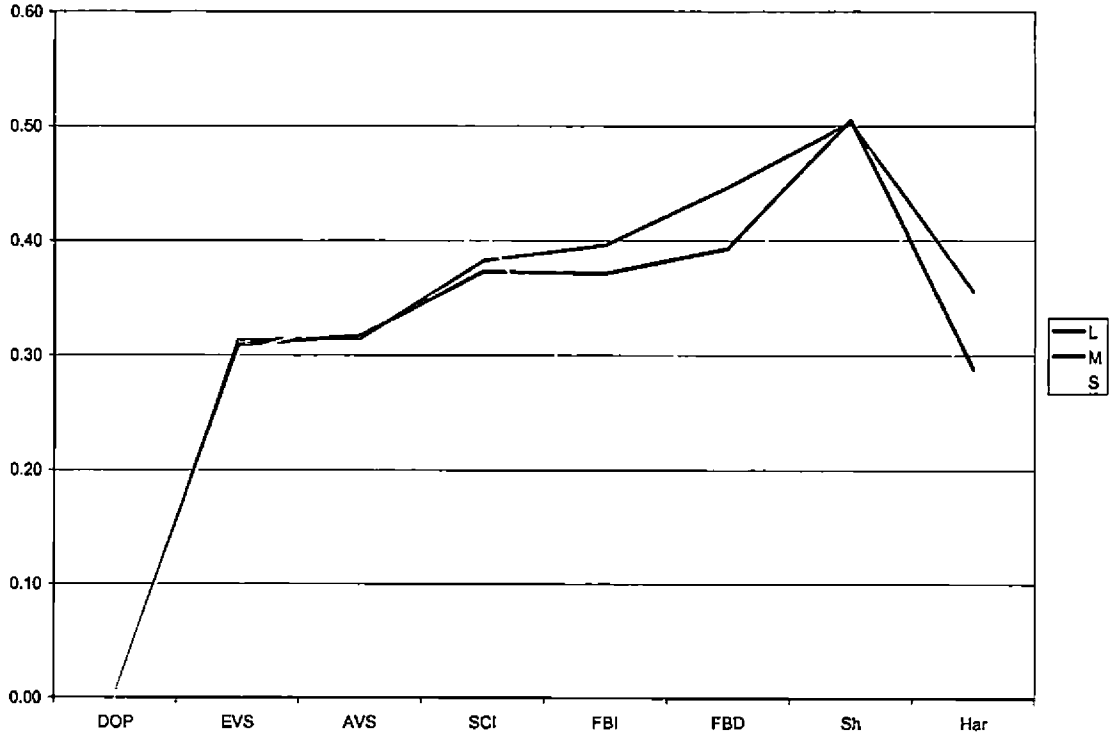


Fig 55. Specific Corm weight – Secondary Corm

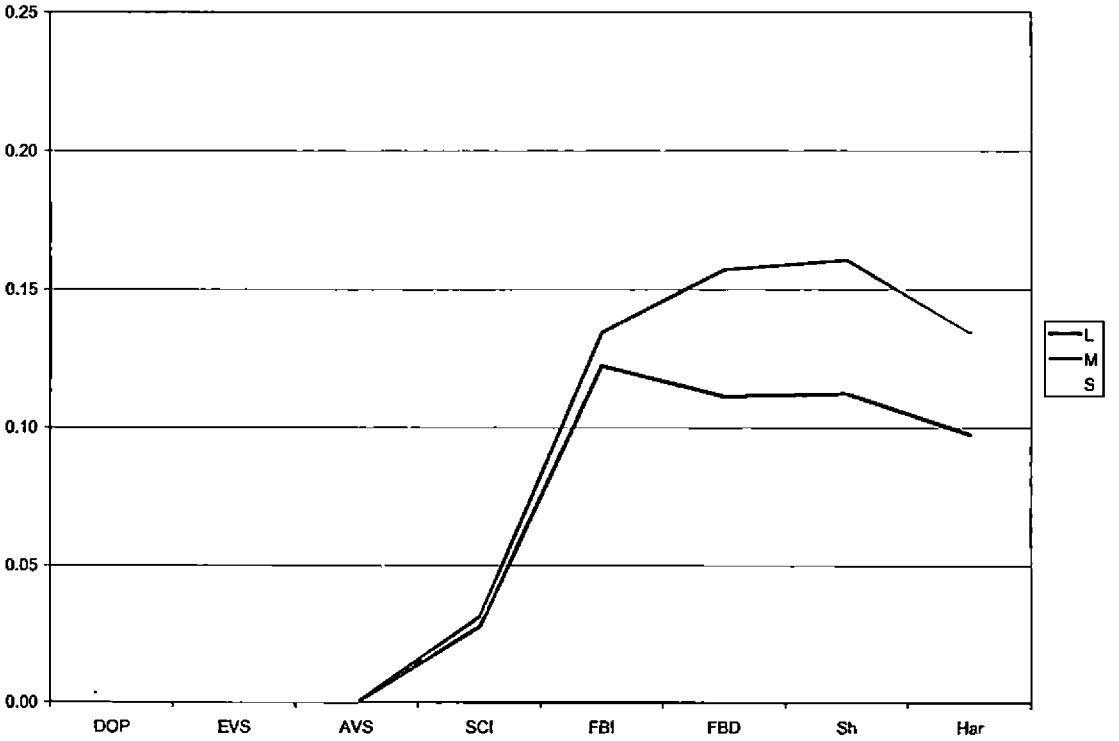


Fig 56. Specific Corm weight – Whole Corm

Table 57. Absolute Growth Rate – Primary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.0000	0.0573	0.0950	-0.1793	-4.5272	-2.6264	-2.8969	-1.4139
M	0.0000	0.0894	0.1331	0.1554	-2.7730	-1.5561	-2.9030	-0.6814
S	0.0000	0.0938	0.2839	-0.3467	-1.9595	-0.6548	-0.2267	-0.4396

Table 58. Absolute Growth Rate – Secondary Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.0000	0.0000	0.0000	0.2960	2.4387	2.8579	2.0806	-0.0860
M	0.0000	0.0000	0.0000	0.1973	1.6977	2.7407	1.6207	-0.1184
S	0.0000	0.0000	0.0000	0.7087	1.3493	0.3616	0.2363	-0.2591

Table 59. Absolute Growth Rate – Whole Corm

	DOP	EVS	AVS	SCI	FBI	FBD	Sh	Har
L	0.0000	0.0573	0.0950	0.1167	-2.0885	0.2314	-0.8162	-1.4999
M	0.0000	0.0894	0.1331	0.3527	-1.0753	1.1846	-1.2823	-0.7998
S	0.0000	0.0938	0.2839	0.3620	-0.6102	-0.2931	0.0096	-0.6987

Fig 57. Absolute Growth Rate – Primary Corm

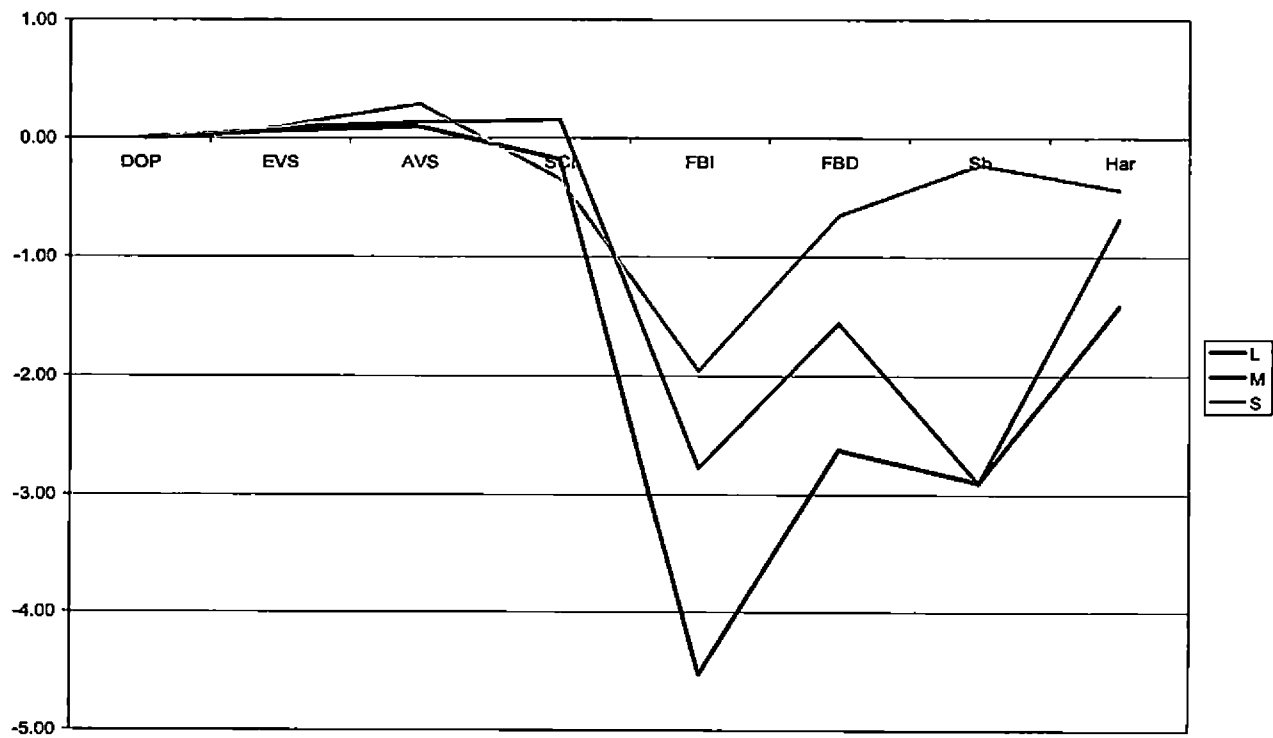


Fig 58. Absolute Growth Rate – Secondary Corm

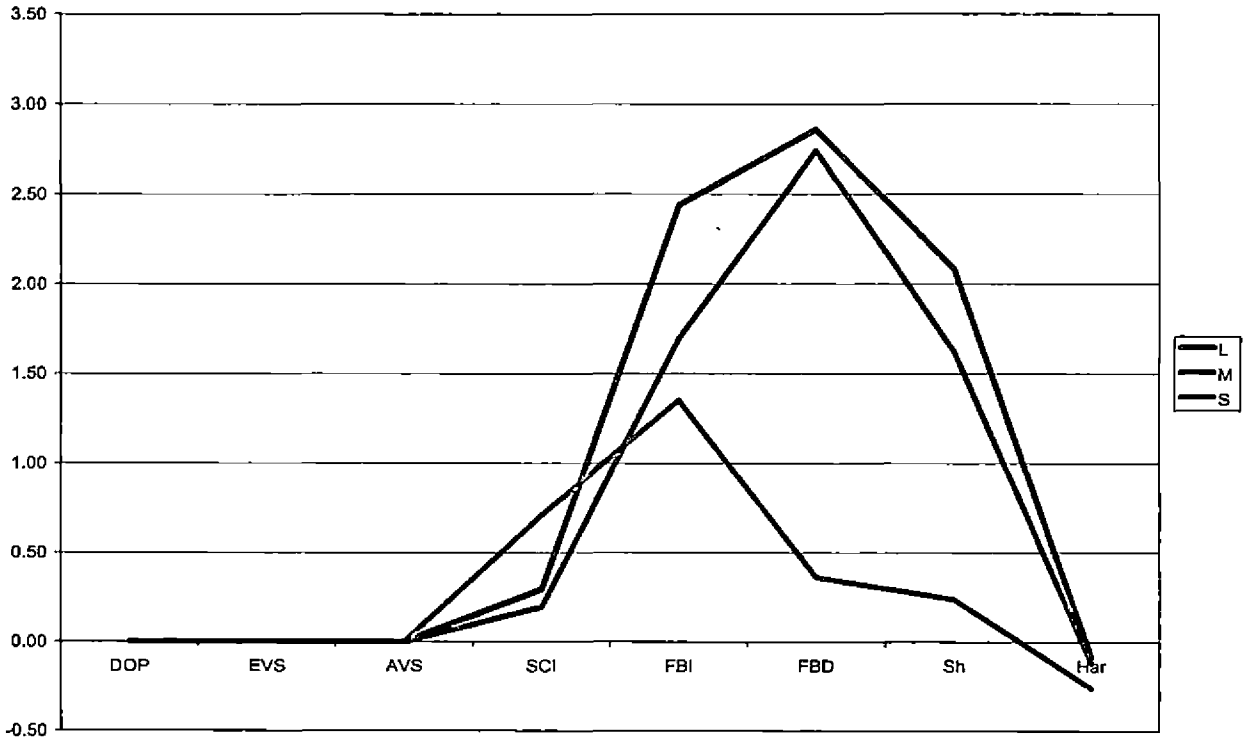
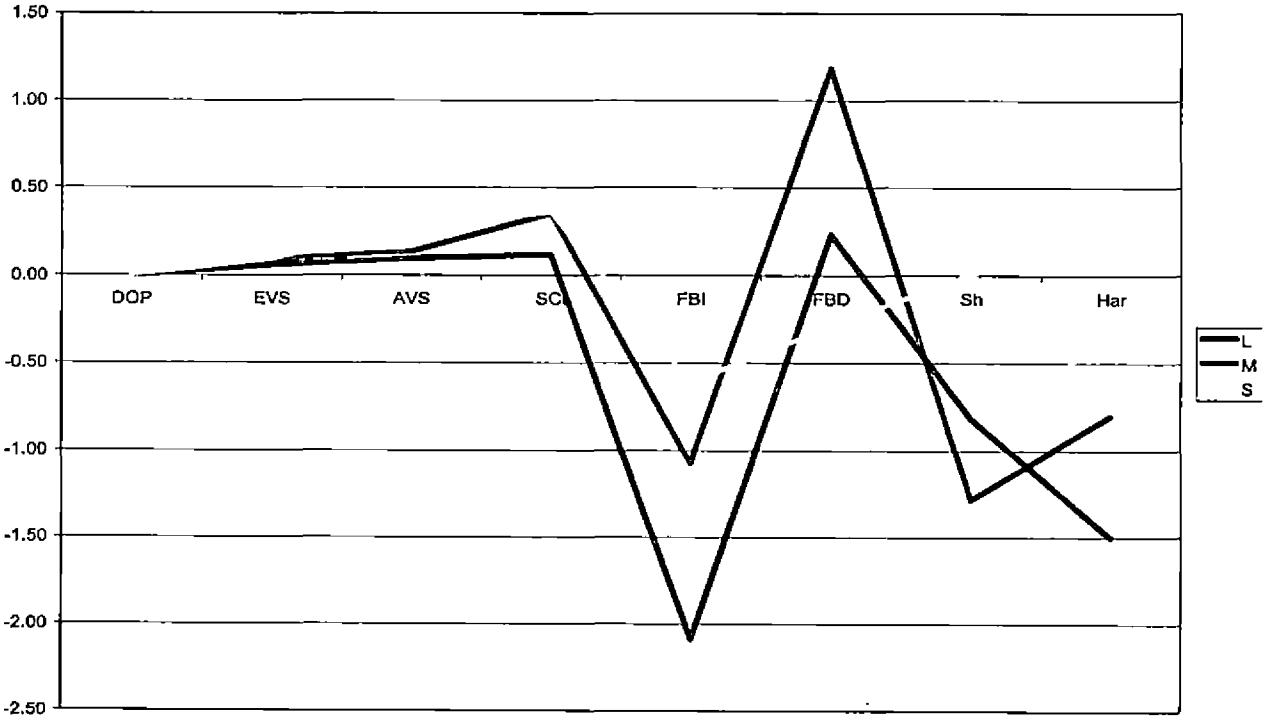


Fig 59. Absolute Growth Rate – Whole Corm



4.2.4.7 Net Assimilation Rate

The Net Assimilation Rate (NAR) of the primary corm in case of large, medium and small corm size peaked at EVS. Values were positive only upto AVS (table 60-62 and fig. 60-62).

In contrast, though the values were small, they were positive in case of secondary corm upto shooting. In large and medium corm size, it peaked at FBI stage whereas in small corm size, it was the maximum at SCI stage.

The whole corm NAR incremental values between biotic phases peaked at EVS in all the large, medium and small corm sizes. In all the cases, the incremental values were positive upto SCI stage

4.2.5 Thermal unit requirement and photoperiodic response in relation to size of planting material

The heat unit requirement (GDD) and photoperiodic response (PTU & ITU) are presented in tables 63 and 64. The data reveal that the corm size definitely influences the requirement from planting to reach the SCI stage. The requirement of heat units to reach the SCI stage being highest in the smallest corm size and increase in requirement being in gradation with the size of corm or in short, the larger the corm size, the heat unit requirement being smaller. In other words, the requirement of heat units to reach SCI stage is grossly dependant on corm size. The GDD requirements from SCI to FBI, from

Table 60. Net Assimilation Rate – Primary Corm

	EVS	AVS	SCI	FBI	FBD	Sh	Har
Large	0.00013	0.00001	-0.00001	-0.00009	-0.00004	-0.00005	0.00000
Medium	0.00037	0.00002	0.00001	-0.00008	-0.00003	-0.00005	-0.00002
Small	0.00193	0.00031	-0.00007	-0.00012	-0.00002	-0.00001	-0.00002

Table 61. Net Assimilation Rate – Secondary Corm

	EVS	AVS	SCI	FBI	FBD	Sh	Har
Large	0	0	0.000013	0.000047	0.000044	0.000034	-0.000002
Medium	0	0	0.000011	0.000047	0.000046	0.000029	-0.000003
Small	0	0	0.000136	0.000081	0.000012	0.000008	-0.000012

Table 62. Net Assimilation Rate – Whole Corm

	EVS	AVS	SCI	FBI	FBD	Sh	Har
Large	0.000126	0.000014	0.000005	-0.000040	0.000004	-0.000013	-0.000031
Medium	0.000366	0.000024	0.000020	-0.000030	0.000020	-0.000023	-0.000023
Small	0.001935	0.000307	0.000069	-0.000036	-0.000010	0.000000	-0.000032

Fig 60. Net Assimilation Rate – Primary Corm

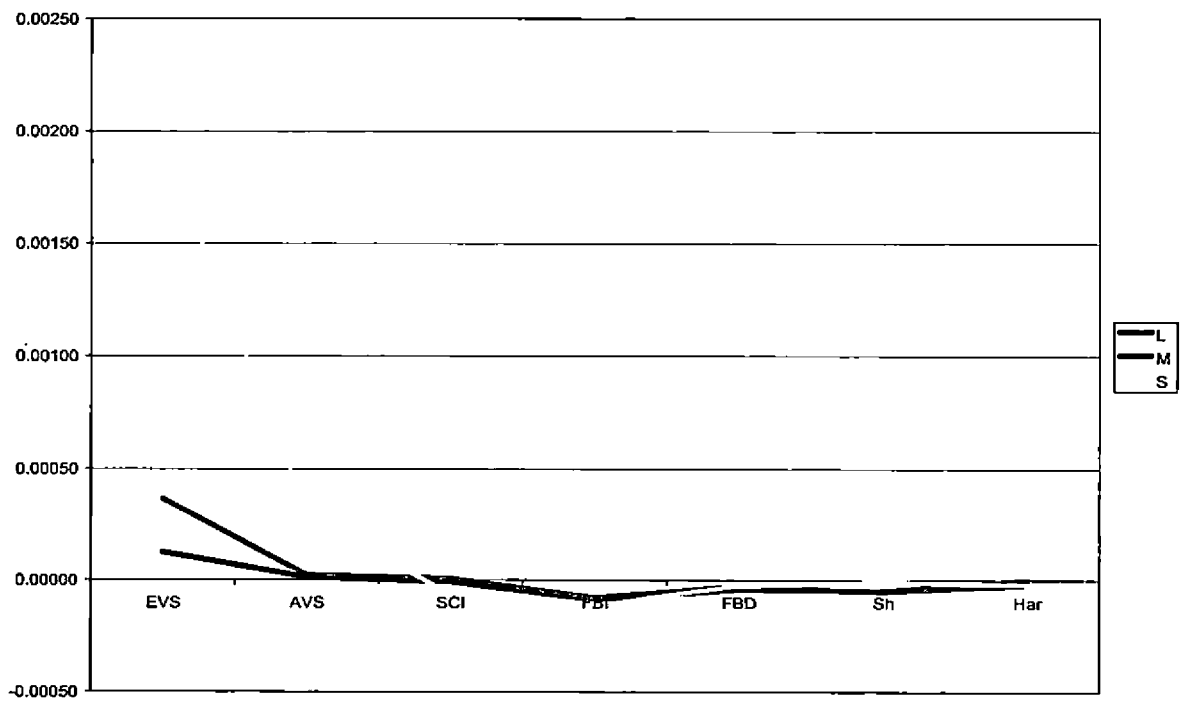


Fig 61. Net Assimilation Rate – Secondary Corm

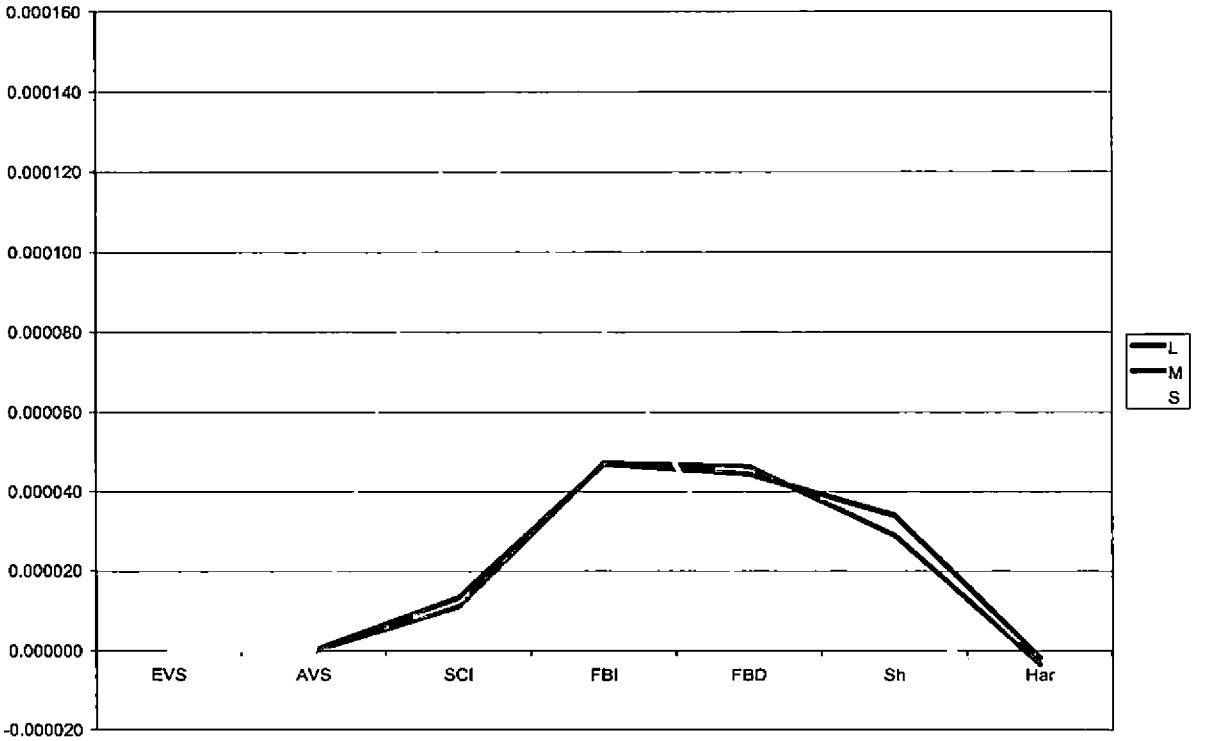


Fig 62. Net Assimilation Rate – Whole Corm

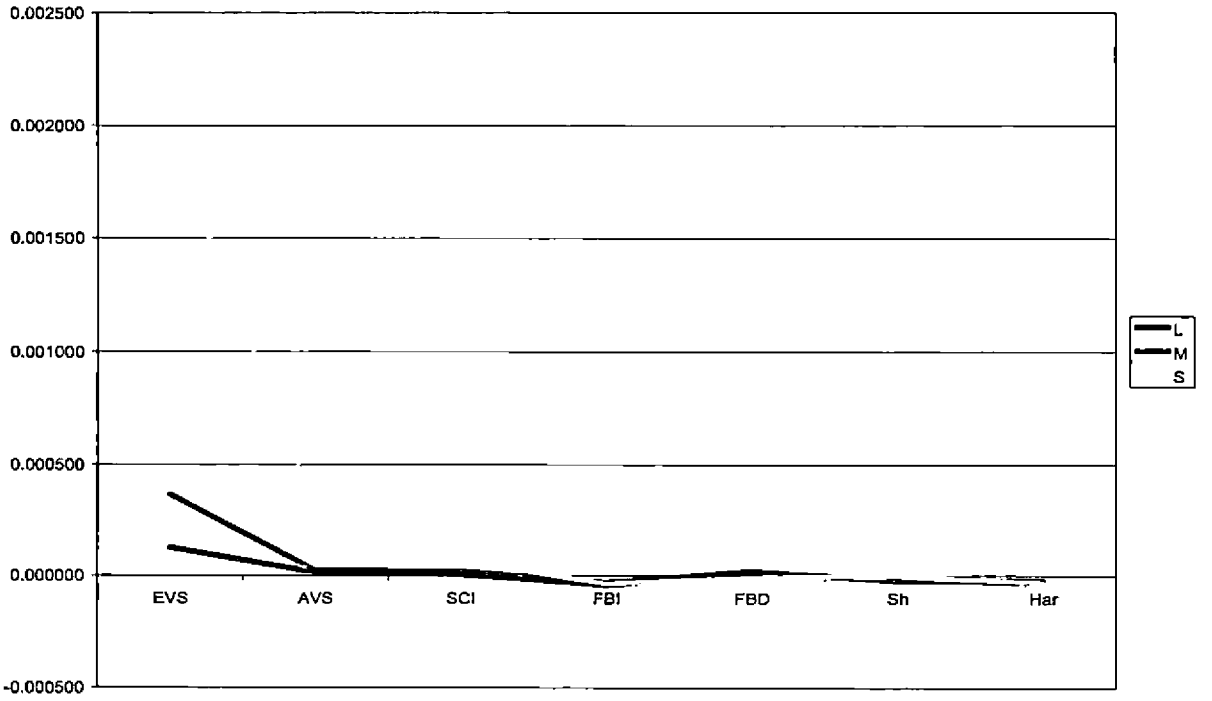


Table 63. Thermal units requirement and photoperiodic response in relation to size of planting material

Corm Size	Plt – 2^0 Corm			2 Corm – FBI			FBI – FBD			FBD – Shoot			Shooting – Harv		
	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU	GDD	PTU	ITU
Large	816.26	9744.10	4028.78	609.55	6952.42	4726.80	206.35	2550.49	1742.59	260.50	3219.78	2163.94	1297.35	16350.52	7101.67
Medium	1041.81	12438.22	5787.20	590.35	6808.79	4710.96	260.50	3219.78	2163.94	222.75	2753.19	1817.06	1254.90	15934.01	5858.67
Small	1225.41	14465.16	7196.65	667.25	8001.62	5465.45	222.75	2753.19	1817.06	235.90	2922.92	1393.35	1245.20	15939.63	5449.62

Table 64. Photoperiodic responses in terms of GDD, PTU and ITU from different stages to harvest

Corm Size	GDD			PTU			ITU			ITU/PTU		
	Pl-Har	2 Corm - Har	FBI - Har	Pl-Har	2 Corm - Har	FBI-Har	Pl-Har	2 Corm-Har	FBI-Har	Pl-Har	2 Corm -Har	FBI-Har
Large	3190.01	2373.75	1764.20	38817.30	29073.20	22120.78	19763.77	15734.99	11008.19	0.51	0.54	0.50
Medium	3370.31	2328.50	1738.15	41153.99	28715.77	21906.98	20337.83	14550.63	9839.67	0.49	0.51	0.45
Small	3596.51	2371.10	1703.85	44082.53	29617.37	21615.74	21322.13	14125.48	8660.03	0.48	0.48	0.40

FBI to FBD, from FBD to Shooting and from shooting to harvest is almost the same and is not influenced by the corm size as the variations are very subtle.

The GDD, PTU and ITU from planting to harvest, SCI to harvest and FBI to harvest give a more explicit result. The SCI to harvest and FBI to harvest have almost registered equal values but when the crop cycle was considered in its entirety, there was a variation that clearly indicated the concept. As the corm size increased, the GDD requirement was less or for the smaller corm size, the GDD requirement is more. A similar trend is also observed at PTU and ITU levels.

The ratio of ITU/PTU again revealed a very important indication. As the values exceeded 0.5, yields were observed to be high. In other words, the efficiency of realization of degree days (*i.e.* realized units as a part of the total units) is more in larger corm size.

4.2.6 Anatomy and physiology of secondary corm formation

The planted corm or the paired and treated sucker consisting of root initials slowly peeping out purely consist of a distinguishable central portion referred as the central cylinder and the outer cortex. The junction between the two is marked by longitudinal vascular bundles. The ground tissue made up of starchy parenchyma shows intense staining with Potassium Iodide (KI).

Within a fortnight of planting, the roots forage the soil. Simultaneously, the growing point at the central tip gets activated and begins to push out the first leaf by the third week after planting. By about a month after planting, the central cylinder becomes explicit with the development of leaf mitotic activity. This is visualized at the bases as dividing cells at the top of the dome which becomes much more active by AVS, slightly pushing the cortex cells in the outward plane on the one side and the growing point getting elevated by the dividing cells at leaf bases. This stage is visualized as a swelling of the planted corm and can be termed as "Early Bulking" or "Planted corm swelling / Bulking / Enlargement".

The next stage is the emergence of the secondary corm that occurs by the development of the growing point. The cells of the corpus on either side of the growing point and the few layers of central mother zone undergoes rapid cell division (i.e. towards the upper part) (Plate 46), whereas the lower part below remains as it is (Plate 47)

Plate 46

Plate 47

These actively dividing cells which are initially in the upper direction carries with it the growing point or the apical primordia and now becomes prominent as a swollen new corm (Plate 48) over the corm (the planted part). The constriction that is observed in

between, at this stage is actually a zone of separation or an interphase between the actively dividing cells on the upper part and the non-dividing cells on the lower part which is the planted corm. This phase which marks the onset of the secondary corm development could be termed as ***Secondary Corm Initiation Phase.*** In the initial stages, it is evident as small upper bulked area with a constriction (c) (demarcation separating the new and old corm) and then the planted corm at the under surface (plate 49 and 50). An L.S. of the corm at this stage revealed that the cells in old corm are live and well connected to the growing point (plate 51).

Plate 48

Plate 49

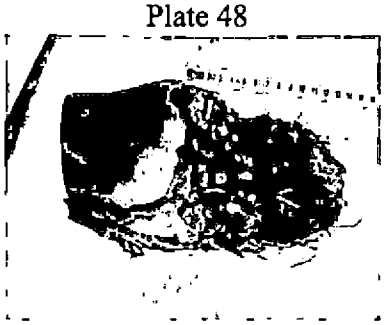


Plate 50

Plate 51

Thereafter, the turn of events shift to the secondary corm which turns as a seat of intense mitotic activity. From this stage onwards, the new corm develops and becomes the nurturing point of the growing apex. Thus the secondary corm that develops really takes over as the structural and developing functional corm of the developing banana plant by housing the growing point at its apical central tip.

The primary corm remains live and connected to secondary corm on the terminal point of which rests the growing apex. The primary corm gradually gives way to the new developing corm as evident by the progressive reduction in size of the planted corm. As the growth of the plant continues steadily, the outer epidermis becomes necrotic and gradually this progresses into the interior from all directions. The primary corm which remained live and intact at flower bud initiation and differentiation begins its progressive march to death (physiological stage of senescence) from the physiological event after bud differentiation but before bunch maturation (plate 52).

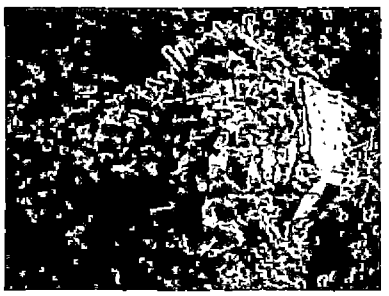


Plate 52

Plate 53

With the further progress in bunching and unfurling of hands and fingers, the functional deterioration of the primary corm is observed with progressive death of cells from the periphery. Towards half maturity of the fingers what remains is a small live part at the point of connection (erstwhile interconnection point). Even at this stage the primary corm although almost totally necrotic, remains attached to the plant as an appendage (plate 53) unless some external force of separation or the push of a developing sucker totally separates it out.

The secondary corm on the other hand expands further. Initially the growth is observed at the leaf primordial bases by active cell division (plate 54). Thereafter, the corpus and the central cylinder are also seen to be actively dividing zone (plate 55). Thus, the secondary corm is observed to be a zone of actively dividing cells in all directions.

Plate 54

Plate 55

The next phase of corm development is observed as a stage of rapid growth with cell divisions becoming highly intensive. A progressive cell division in all planes is observed at this stage (plates 56-58).

Plate 56

Plate 57

Plate 58

This stage is matched with an incremental growth in the corm size. This stage could be termed as a stage of ***Early Corm Bulking Stage.*** This stage of corm development serves as a structural support to the pseudostem as it synchronizes with the very active vegetative phase of the plant visualized as a stage of rapid leaf production and pseudostem development.

Further progress of the corm development is observed with age. The developing corm is observed to increase much more than what was observed hitherto. This stage is also characterized by active cell division at leaf primordial bases (plate 59) and cell division at all planes but mostly in the longitudinal plane (plate 60). One of the most striking features of this phase is that active cell division could be observed at the sub-apical zone (plate 61). This active sub-apical zone cell division is a characteristic feature of this phase. Quantitatively this phase is observed to be a stage of rapid bulking or can be termed as the ***Rapid Corm Bulking Stage.*** This stage in the biotic development of the plant coincides with the most active vegetative stage.

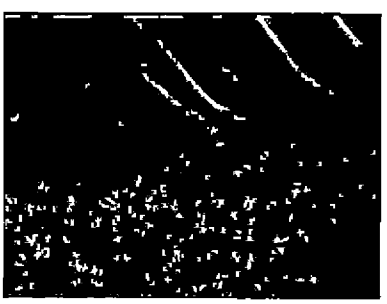


Plate 59

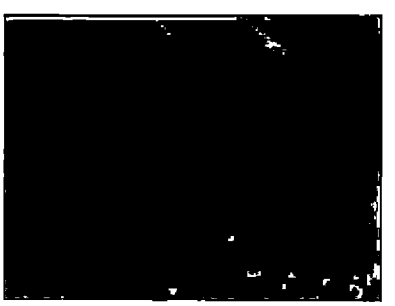


Plate 60

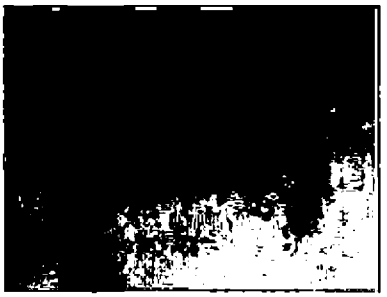


Plate 61

Plate 62

The next phase in the development of the corm coincides with the ontogenic march to the reproductive phase. The growing point which was hitherto on a plane with the leaf primordial bases suddenly gets raised (plate 62). In the phasic development of the plant, this is the stage in which the growing point switches over from the vegetative to the reproductive phase and all the turn of events in the transformation to the reproductive phase takes place at the level of the growing point. This stage may be termed as the flower bud initiation stage (plate 63).

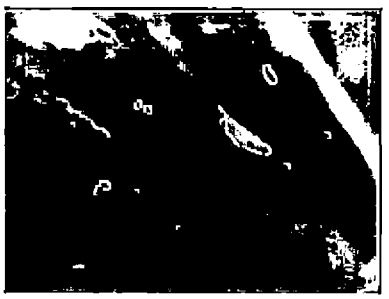


Plate 63

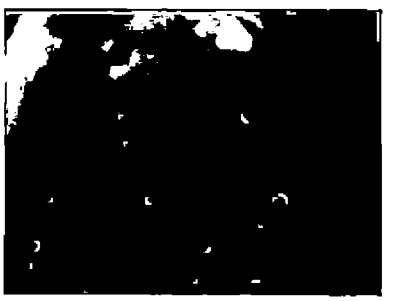


Plate 64

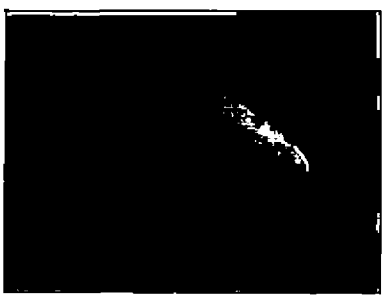


Plate 65

Prior to the bud initiation, cell enlargement is also observed. At flower bud initiation, the growing point develops in a convex shape (plate 64). An active mitotic area is seen below the growing tip in the central mother zone (plate 65). Bud initiation is observed to coincide with the peak collar girth. This bud initiation is immediately followed by the bud differentiation characterized by the development of the bracts (plates 66&67) and the progressive march from the vegetative phase to the reproductive phase is on.

Plate 66

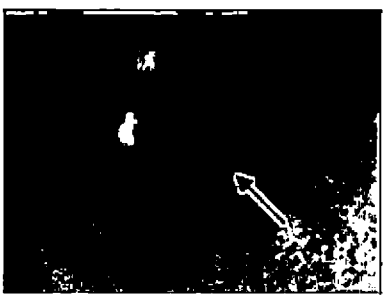


Plate 67

This stage is the accepted stage of Flower Bud Differentiation Stage. A characteristic point which has not been reported is that at this stage the growing point is seen to be raised further into the pseudostem (varying from 10 to 15 cms) (plates 68 & 69). Here also the corm bulking is observed. Thereafter, the differentiated primordia elongates further into the pseudostem (plates 70 & 71) leading to shooting. This stage at FBD and shooting represent peak bulking and could be termed as peak bulking or maximum bulking.

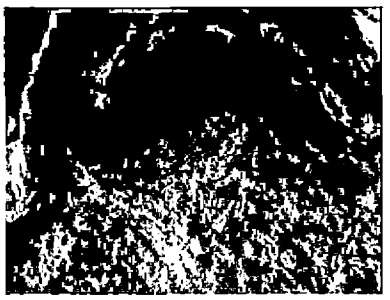


Plate 68

Plate 69

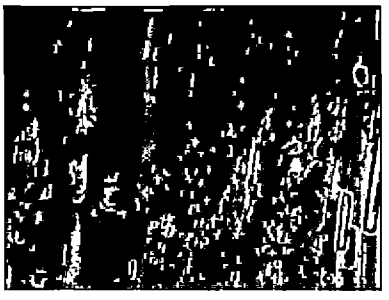


Plate 70

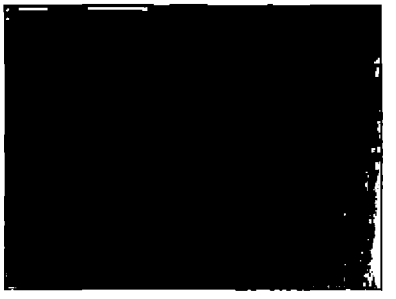


Plate 71

At this stage also the secondary corm is found to increase in size. At any stage of development of corm, suckers could gradually arise. Anatomically, this activity is seen as extension or protrusion from the central cylinder through the cortex to the exterior. Once the crop has reached the shooting stage, the importance of the corm switches over from the role of housing the bud which had turned reproductive to an active site of suckering. Thus functionally, the corm transforms itself to a propagative activity or perpetuation of its kind with the developing suckers remaining dependant on the mother plant.

4.3. Hastening secondary corm formation and impact on yield and crop life span

4.3.1. Hormone Dip Method

4.3.1.1 Plant Height

Normal plant height was observed only in the case of control plants, which was also the highest recorded value among the treatments (table 65 and fig 63). The lowest values were recorded in the case of plants treated with PCBA 500 ppm followed closely with PCBA 250, NAA 500 and ABA 250ppm. The plants treated with IAA 250 and 500 ppm also showed higher values for plant height but was lower than that of plants under control.

4.3.1.2 Collar Girth

The data presented in table 66 and fig 64 also shows a similar trend. In general, the collar girth showed a slightly lesser value in almost all treatments till AVS when compared to the control plants. Thereafter, the plants treated with IAA 250 and 500ppm exhibited a progressive increase in collar girth till FBD, the values higher than the control plants. PCBA treated plants however retained its lower values for collar girth even though they could overcome the initial stunted nature after AVS.

4.3.1.3 D-Leaf Area

D-leaf area of all the treatments showed lesser values than the control plants till post SCI stage (table 67 and fig 65) and it was higher for IAA treated plants during the later half. All other treatments continued to show lesser leaf area throughout its life time with the values of PCBA treated plants being the lowest.

Table 65. Plant height (cm) at different stages of the hormone dip method

	EVS	AVS	SCI	FBI	FBD	Sh	Harv
PCBA250	17.56^{d}	33.95^{f}	53.4^{e}	121.08^{f}	149.55^{f}	171.54^{e}	173.5^{f}
PCBA500	15.32^{e}	30.58^{h}	49.57^{f}	118.54^{f}	131.35^{g}	164.86^{f}	169.47^{g}
NAA250	18.75^{d}	35.45^{e}	60.22^{d}	132.78^{d}	164.7^{d}	177.7^{d}	181.44^{d}
NAA500	17.2^{d}	37.85^{d}	58.6^{d}	128.86^{e}	162.81^{d}	173.35^{e}	176.5^{ef}
IAA250	26.57^{b}	43.84^{b}	88.35^{b}	165.37^{b}	198.43^{b}	217.27^{b}	220.3^{b}
1AA500	24.33^{c}	42.15^{c}	83.14^{c}	151.4^{c}	190.85^{c}	211.1^{c}	215.46^{c}
ABA250	17.39^{d}	32.66^{g}	60.53^{d}	129.8^{dc}	155.48^{e}	178.73^{d}	179.65^{de}
Control	30.52^{a}	51.55^{a}	105.65^{a}	182.54^{a}	222.67^{a}	235.46^{a}	237.88^{a}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 63. Plant height (cm) at different stages of the hormone dip method

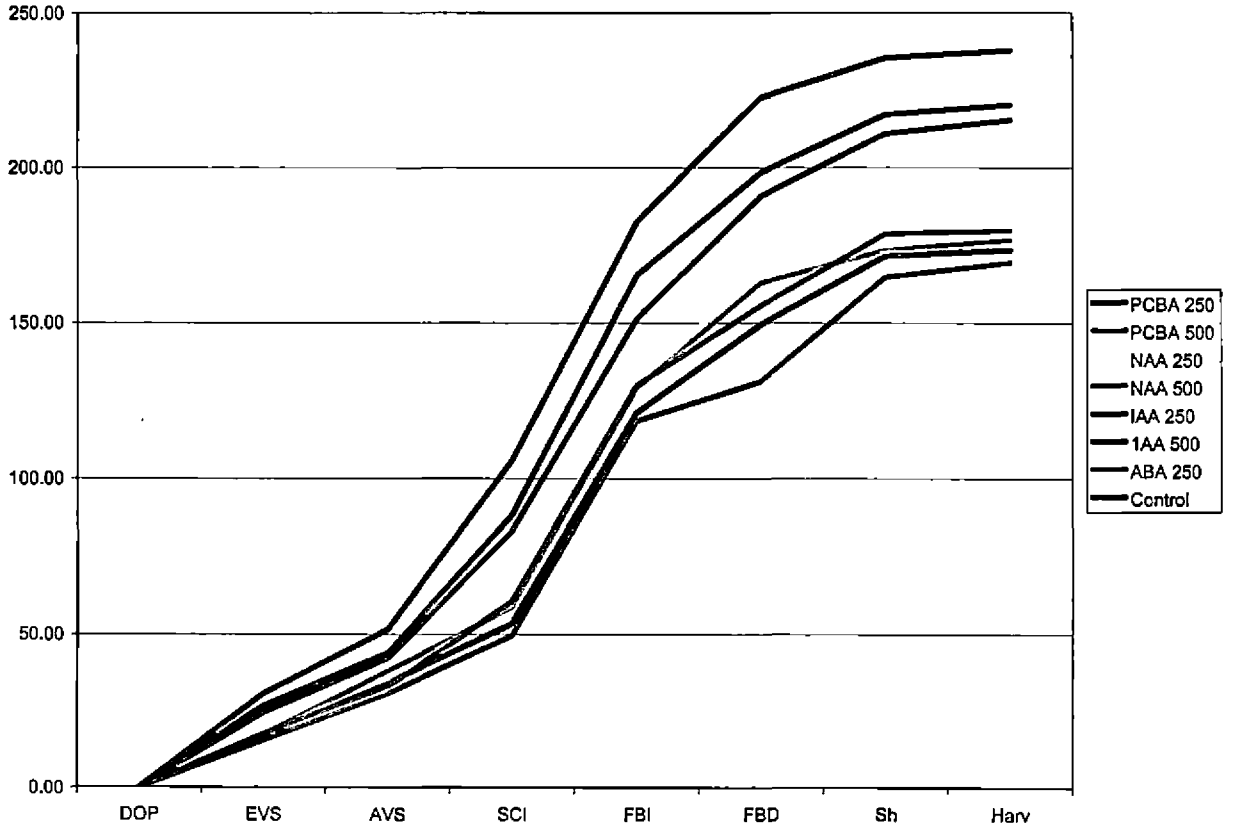


Table 66. Collar girth (cm) at different stages of the hormone dip method

	EVS	AVS	SCI	FBI	FBD	Sh	Harv
PCBA 250	8.12^{d}	14.50^{cd}	18.53^{d}	30.49^{d}	42.94^{e}	48.65^{de}	46.52^{d}
PCBA 500	8.00^{d}	12.30^{e}	15.44^{e}	28.11^{e}	40.10^{f}	46.77^{e}	45.44^{d}
NAA 250	10.50^{c}	14.04^{d}	20.95^{d}	32.41^{c}	45.55^{cd}	51.25^{c}	49.85^{d}
NAA 500	10.50^{c}	14.00^{d}	18.50^{d}	30.15^{d}	44.20^{de}	50.62^{cd}	47.60^{cd}
IAA 250	12.80^{a}	15.43^{b}	32.65^{a}	45.50^{a}	58.53^{a}	59.50^{a}	56.39^{a}
1AA 500	12.50^{a}	15.00^{bc}	30.80^{b}	43.57^{b}	56.58^{b}	56.68^{b}	52.58^{b}
ABA 250	8.00^{d}	14.72^{d}	18.20^{d}	32.69^{c}	43.55^{e}	48.20^{e}	45.75^{d}
Control	11.10^{b}	19.82^{a}	22.96^{c}	42.81^{b}	45.93^{c}	50.54^{cd}	48.81^{c}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 64. Collar girth (cm) at different stages of the hormone dip method

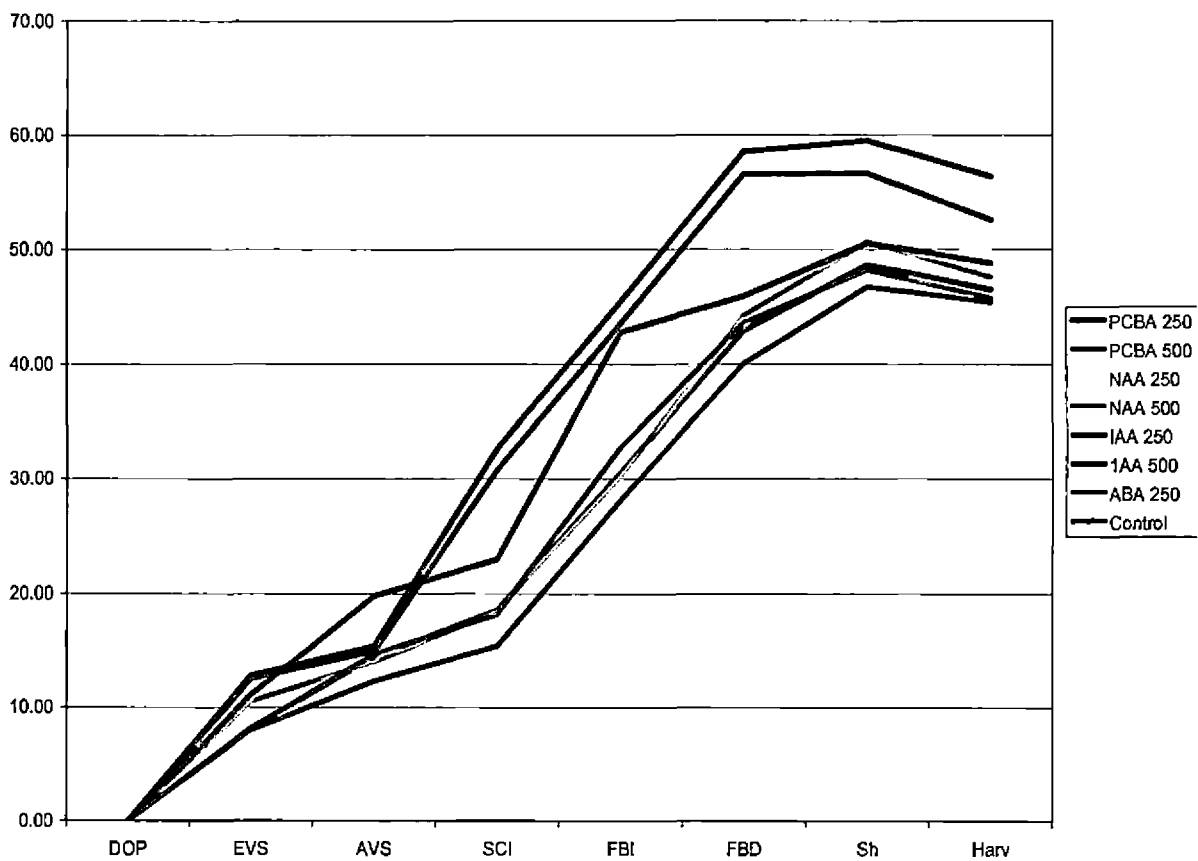
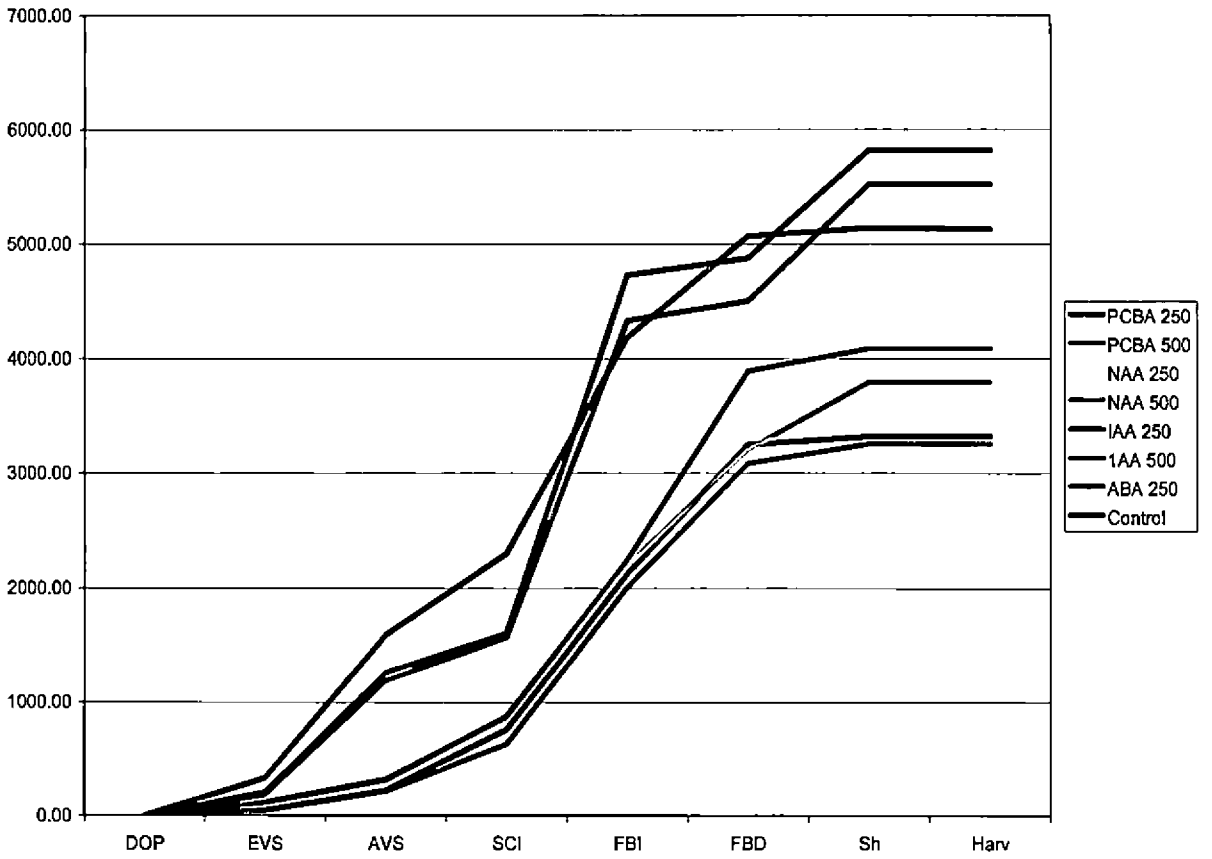


Table 67. D-Leaf Area (cm^2) at different stages of the hormone dip method

	EVS	AVS	SCI	FBI	FBD	Sh	Harv
PCBA 250	50.66^{e}	222.54^{f}	758.25^{d}	2124.54^{de}	3250.65^{f}	3323.57^{f}	3323.57^{f}
PCBA 500	47.65^{e}	214.68^{f}	628.56^{e}	2008.65^{e}	3089.40^{f}	3259.40^{f}	3259.40^{f}
NAA 250	123.10^{d}	351.50^{d}	895.34^{c}	2234.60^{d}	3450.50^{e}	3888.95^{e}	3888.95^{e}
NAA 500	120.00^{d}	323.50^{de}	865.68^{c}	2198.54^{d}	3206.57^{f}	3792.00^{e}	3792.00^{e}
IAA 250	205.65^{b}	1259.35^{b}	1607.68^{b}	4733.09^{a}	4881.27^{b}	5819.54^{a}	5819.54^{a}
1AA 500	188.37^{c}	1196.20^{c}	1574.50^{b}	4333.11^{b}	4509.30^{c}	5525.45^{b}	5525.45^{b}
ABA 250	116.54^{d}	310.86^{e}	875.32^{c}	2243.87^{d}	3889.50^{d}	4087.25^{d}	4087.25^{d}
Control	331.97^{a}	1592.91^{a}	2302.10^{a}	4183.42^{c}	5067.81^{a}	5137.83^{c}	5127.83^{c}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 65. D-Leaf Area (cm^2) at different stages of the hormone dip method



4.3.1.4 Leaf retention at different stages

The leaf retention in different treatments presented in table 68 and fig 66 showed a varying pattern. Maximum retention of leaves was observed for plants treated with both the concentrations of IAA and for control plants. Another interesting feature is that there was maximum retention of leaves in the case of PCBA treated plants till post SCI stage whereas it was least in IAA treated plants for the same period. However, leaves retained on the PCBA treated plants were rosette as is evident from the plates

Plate 72. Field showing banana plants under hormone dip treatment

Plate 73. Rosette stature of PCBA treated plant

Plate 74. PCBA 500ppm treated plant recovering from its stunted nature

Plate 75. PCBA 250ppm treated plant recovering from its stunted nature

Table 68. Leaf retention at different stages of the hormone dip method

	EVS	AVS	SCI	FBI	FBD	Sh	Harv
PCBA 250	6.35^{a}	8.56^{a}	11.30^{a}	11.63^{b}	12.05^{c}	10.06^{d}	5.20^{c}
PCBA 500	5.85^{b}	8.05^{c}	11.25^{a}	11.28^{c}	11.88^{c}	9.80^{e}	4.85^{d}
NAA 250	4.30^{c}	6.70^{d}	10.50^{b}	10.11^{d}	10.00^{de}	9.65^{e}	5.85^{b}
NAA 500	4.33^{c}	6.30^{e}	10.30^{b}	10.37^{d}	10.20^{d}	9.13^{f}	5.75^{b}
IAA 250	4.30^{c}	5.47^{f}	7.47^{c}	11.50^{b}	12.93^{a}	11.60^{a}	6.20^{a}
1AA 500	4.50^{c}	5.65^{f}	7.36^{c}	12.10^{a}	12.53^{b}	10.60^{c}	5.75^{b}
ABA 250	3.20^{d}	6.84^{d}	7.28^{c}	9.56^{e}	9.89^{e}	9.66^{e}	4.23^{e}
Control	5.50^{b}	8.25^{b}	10.85^{b}	11.56^{b}	12.60^{b}	11.25^{b}	6.58^{a}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 66. Leaf retention at different stages of the hormone dip method

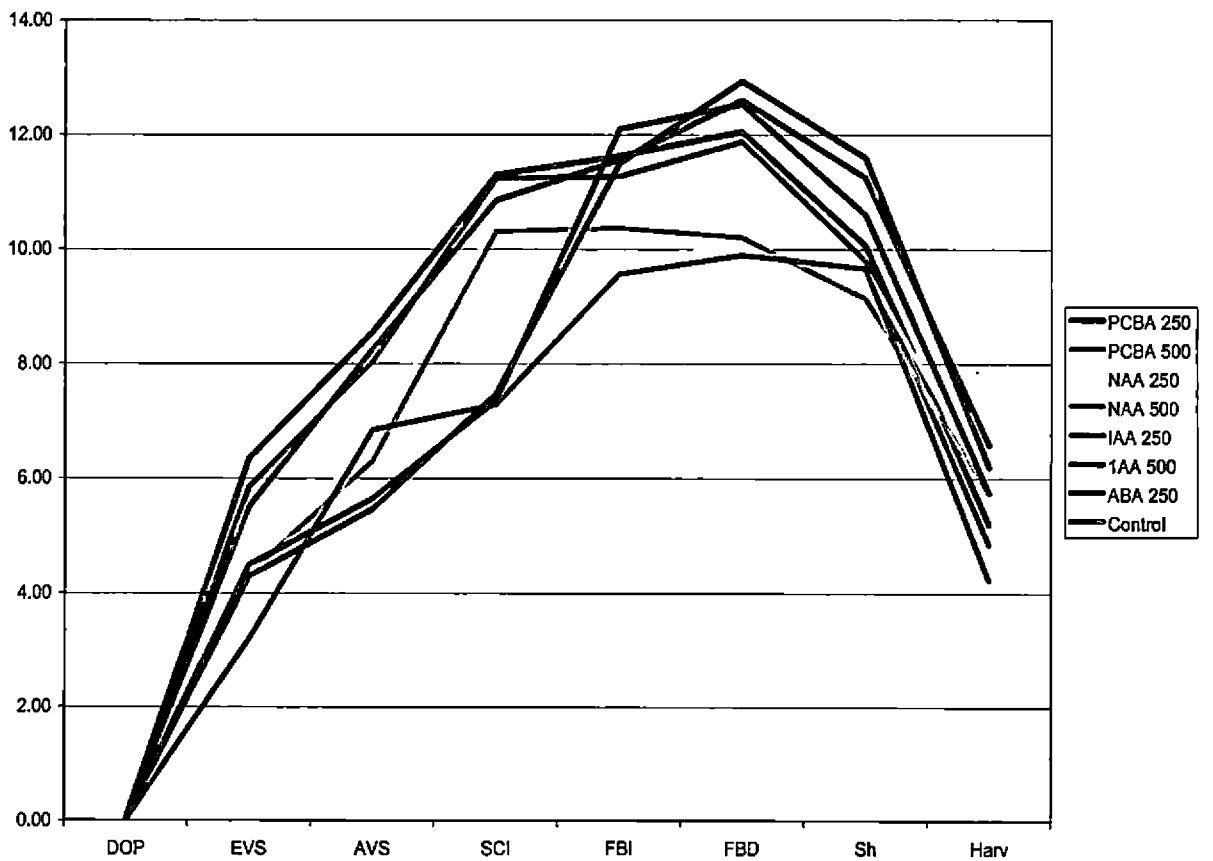
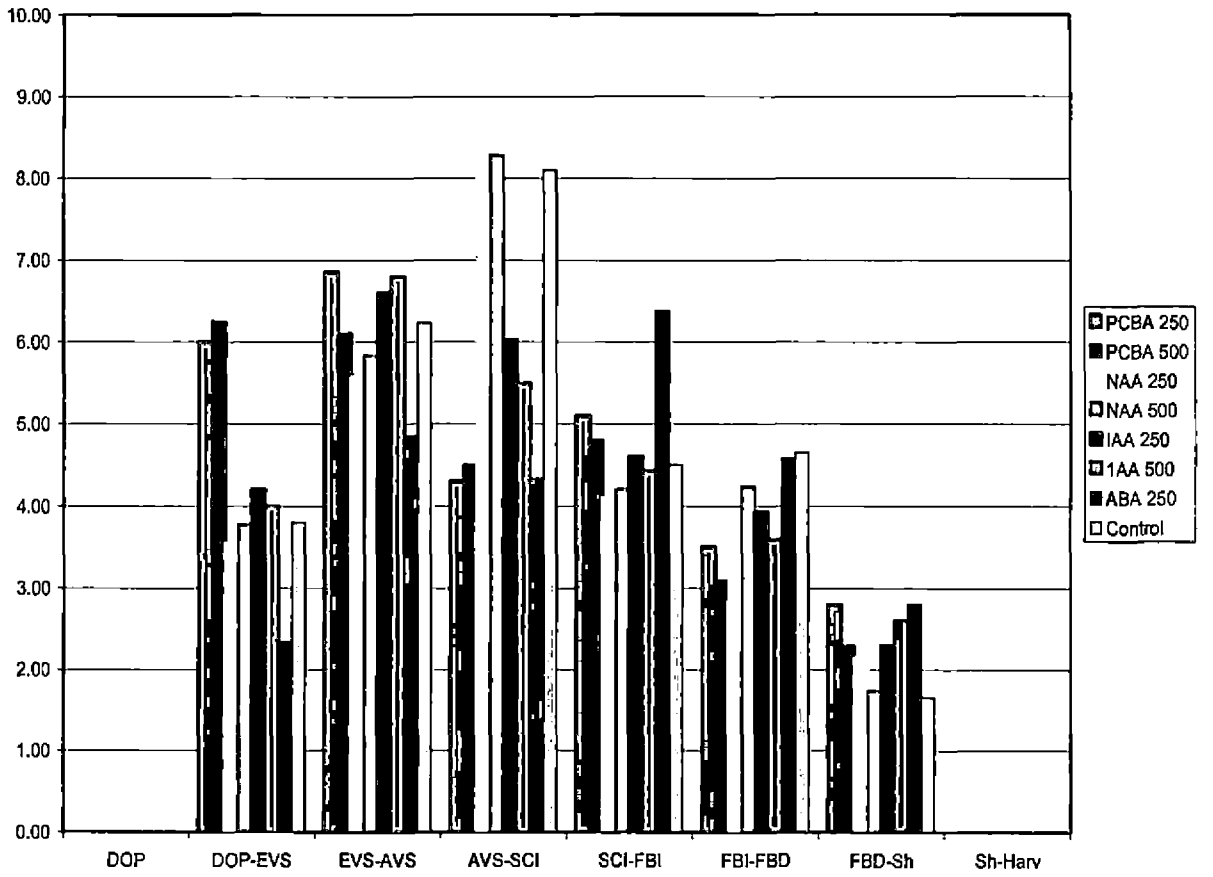


Table 69. New leaves produced at different stages of the hormone dip method

	DOP-EVS	EVS-AVS	AVS-SCI	SCI-FBI	FBI-FBD	FBD-Sh	Sh-Harv
PCBA 250	6.00[a]	6.85[a]	4.30[d]	5.10[b]	3.50[d]	2.80[a]	0
PCBA 500	6.25[a]	6.10[b]	4.50[d]	4.80[c]	3.09[f]	2.30[c]	0
NAA 250	3.55[c]	5.57[c]	8.73[a]	4.10[e]	3.27[de]	2.15[d]	0
NAA 500	3.77[c]	5.83[c]	8.27[b]	4.20[e]	4.23[b]	1.73[e]	0
IAA 250	4.20[b]	6.60[a]	6.03[c]	4.60[c]	3.93[c]	2.30[c]	0
1AA 500	4.00[b]	6.80[a]	5.50[c]	4.43[de]	3.60[d]	2.60[b]	0
ABA 250	2.35[d]	4.85[d]	4.33[d]	6.38[a]	4.58[a]	2.80[a]	0
Control	3.80[c]	6.23[b]	8.10[b]	4.50[cd]	4.65[a]	1.66[e]	0

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 67. New leaves produced at different stages of the hormone dip method



4.3.1.5 New leaves produced at different stages

The maximum number of new leaves produced during the initial stages was by PCBA treated plants (table 69 and fig 67). But it was found to be rosette and the individual leaves were thicker and more brittle than those on control plants. During AVS to SCI stage, the maximum number of new leaves was produced by the treatments with NAA, closely followed by the plants under control. During the period from SCI to FBI stage, the plants initially stunted by ABA treatment recovered and produced the maximum number of leaves. During FBI to FBD and from FBD to shooting stages, the number of new leaves produced was almost same irrespective of the treatments.

4.3.1.6 Yield and bunch characters

The data on yield and bunch characters of plants under hormone dip method are presented in table 70.

4.3.1.6.1 Bunch weight

The bunch weight of 5.80 kg recorded by plants under PCBA 250 ppm treatment was significantly superior to other treatments followed by plants under control.

4.3.1.6.2 D-Finger weight

Maximum weight of D-finger was recorded by the bunches from PCBA 250 ppm treated plants followed by NAA 250 ppm and the lowest was from the control plants.

Table 70. Yield parameters - Hormone Dip

Treatments	Bunch wt	D- Finger wt.	D-L	D-B	Pedicel Index		Curvature Index	Shelf life	No. of Days to harvest
	(kg)	(g)	(cm)	(cm)	prox.	Dist.		Days	Days
PCBA 250	5.80[a]	181.25[a]	21.50[a]	3.50[c]	1.96[d]	1.80[e]	614.29[b]	18.00[c]	296[a]
PCBA 500	4.67[e]	165.00[c]	19.40[d]	3.75[a]	1.99[d]	2.17[c]	520.36[e]	33.00[a]	244[d]
NAA 250	4.72[d]	172.50[b]	20.63[c]	3.45[d]	2.07[c]	2.38[a]	602.01[c]	23.50[b]	261[c]
NAA 500	5.30[b]	140.00[f]	18.50[e]	3.50[c]	1.88[e]	1.54[f]	528.57[e]	7.00[f]	261[c]
IAA 250	4.95[c]	156.00[d]	18.60[e]	3.82[a]	2.20[b]	2.19[c]	491.90[g]	15.40[d]	260[c]
IAA 500	4.28[f]	158.00[d]	19.10[d]	3.52[c]	2.18[b]	2.27[b]	543.42[d]	11.60[e]	260[c]
ABA 250	4.60[d]	150.00[e]	21.00[b]	3.00[e]	2.28[a]	2.13[c]	700.00[a]	8.00[f]	291[b]
CONTROL	5.42[b]	137.78[f]	18.29[e]	3.64[b]	2.19[b]	2.04[d]	505.16[f]	11.64[e]	261[b]

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

4.3.1.6.3 Curvature Index

The fingers from ABA treated plants had the maximum curvature index revealing maximum straightness of fingers followed by PCBA 250 ppm. All other treatments showed more or less similar values.

4.3.1.6.4 Pedicel Index

Maximum Pedicel Index (PI) at fruit/peel junction was in the case of ABA treated plants followed by IAA treated plants and control. The higher values show the vulnerability of the fruit to shedding.

4.3.1.6.5 Days to maturity / harvest

The number of days to maturity / harvest was least in PCBA 500 ppm treated plants and the maximum was for PCBA 250 ppm and closely followed by ABA treatment.

4.3.2. Hormone Injection Method

4.3.2.1 Plant height

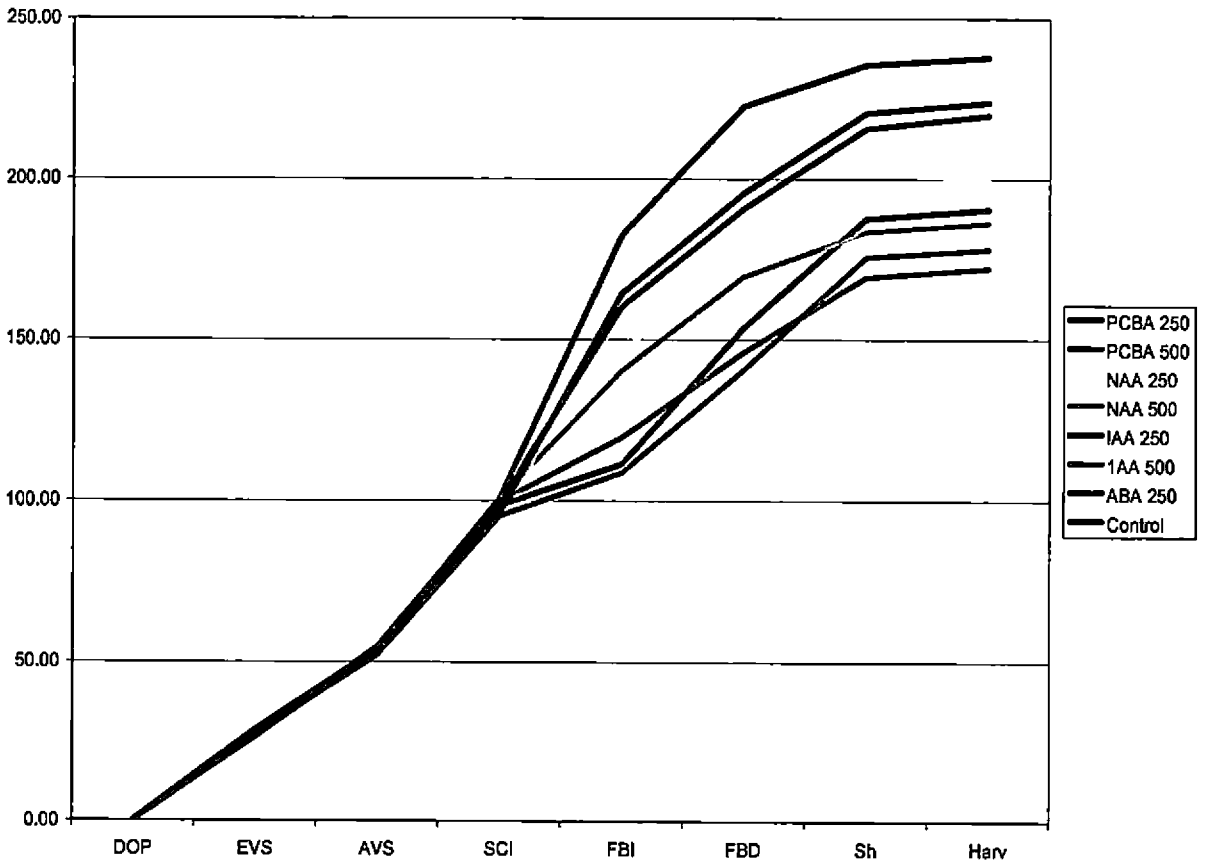
The height of the plant showed significant differences with the treatments as is evident from table 71 and fig 68. Maximum height among the treatments was attained by the plants treated with IAA 250 ppm whereas the stature was short in the case of plants treated with ABA 250 ppm. However, the plants under control were the tallest.

Table 71. Plant height (cm) at different stages of the hormone injection method

	PCBA 250	PCBA 500	NAA 250	NAA 500	IAA 250	1AA 500	ABA 250	Control
DOP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EVS	28.52^{a}	27.53^{a}	26.40^{b}	27.22^{a}	26.98^{a}	26.25^{b}	27.50^{a}	27.03^{a}
AVS	54.12^{a}	52.10^{c}	54.87^{a}	53.10^{b}	54.56^{a}	53.66^{b}	54.62^{a}	53.87^{b}
SCI	98.48^{c}	95.22^{e}	99.68^{b}	100.50^{a}	96.24^{d}	99.24^{b}	99.57^{bc}	100.57^{a}
FBI	111.26^{e}	108.65^{f}	146.58^{c}	140.22^{c}	164.50^{b}	160.40^{b}	119.53^{d}	182.54^{a}
FBD	153.68^{f}	140.70^{h}	174.35^{d}	169.50^{e}	195.67^{b}	190.85^{c}	145.97^{g}	222.67^{a}
Sh	187.66^{e}	175.68^{g}	197.60^{d}	183.42^{f}	220.56^{b}	215.65^{c}	169.35^{h}	235.46^{a}
Harv	190.57^{e}	178.23^{g}	200.00^{d}	186.16^{f}	223.87^{b}	219.88^{c}	172.12^{h}	237.88^{a}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 68. Plant height (cm) at different stages of the hormone injection method



4.3.2.2 Collar girth

There was a definite difference in the collar girth of all the plants under treatment after AVS. The plants treated with IAA 250 and 500 ppm exhibited higher values of collar girth compared to the control (table 72 and fig 69). These plants also showed a progressive increase in collar girth till FBD and thereafter a decline. The least collar girth was observed in the plants treated with ABA 250 ppm closely followed by PCBA and NAA treatments.

4.3.2.3 D-Leaf area

The D-Leaf area values presented in table 73 and fig 70 showed a much more interesting result. Contrary to the normal trend of increasing leaf area values from EVS to shooting stage, the D-leaf area of plants treated with PCBA 250 and 500 ppm exhibited a negative trend till FBI stage and thereafter increased to a steady value at FBD and shooting. Also the NAA treated plants showed a meager increment till FBI and thereafter increased progressively. The plants treated with IAA 250 had the highest values for D-Leaf area at any physiological stage.

4.3.2.4 Total number of leaves

The leaf retention on the plant at any particular stage also showed interesting trends (table 74 and fig 71). Maximum retention of leaves was observed in plants treated with both concentrations of IAA. A negative trend was found in the case of plants treated with PCBA and ABA till post SCI stage but thereafter regained normal trends but with lesser values.

Table 72. Collar girth (cm) at different stages of the hormone injection method

	PCBA 250	PCBA 500	NAA 250	NAA 500	IAA 250	1AA 500	ABA 250	Control
DOP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EVS	19.50^{a}	18.04^{a}	19.27^{a}	18.97^{a}	19.21^{a}	18.75^{a}	19.50^{a}	19.07^{a}
AVS	26.20^{a}	25.00^{a}	25.57^{a}	24.66^{b}	25.40^{a}	24.59^{b}	26.95^{a}	25.57^{a}
SCI	30.45^{d}	28.66^{f}	30.41^{d}	29.46^{e}	44.39^{a}	41.53^{b}	27.23^{g}	34.83^{c}
FBI	34.99^{d}	33.86^{e}	35.03^{d}	32.20^{f}	55.50^{a}	50.26^{b}	30.56^{g}	43.00^{c}
FBD	38.23^{e}	36.77^{f}	42.53^{d}	38.69^{e}	67.88^{a}	61.50^{b}	33.87^{g}	46.55^{c}
Sh	42.55^{e}	40.00^{f}	49.68^{d}	41.97^{g}	65.38^{a}	60.33^{b}	35.66^{h}	52.64^{c}
Harv	40.13^{d}	37.66^{e}	47.83^{c}	40.12^{d}	62.50^{a}	58.91^{b}	33.75^{f}	49.80^{c}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 69. Collar girth (cm) at different stages of the hormone injection method

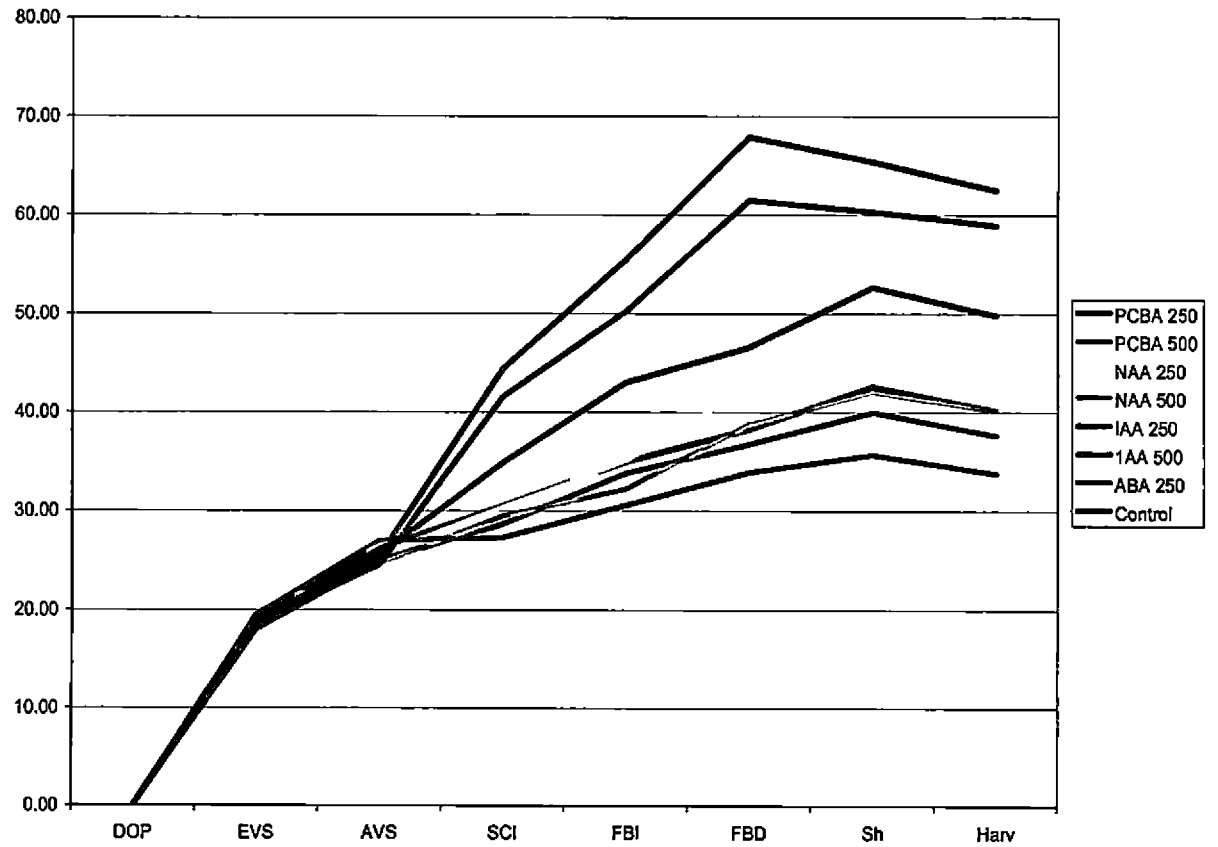


Table 73. D-Leaf Area (cm^2) at different stages of the hormone injection method

	PCBA 250	PCBA 500	NAA 250	NAA 500	IAA 250	1AA 500	ABA 250	Control
DOP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EVS	944.56[a]	936.54[b]	930.15[b]	924.67[c]	955.32[a]	924.10[c]	930.66[b]	934.67[b]
AVS	1103.57[f]	1152.30[e]	1510.35[d]	1508.10[d]	1549.80[a]	1522.00[c]	1538.40[b]	1540.29[a]
SCI	1414.23[d]	1234.50[e]	2365.14[b]	2234.80[c]	3865.15[a]	3801.46[a]	2238.50[c]	3214.24[b]
FBI	1549.63[f]	1447.20[g]	2434.80[e]	2398.50[e]	5680.30[a]	5290.35[c]	3568.40[d]	5398.43[b]
FBD	3160.78[g]	2996.35[h]	3500.86[e]	3349.60[f]	7961.46[a]	7368.16[b]	3980.47[d]	5597.28[c]
Sh	3498.56[g]	3239.84[h]	3489.57[e]	3450.25[f]	8825.90[a]	8225.33[b]	4229.43[d]	5824.00[c]
Harv	3498.56[g]	3239.84[h]	3489.57[e]	3450.25[f]	8825.90[a]	8225.33[b]	4229.43[d]	5824.00[c]

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 70. D-Leaf Area (cm^2) at different stages of the hormone injection method

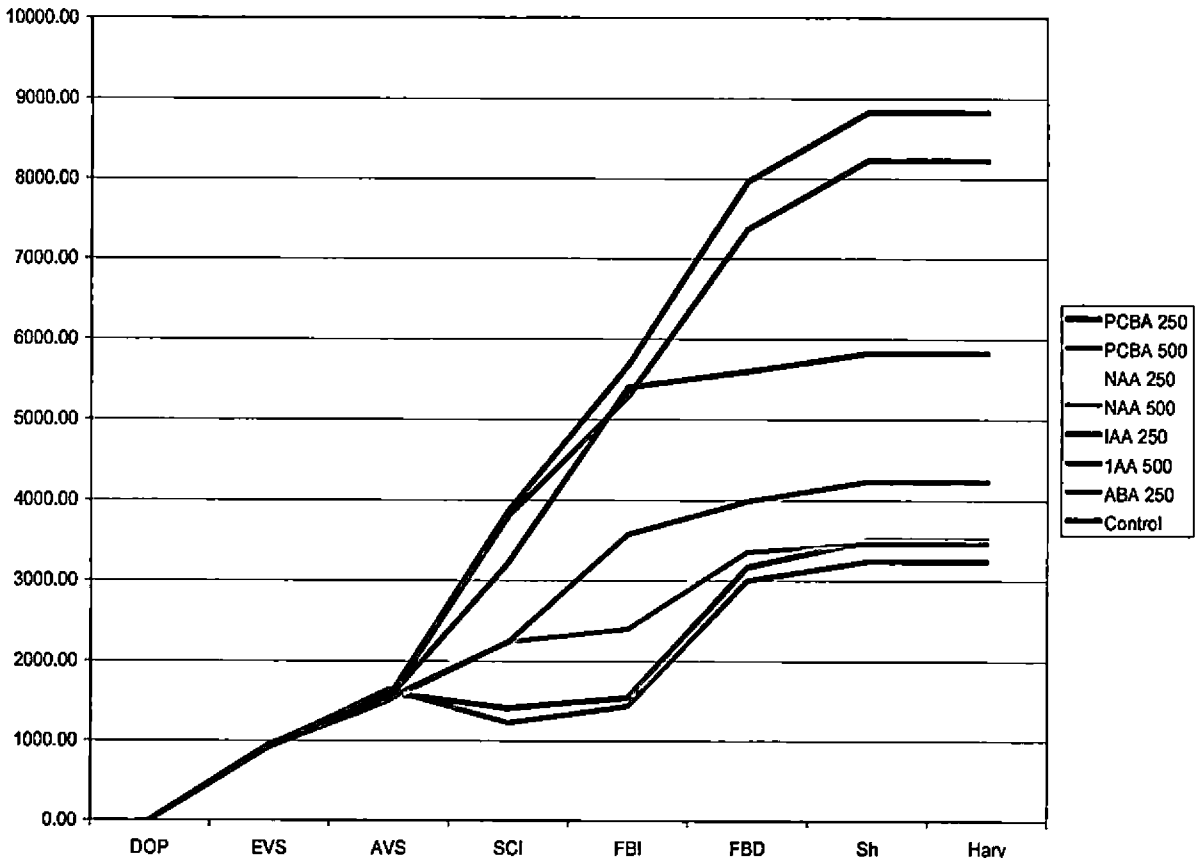


Table 74. Leaf retention at different stages of the hormone injection method

	PCBA 250	PCBA 500	NAA 250	NAA 500	IAA 250	1AA 500	ABA 250	Control
DOP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
EVS	4.00^{b}	3.80^{c}	4.01^{b}	3.95^{b}	4.20^{a}	3.88^{c}	4.10^{a}	4.00^{b}
AVS	7.52^{a}	7.50^{a}	7.33^{c}	7.25^{d}	7.45^{b}	7.55^{a}	7.25^{d}	7.37^{c}
SCI	8.00^{d}	7.88^{d}	9.03^{c}	9.00^{c}	12.23^{a}	11.85^{b}	7.33^{e}	12.03^{b}
FBI	10.55^{c}	10.23^{c}	10.24^{c}	10.05^{c}	12.50^{a}	11.90^{b}	9.95^{cd}	12.63^{a}
FBD	10.05^{d}	10.88^{c}	10.10^{d}	9.80^{0}	12.88^{a}	12.10^{b}	10.00^{d}	10.83^{c}
Sh	9.18^{f}	9.12^{f}	9.92^{d}	9.82^{d}	12.24^{a}	11.50^{b}	9.45^{e}	10.57^{c}
Harv	4.20^{e}	4.08^{e}	5.12^{c}	5.00^{cd}	7.50^{a}	6.52^{b}	4.88^{d}	5.23^{c}

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 71. Leaf retention at different stages of the hormone injection method

4.3.2.5 New leaves produced

The maximum number of new leaves at the initial growing stages was produced by the plants treated with IAA (table 75 and fig 72) and the new leaf production was retarded by PCBA treatments during the same period. However, post SCI stage, these plants were found to be relieved from their physiological retardation and produced more leaves during FBI and FBD stages.

Plate 76. Stunted nature of PCBA injected plant

Plate 77. PCBA injected plant recovered from its stunted nature

4.3.2.6 Yield and bunch characters

The data on yield and bunch characters of plants under hormone injection method are presented in table 76.

Table 75. New leaves produced at different stages of the hormone injection method

	PCBA 250	PCBA 500	NAA 250	NAA 500	IAA 250	1AA 500	ABA 250	Control
DOP	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DOP-EVS	3.00^{e}	3.10^{e}	4.20^{c}	3.80^{d}	4.80^{a}	4.50^{b}	3.75^{d}	3.75^{d}
EVS-AVS	5.83^{c}	4.83^{d}	4.99^{d}	4.70^{d}	6.75^{a}	6.50^{b}	5.84^{c}	6.33^{b}
AVS-SCI	2.23^{d}	2.25^{d}	6.75^{b}	6.27^{c}	6.85^{b}	6.45^{c}	2.15^{d}	8.00^{a}
SCI-FBI	4.95^{c}	5.00^{c}	6.10^{a}	5.00^{c}	4.50^{d}	4.09^{e}	5.35^{b}	4.60^{d}
FBI-FBD	5.50^{a}	5.40^{a}	4.27^{c}	4.23^{c}	3.22^{d}	3.01^{d}	4.42^{b}	4.50^{b}
FBD-Sh	3.95^{b}	4.30^{a}	1.15^{f}	1.03^{f}	2.25^{d}	2.45^{c}	2.75^{c}	1.73^{e}
Sh-Harv	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Fig 72. New leaves produced at different stages of the hormone injection method

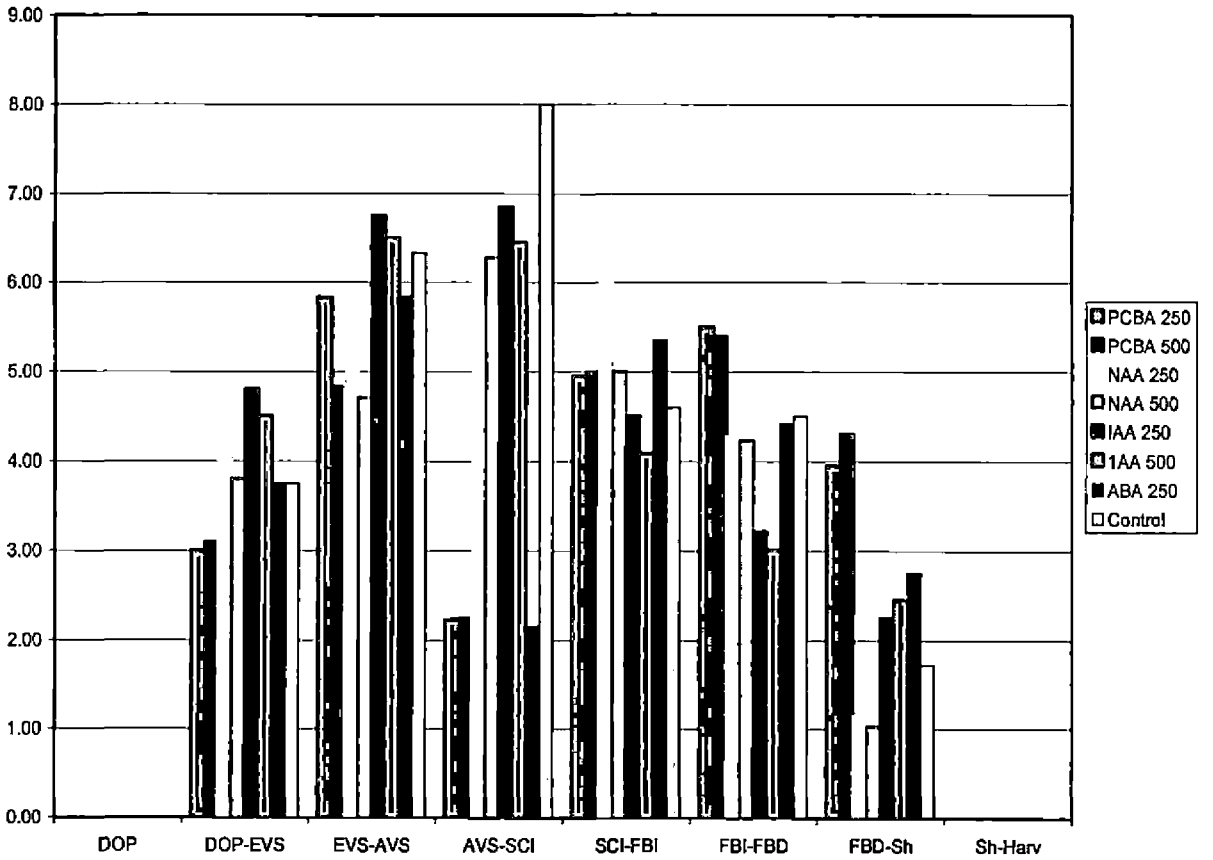


Table 76. Yield parameters - Hormone Injection Method

Treatments	Bunch wt	D- Finger wt.	D-L	D-B	Pedicel Index		Curvature Index	Shelf life	No. of Days to harvest
	(kg)	(g)	(cm)	(cm)	prox.	Dist.		Days	Days
PCBA 250	5.10[a]	228.33[a]	20.30[a]	3.50[a]	1.59[a]	1.51[a]	580.00[a]	12.40[a]	336[b]
PCBA 500	5.00[a]	210.00[e]	19.00[bc]	3.50[a]	1.75[a]	1.97[a]	542.86[e]	13.40[a]	291[e]
NAA 250	5.30[a]	213.00[b]	20.00[ab]	3.60[a]	1.46[a]	1.56[a]	555.56[c]	10.23[b]	306[cd]
NAA 500	4.98[a]	213.75[b]	18.00[c]	3.70[a]	1.43[a]	1.43[a]	486.49[g]	8.10[d]	306[cd]
IAA 250	5.57[a]	207.50[d]	19.00[bc]	4.00[a]	1.75[a]	1.75[a]	475.00[h]	9.70[bc]	306[cd]
IAA 500	4.32[a]	207.50[d]	19.50[ab]	3.50[a]	1.46[a]	1.78[a]	557.14[b]	8.90[cd]	305[d]
ABA 250	4.67[a]	195.00[e]	20.00[ab]	3.70[a]	2.01[a]	1.69[a]	540.54[f]	7.80[d]	352[a]
CONTROL	5.35[a]	185.91[f]	18.00[c]	3.30[a]	1.59[a]	1.62[a]	545.45[d]	10.80[b]	307[c]

Data represents mean value of fifteen replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

4.3.2.6.1 Bunch weight

Weight of the bunch was the maximum in plants treated with IAA 250 ppm followed by control and PCBA treated plants. The least bunch weight was observed in plants treated with IBA 500 ppm.

4.3.2.6.2 D-Finger weight

The D-finger weight showed almost a similar trend with that of corm dip method, the highest value for PCBA 250 ppm treated plants and the least for the plants under control.

4.3.2.6.3 Curvature Index

The fingers from PCBA 250 ppm treated plants had the maximum curvature index revealing maximum straightness of fingers followed by IAA 500 and NAA 250 ppm.

4.3.2.6.4 Pedicel Index

Maximum Pedicel Index (PI) at fruit/peel junction was in the case of ABA treated plants followed by IAA 250 ppm and PCBA 500 ppm treated plants. The higher values show the vulnerability of the fruit to shedding.

4.3.2.6.5 Days to maturity / harvest

The number of days to maturity / harvest was least in PCBA 500 ppm treated plants and the maximum was for ABA 500 ppm and closely followed by PCBA 250 ppm treatment.

4.4 Efficiency of absorption of nutrients using ^{32}P and translocation of photosynthates using ^{14}C.

4.4.1 Efficiency of absorption of nutrients using ^{32}P

4.4.1.1 Root activity at various biotic phases

In the initial sampling on the 5th day after application (DAA), recovery of activity in roots was observed mostly at half maturity bunch stage and FBI stage; probably due to the high requirements as roots at this stage are most active (table 77a and 77b). A comparison with activity of roots at other stages revealed that more than three fourth of recovery was observed at FBI stage.

On the tenth day, the roots at all biotic phases except that at EVS were active. Again, near to fifty percent of root activity was at FBI stage followed by that at shooting and SCI stage.

In the last sampling, the roots at all biotic phases were active. A shift in maximum relative activity was observed in the EVS and later two phases accounting for the lion's share.

4.4.1.2 Root activity in various flushes at different sampling intervals

The root activity in various flushes at different sampling intervals is presented in tables 78a and 78b. In the earliest sampling, ^{32}P recovery was observed only in the fourth

Table 77a. Recovery of activity (cpm/g) in roots at different growth phases and at different sampling intervals

	5th Day			10th Day			15th Day		
	R_1	R_2	R_3	R_1	R_2	R_3	R_1	R_2	R_3
½ Maturity	13	13	13	11	11	11	883	100	487
Shooting	0	0	0	65	65	65	282	370	364
FBD	3	3	3	20	20	20	95	27	41
FBI	212	17	77	74	325	136	98	22	41
SCI	0	0	0	56	56	56	46	12	145
AVS	0	0	0	8	8	8	32	55	14
EVS	0	0	0	0	0	0	353	668	555

Table 77b. Root activity (%) in various growth phases at different sampling intervals

	5th Day				10th Day				15th Day			
	R_1	R_2	R_3	*Av*	R_1	R_2	R_3	*Av*	R_1	R_2	R_3	*Av*
½ Maturity	5.7	39.39	13.98	*19.69*	4.70	2.27	3.72	*3.56*	49.36	7.97	29.37	*28.90*
Shooting	0	0	0	*0*	27.79	13.40	21.96	*21.05*	15.76	29.51	21.95	*22.41*
FBD	1.32	9.09	3.23	*4.55*	8.55	4.12	6.76	*6.48*	5.31	2.15	2.47	*3.31*
FBI	92.98	51.52	82.80	*75.77*	31.62	67.00	45.95	*48.19*	5.48	1.75	3.14	*3.46*
SCI	0	0	0	*0*	23.93	11.55	18.92	*18.13*	2.57	0.96	8.75	*4.09*
AVS	0	0	0	*0*	3.41	1.65	2.70	*2.59*	1.78	4.39	0.84	*2.34*
EVS	0	0	0	*0*	0	0	0	*0*	19.73	53.27	33.48	*35.49*

Table 78a. Recovery of activity (cpm/g) in various flushes of roots at different sampling intervals

Flush	5th Day			10th Day			15th Day		
	R_1	R_2	R_3	R_1	R_2	R_3	R_1	R_2	R_3
1st	0	0	0	0	0	0	353	668	555
2nd	0	0	0	8	8	8	32	55	14
3rd	0	0	0	56	56	56	46	12	145
4th	77	17	212	74	325	136	98	22	52
5th	0	0	0	65	65	65	282	370	364

Table 78b. Root activity (%) in various flushes at different sampling intervals

Flush	5th Day				10th Day				15th Day			
	R_1	R_2	R_3	*Av*	R_1	R_2	R_3	*Av*	R_1	R_2	R_3	*Av*
1st	0	0	0	*0*	0	0	0	*0*	43.53	59.27	49.12	*50.64*
2nd	0	0	0	*0*	3.94	1.76	3.02	*2.91*	3.95	4.88	1.24	*3.36*
3rd	0	0	0	*0*	27.59	12.33	21.13	*20.35*	5.67	1.06	12.83	*6.52*
4th	100	100	100	*100*	36.45	71.59	51.32	*53.12*	12.08	1.95	4.60	*6.21*
5th	0	0	0	*0*	32.02	14.32	24.53	*23.62*	34.77	32.83	32.21	*33.27*

flush. In the mid sampling date, no recovery was observed in the first flush and the fourth flush alone accounted for more than 50 percent of activity. The last three flushes together account for ninety seven percent of the total activity.

On the contrary, in the last sampling, the first flush accounted for more than fifty percent activity followed by the last (fifth) flush, which accounted for 33 percent of activity.

The study reveals that, in the early two flushes, photosynthate requirement for root growth was required only in the late stage and in the early stage it was more dependant upon the corm reserves.

4.4.1.3 Temporal accumulation of ^{32}P in various tissues

Studies in the EVS showed differential accumulation in tissues with passage of time and is presented in table 79. On the 5th DAA, accumulation was noticed only in the pseudostem, whereas on the 10th DAA it was observed only in the primary corm; which means that cent percent accumulation occurred only in these tissues in the above samplings. In the final sampling interval, recovery of activity was observed in all tissues with the pseudostem accounting for 46% of activity followed by primary corm (24.38%) and leaf (13.46%).

Table 79. Temporal accumulation of ^{32}P in various tissues (%)

Percentage	Half Maturity			Shooting			FBD			FBI		
	5 DAA	10 DAA	15 DAA	5 DAA	10 DAA	15 DAA	5 DAA	10 DAA	15 DAA	5 DAA	10 DAA	15 DAA
Pri corm	0.00	0.00	0.12	0.00	1.89	4.00	50.00	0.00	25.44	0.00	4.79	18.98
Sec Corm	0.00	43.99	9.71	0.00	13.93	13.72	15.00	13.89	14.66	0.00	39.39	38.53
Roots	17.31	23.04	28.82	0.00	40.93	7.64	15.00	55.56	18.55	100.00	16.82	12.60
Pseudo	41.25	0.00	11.32	0.00	8.97	4.30	0.00	0.00	18.71	0.00	26.33	18.99
D Leaf	0.00	2.10	11.96	0.00	0.00	11.08	20.00	30.55	7.15	0.00	9.55	0.00
D Petiole	0.00	18.29	7.39	0.00	10.54	7.56	0.00	0.00	15.50	0.00	3.13	10.90
Boot	0.00	0.00	3.52	0.00	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00
D Finger	38.44	12.58	14.90	81.60	15.59	8.09	0.00	0.00	0.00	0.00	0.00	0.00
Male bud	3.00	0.00	12.26	18.40	8.14	43.40	0.00	0.00	0.00	0.00	0.00	0.00

Percentage	SCI			AVS			EVS		
	5 DAA	10 DAA	15 DAA	5 DAA	10 DAA	15 DAA	5 DAA	10 DAA	15 DAA
Pri corm	0.00	5.57	14.45	0.00	35.31	53.85	0.00	100.00	24.38
Sec Corm	0.00	26.10	31.60	0.00	0.00	0.00	0.00	0.00	0.00
Roots	0.00	34.63	6.95	0.00	35.35	4.90	0.00	0.00	8.87
Pseudo	0.00	15.73	14.34	100.00	29.34	26.03	100.00	0.00	46.26
D Leaf	0.00	10.55	15.60	0.00	0.00	3.51	0.00	0.00	13.46
D Petiole	0.00	7.42	17.06	0.00	0.00	11.72	0.00	0.00	7.03
Boot	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
D Finger	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Male bud	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DAA – Days After Application

In the AVS, the trend was almost similar to that observed in EVS, with 100% recovery in the pseudostem in the early sampling. In the second sampling however, accumulation was spread in the primary corm, roots and pseudostem, the former two accounting for the lion's share of more than 35% each. In the final sampling, recovery was spread in all tissues, the maximum being in the primary corm (37%) followed by pseudostem, which is the reverse order seen in EVS.

At SCI stage, in the early sampling, no accumulation was observed in any of the tissues. However, on the 10^{th} day, all tissues showed recovery of activity with maximum accumulation in roots and secondary corm with 35% and 26% respectively. On the other hand, in the final sampling, the secondary corm showed maximum accumulation (32%) followed by leaf and petiole (16% and 17%) respectively.

At the FBI stage, recovery of activity in the early sampling was confined only to the roots. Whereas in the 10^{th} day, recovery was observed in all tissues, the lion's share being in the secondary corm (39%) followed by pseudostem (26%). A similar tend was observed in the final sampling, except that the primary corm also showed sizeable accumulation.

Contradictory to what was observed in the early samplings at EVS and AVS, the pseudostem did not account for any accumulation in the early samplings at FBD stage. Maximum accumulation was observed in the primary corm accounting for 50% of total accumulation followed by leaf, secondary corm and roots. On the 10^{th} day, maximum

accumulation of nearly 56% was observed in the roots followed by leaves and secondary corm. The pseudostem, petiole and primary corm showed no accumulation at all. In the final sampling on the 15th day, accumulation was observed in all tissues with primary corm, roots and pseudostem accounting for 25% and 19% each respectively.

At shooting phase, in the early sampling, accumulation was confined to only two tissues, *viz.* the finger and the male bud accounting to 82% and 18% of the total activity respectively. On the 10th day, recovery was spread in all tissues except the D-leaf and boot leaf. Maximum recovery was observed in the roots (>40%), followed by D-finger. In the final sampling, recovery was observed in all tissues with the giant's share of accumulation being in the male bud (>43%) followed by the secondary corm, leaf and finger respectively. The boot leaf showed negligible value of 0.2%. At half maturity stage of the finger, accumulation was observed in the early sampling only in three tissues, the pseudostem (42%), finger (39%) and roots (18%) in the order. Whereas on the 10th day, pseudostem showed no accumulation at all. Maximum accumulation was observed in the secondary corm followed by roots and petiole. On the 15th day, accumulation was observed in all tissues with the roots showing maximum activity followed by the finger and male bud respectively.

The study overwhelmingly emphasizes the need to de-bud the male inflorescence on the one hand and on the other important major side, it highlights the use of this part as a vegetable with high P nutrient content.

4.4.2. Translocation of photosynthates using ^{14}C.

In the EVS, the maximum photosynthate accumulation was observed in the leaf itself (53.14%) followed by the pseudostem and petiole, the only three tissues which accounted for assimilates (table 80).

At AVS again, the ^{14}C recovery was maximum in the leaf (62.07%) followed by the petiole (14.26%), primary corm and pseudostem, the latter two tissues accounted for a little over eleven percent each. In this stage also, though accumulation spread to primary corm, the relative accumulation was higher in the source leaf.

At SCI, the prominence of the source leaf gradually gets reduced with pseudostem showing maximum accumulation followed by the leaf, petiole and secondary corm. The primary corm did not show any trace of ^{14}C recovery.

At FBI and FBD stages, the importance of source leaf remains just as an organ of carbon assimilation and the entire photosynthate is translocated to the secondary corm and pseudostem. In the FBI stage, the relative accumulation in the former is 83 per cent and the latter is 17 per cent respectively whereas in FBD stage it is 88 percent and 12 per cent respectively. This shows that relative accumulation in secondary corm progressively increases upto FBD stage.

Table 80. Photosynthate translocation and accumulation in various tissues at different plant stages using ^{14}C

	EVS	AVS	SCI	FBI	FBD	Shooting	Half Maturity
Pri corm		160					
%		*11.84*					
Sec Corm			195	352	500		
%			*10.87*	*83.35*	*87.83*		
Roots							
%							
Pseudo	217	165	674	70	70		
%	*39.60*	*11.83*	*37.30*	*16.65*	*12.17*		
D-Leaf	284	909	608				
%	*53.14*	*62.07*	*32.51*				
D-Petiole	39	203	349				
%	*7.26*	*14.26*	*19.31*				
Boot Leaf							
%							
D-Finger						262	1328
%						*26.83*	*76.84*
Male bud						708	402
%						*73.17*	*23.16*

At shooting the entire picture changes. The finger and the male bud together account for the whole photosynthates, with the former accounting for 27 per cent and the latter 73 per cent respectively

At the final biotic phase again the whole photosynthate assimilate is accumulated in the sink namely the finger and the male bud but in the reverse order. The accumulation in the finger being in the order of above 76 percent and that in the male bud being less than 24 per cent. The overall photosynthate mobilization into tissues are really a marked reflection and manifestation of the structural and functional requirement of the plant.

4.5 Studies on the depth of planting

Sprouting was affected by the depth of planting. Suckers which are planted at maximum depth took more time to sprout. Sprouting was earliest in the graded order of shallowness of planting. The morphological characters of the plants under study are presented in tables 81a to 81f.

4.5.1 Morphological characters

4.5.1.1 Height

The stature of the plant is presented in table 81a. An analysis of the data reveals that the plant height was affected in the early stage. By the AVS, the difference tapers off. The shallowest planting recorded the maximum height which decreased with the increase in depth of planting.

4.5.1.2 Collar girth

Collar girth (Table 81b) was the maximum in the case of shallow depth of planting except at SCI and FBD. Towards the latter stages *ie.*, shooting and harvest, collar girth was maximum at shallow depths and minimum in the deepest planting.

4.5.1.3 New leaves produced at each stage

In the EVS number of leaves produced in shallow depth was drastically low but however, towards SCI and FBI wherein more number of leaves was seen in the deepest planting (Table 81c). Towards the last stage, the total leaves produced ranged from 26-28, the former in shallow and the latter in 20 & 30 cm depth.

4.5.1.4 Leaf retention at each stage

Except at the EVS and AVS, the number of leaves retained was almost the same, which was more a reflection of delayed sprouting (Table 81d).

4.5.1.5 D-Leaf area

The D-leaf area was at all the stages the highest in shallowest depth *ie.*, at 10 cm (Table 81e).

4.5.1.6 Canopy area

Canopy area was highest in the shallowest planting at all the stages with the differences increasing with passage of time (Table 81f).

Table 81. Morphological characters of plants in studies on depth of planting

Table 81a. Plant height

	10 cms	20 cms	30 cms
EVS	28.90[a]	17.35[b]	5.80[c]
AVS	41.31[a]	39.40[b]	37.50[c]
SCI	92.12[a]	67.93[b]	91.27[a]
FBI	147.57[b]	143.07[c]	167.38[a]
FBD	177.58[a]	171.57[b]	187.73[c]
Shooting	219.60[a]	214.95[b]	205.12[c]
Harvest	220.90[a]	217.30[b]	206.90[c]

* Notes

Table 81b. Collar girth

	10 cms	20 cms	30 cms
EVS	14.59[a]	10.54[b]	7.77[c]
AVS	20.10[a]	18.23[b]	13.35[c]
SCI	28.41[a]	26.72[b]	28.54[a]
FBI	42.61[a]	40.89[b]	42.65[a]
FBD	46.35[a]	43.67[b]	46.13[a]
Shooting	51.30[a]	46.38[b]	46.34[b]
Harvest	47.30[a]	45.03[b]	44.70[b]

* Notes

Table 81c. New Leaves at each stage

	10 cms	20 cms	30 cms
EVS	4.5[a]	4.6[a]	1.4[b]
AVS	5.9[a]	5.8[a]	5.9[a]
SCI	4.8[b]	3.7[c]	7.3[a]
FBI	6[c]	7.2[b]	7.8[a]
FBD	2.6[a]	2.5[a]	2.5[a]
Shooting	2.4[c]	4[a]	3.1[b]
Harvest	0	0	0

* Notes

Table 81d. Leaf retention at each stage

	10 cms	20 cms	30 cms
EVS	7.50[a]	4.60[b]	1.40[c]
AVS	10.40[a]	10.40[a]	7.30[b]
SCI	9.90[a]	10.10[a]	9.40[a]
FBI	9.20[b]	9.50[a]	9.60[a]
FBD	9.60[a]	9.50[a]	9.20[b]
Shooting	9.70[a]	8.60[b]	8.60[b]
Harvest	7.80[a]	7.10[b]	7.20[b]

* Notes

Table 81e. D-Leaf Area

	10 cms	20 cms	30 cms
EVS	64.55[a]	61.79[a]	18.46[b]
AVS	714.11[a]	649.07[b]	572.33[c]
SCI	1254.59[a]	1034.50[c]	1150.82[b]
FBI	2773.80[a]	2377.49[c]	2538.78[b]
FBD	3252.04[a]	2655.49[c]	2973.26[b]
Shooting	3494.29[a]	3396.94[b]	2943.66[c]
Harvest	3494.29[a]	3396.94[b]	2943.66[c]

* Notes

Table 81f. Canopy Area

	10 cms	20 cms	30 cms
EVS	484.10[a]	284.25[b]	25.85[c]
AVS	7426.75[a]	6750.34[b]	4177.99[c]
SCI	12420.43[a]	10448.47[b]	10817.67[b]
FBI	25518.98[a]	22586.12[c]	24372.31[b]
FBD	31219.60[a]	25227.11[c]	27353.97[b]
Shooting	33894.60[a]	29213.67[b]	25315.50[c]
Harvest	27255.45[a]	24118.26[b]	21194.37[c]

* Notes

* Data represents mean value of thirty replications
* DMRT Test performed for row comparison
* Values with same superscript form a homogenous group (comparison row-wise only) at 5% significance level

4.5.2 Yield and bunch characters

The yield and bunch characters in this experiment (table 82) did not vary significantly between treatments with respect to bunch weight, number of hands, number of fingers, pedicel index, curvature index or shelf life. But earliness was observed in shallow planted suckers (10 cm) followed by 20 cm and 30 cm in the order.

4.6 Studies on Retention *Vs* Detachment of Primary Corm

Plate 78. Field layout of the *ex situ* treatments

Table 82. Yield parameters – Depth of planting

Treatments	Bunch wt	No. of hands	No. of fingers	D-finger weight	Pedicel Index		Curvature Index	Shelf life	No. of Days to harvest
	(kg)			(g)	Prox.	Dist.		Days	Days
10 cm	3.18[a]	3.8[a]	14.4[a]	189.2[a]	2.35[a]	2.14[a]	460[c]	2.67[a]	341[c]
20 cm	3.30[a]	4.0[a]	14.6[a]	186.1[b]	2.28[a]	2.04[a]	463[b]	2.77[a]	352[b]
30 cm	3.00[a]	3.7[a]	14.1[a]	186.8[b]	2.33[a]	2.10[a]	467[a]	2.70[a]	363[a]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

4.6.1 Morphological characters

4.6.1.1 Plant Height

Height of the plants under the different treatments did not vary much till SCI stage (table 83). But differences were seen from SCI with the *in situ* retained plants exhibiting the maximum height and the shortest plants were observed in the *ex situ* top cut plants.

4.6.1.2 Collar Girth

There is a comparable reduction in collar girth in the primary corm detached and planted suckers till harvest (table 84). This was closely followed by the *ex situ top cut* planting. The largest collar girth was observed by the *in situ* retained plants.

4.6.1.2 Retention of leaves

The total number of leaves retained on the plant at any particular stage did not show any significant difference. However, the *ex situ* primary corm detached plants showed least retention leaves at harvest whereas the maximum retention of leaves at harvest was observed in *in situ* retention of plants (table 85).

4.6.2 Yield and Bunch characters

The yield and bunch characters of the plants under the study are presented in table 86.

Table 83. Plant height (cm) in Retention *Vs* Detachment studies

Treatments	EVS	AVS	SCI	FBI	FBD	Sh	Harv
In situ retention	30.35[a]	52.50[a]	80.60[a]	151.83[b]	182.69[b]	227.31[a]	229.90[a]
Ex situ planting as such	30.53[a]	52.92[a]	79.96[a]	127.28[c]	180.15[b]	210.87[b]	214.80[b]
Ex situ planting top cut	30.72[a]	52.34[a]	80.84[a]	110.60[d]	138.70[c]	162.17[c]	166.20[c]
Ex situ primary corm detached	30.50[a]	52.51[a]	80.60[a]	165.60[a]	188.70[a]	210.66[b]	212.90[b]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table 84. Collar girth (cm) in Retention *Vs* Detachment studies

Treatments	EVS	AVS	SCI	FBI	FBD	Sh	Harv
In situ retention	7.85[a]	15.70[b]	25.10[a]	40.43[a]	48.35[a]	57.01[a]	53.10[a]
Ex situ planting as such	7.90[a]	15.83[b]	22.50[b]	33.83[b]	47.03[b]	50.81[b]	47.10[b]
Ex situ planting top cut	7.95[a]	16.25[a]	22.00[b]	33.66[b]	40.31[c]	47.92[c]	43.60[c]
Ex situ primary corm detached	7.89[a]	16.30[a]	25.10[a]	34.90[b]	40.43[c]	45.81[d]	41.30[d]

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table 85. Total leaves produced in Retention *Vs* Detachment studies

Treatments	EVS	AVS	SCI	FBI	FBD	Sh	Harv
In situ retention	6^{a}	8^{a}	10^{b}	12^{b}	13^{a}	14^{a}	8^{a}
Ex situ planting as such	5^{a}	8^{a}	11^{a}	13^{a}	13^{a}	14^{a}	7^{b}
Ex situ planting top cut	6^{a}	8^{a}	11^{a}	10^{c}	13^{a}	14^{a}	6^{c}
Ex situ primary corm detached	6^{a}	8^{a}	10^{b}	10^{c}	12^{b}	13^{b}	5^{d}

Data represents mean value of thirty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

Table 86. Yield and bunch characters of Retention *Vs* Detachment studies

Treatments	Days to harvest	Bunch wt	Hands	Total Fingers	D-finger weight	Shelf Life	Finger		Curvature Index	Filling Index		PI	PI
		(kg)	(no)		(g)		Length	Girth		L/W	W/L	Prox	Dist.
In situ retention	260^{d}	8.92^{a}	5.80^{a}	53.30^{a}	195.50^{a}	4.40^{a}	19.9^{a}	12.94^{a}	506.21^{b}	0.10^{d}	9.85^{a}	2.27^{c}	1.90^{c}
Ex situ planting as such	306^{c}	7.75^{b}	5.40^{a}	42.40^{b}	192.00^{a}	3.20^{b}	20.3^{a}	12.80^{a}	533.37^{a}	0.11^{c}	9.56^{b}	2.64^{a}	2.47^{a}
Ex situ planting top cut	313^{b}	4.35^{c}	4.20^{b}	27.00^{c}	136.00^{b}	3.20^{b}	16.54^{b}	11.22^{b}	455.36^{c}	0.12^{b}	8.49^{c}	2.42^{b}	2.10^{b}
Ex situ primary corm detached	328^{a}	2.90^{d}	3.80^{c}	22.50^{d}	120.50^{c}	3.00^{b}	16.51^{b}	11.20^{b}	401.47^{d}	0.14^{a}	7.55^{d}	2.35^{bc}	1.89^{c}

Data represents mean value of twenty replications
DMRT Test performed for column comparison
Values with same superscript form a homogenous group (comparison column-wise only) at 5% significance level

4.6.2.1 Days to harvest

The least number of days taken to harvest was the *in situ* retention and *ex situ* planted suckers as such, the former being earlier than the latter by more than a month. The pseudostem cut plants came to harvest at the next stage, the difference being more than a fortnight than the *ex situ* planting. The primary corm detached took maximum time to reach harvest.

4.6.2.2 Bunch yield

Bunch yield was maximum in the *in situ* treatment (8.92 kg) followed by *ex situ* intact planting (7.8 kg). Both the *ex situ* top cut and *ex situ* primary corm detached plants gave inferior incomparable yields.

4.6.2.3 Number of hands and Number of fingers

The yield data was more a reflection of hands and fingers. The intact plants retained as such and replanted gave on an average more number of hands and fingers.

4.6.2.4 Length of fingers

The length of fingers was the highest in the *ex situ* intact planting followed by *in situ* retention as such. The other two treatment's average values were comparatively inferior.

4.6.2.5 Girth of fingers

The grade of the fingers in terms of the girth was maximum in the *in situ* retention treatment followed by the *ex situ* intact planting. Both the other treatments prove that the partial removals severely affect the roundness of the fruit at harvest.

4.6.2.6 Filling index

The filling index was the highest in *in situ* retention followed by *ex situ* intact planting.

4.6.2.7 D-finger weight

D-finger weight differences were pronounced with weights being the maximum in the suckers maintained intact at planting (*in situ* retention and *ex situ* planting) and the average weight differences between the above two being very small. The other two treatments produced inferior quality fingers as evident from its very less average weights.

4.6.2.8 Curvature Index

Maximum values were registered by the *ex situ* intact planting treatment showing that the fruits were least curved, followed by the *in situ* retention treatment. The values of the pseudostem cut and primary corm detached were low showing that the fruits were curved.

4.6.2.9 Pedicel Index

Pedicel index showed a distinct variation with *ex situ* intact planting registering maximum values. The *in situ* retention treatment registered the least values which were more a reflection of increased diameter of petiole.

4.6.2.10 Shelf Life

The shelf life of fruit was the maximum in the *in situ* retention treatment. The *ex situ* intact planting and pseudostem cut and removed treatment showed the same shelf life whereas the lowest was in primary corm detachment treatment.

Discussion

DISCUSSION

Bananas are among the largest herbs in the world. They are perennials cultivated as annuals with tall aerial shoots that arise from the swollen fleshy corms. The aerial shoots comprising of the petioles that subtend the leaves are spirally arranged and their long overlapping bases form a tough pseudostem. This forms the shoot in the vegetative phase. In the reproductive phase, through the centre of the pseudostem, the terminal inflorescence grows. In short, the aerial shoot in the reproductive phase consist of the above with the bunch and the male bud.

The swollen corm, the seat of the entire growth, development and differentiation is the hub of all the activities in the continuous production of leaves in the vegetative stage and the bunch in the ontogenic transformation in the reproductive stage. Yield *per se* is predetermined in terms of the number of hands and fingers at the growing tip level and can be visualized at the primordial level as the growing tip changes from the vegetative to reproductive phase (Biju and Kurien, 1994).

The present study revolves around this swollen base – the corm. The discussion of the results generated in this study are explained under the following broad sub headings.

5.1. Seasonal effects on biotic events and yield in banana

Among the bimonthly plantings the mid June planting gave the highest yield and better finger characters. A critical analysis of all the conditions prevailing during the crop span revealed that there were no limitations and the crop received heavy rainfall during the early stage and a well distributed rainfall for well over six months. Thus the crop has received ambient favourable conditions during its ontogenic transformation and critical phases of flower bud initiation, differentiation and shooting. The Dec-January months again provide ideal optimum conditions for leaf production and retention with day/night temperature in the range of 30-35/20-25°C which coincides with the pre shooting stage of the crop.

A second reason for the high yield of June planting is the number of leaves retained at shooting and harvesting which is one of the theories proposed on flowering in banana. The results of the findings of planting of a recently concluded four year project carried out in all the five agro-ecological zones of Kerala point to and conclusively prove the overwhelming effect of leaf area and bunch yield. Exhaustive studies using labeled $^{14}CO_2$ had also confirmed that different leaves contribute differentially to the development of different hands and this can explain why the older hands particularly the second have better finger characters (Kurien, 2008). The present study has also confirmed and proves beyond doubt that higher yield realized are in the plantings where the number of leaves retained at harvest is more, thereby an increased leaf area and consequent

photosynthetic harvest for nourishment of developing hands and fingers and ultimately resulting in higher yields. Conversely, the February planting recorded least retention of leaves at harvest and hence the worst yield.

In the state, the Nendran bananas are planted predominantly in two seasons, namely the August–September (irrigated) and Feb-March (rainfed summer bananas). Kerala also has the dubious distinction of having one of the richest clonal variations and yet one of the lowest productivity in the whole nation. This is mainly due to the low yield standards realized in summer bananas.

Another probable reason is that of the root characters, the data presented on the different root characters substantiates and validates the profound influence of roots and its bearing on yield.

A fourth significant aspect is of realization of thermal units i.e. the ratio of photo-thermal units to the realization of heat units against the theoretical potential. The estimates reveal that as this ratio nears to 0.5 the yield recorded is the best.

Hence the above different factors could have either individually or collectively acted to contribute to the maximum realization of yield as in June planting or adversely affected to result in poor yields as in February planting.

5.2 Developmental physiology of banana corm based on graded corm size

A lot of research work has been done on inducing early bunch in banana that too using bigger size corm. The definite advantage of using this big size corms in initiating early bunches has been well documented. In the present study also, not only early bunches were initiated and harvested, the real process in operation has been well understood.

Convincing results have been generated to show to the extent that the larger size corm takes lesser time to SCI stage. The larger the size, the earlier was the time taken to reach SCI. From the point of SCI to harvest, it was almost the same requirement for all graded size of corms.

One of the main factors influencing earliness beginning from sprouting to harvest should have been the high amount of reserves the starchy corm has retained. The smaller corm size had to thrive on the limited supply of reserves and hence should have lead to the delayed sprouting and delayed invigoration. In the present study, initially a swelling of the primary corm was observed in all grade sizes. At AVS, the primary corm has been observed as a major sink in both the ^{32}P and ^{14}C studies which also coincides with the stage of primary corm enlargement. The larger planted corms are more bulked and more bountiful in their available reserves. Thus the larger corms should have functioned in a more efficient role till the crop harvest than the smaller corms as the effect of planted corms have been observed upto harvest.

Another major point to be reckoned is the maturity factor of the corm to the onset of SCI. The larger corms have definitely taken much lesser time calculated on the basis of GDD, the values show that the smallest corm required 1½ times more and the medium required another quarter time to reach SCI. This clearly shows that perception of temperature stimulus is better oriented in larger corms. Thus a signal-stimulus-response factor is likely to be in operation.

Another factor is that in the larger corms, the complimentary role played by the primary corm is far more efficient and probably being larger in volume and size, should have been more durable over a longer or extended period of time. The extended period coincides with the critical periods of shooting and maturity. This is evident from the dry weights of larger corms observed in the study.

A third factor in operation is the development of secondary corm. The larger corms produced secondary corms that took lesser time to the stage of peak bulking. However, when the stage from SCI to harvest was calculated, the thermal units (GDD) were almost uniform for almost all the three graded sizes. Thus the earliness of a bunch, other things remaining common, is actually the earliness to reach SCI. Though many reports are there which emphasizes the earliness of bunching in corms of larger size, the real reason has never been explained. The study for the first time reports that it is the earliness to SCI that determine the bunches to reach earliness.

The fourth major concern is at the level of the roots. The first and second flush of roots being on the primary corm, there is a natural compression of the duration of these two flushes in the large size corms. The third, fourth and fifth flushes have almost received the same duration and is more or less dependant on the size of the corms. The real factor lies at the level of the root growth characters. Better morphological characters of the roots *viz.* length, thickness, longevity etc are observed in the case of large corm size. Thus it should be presumed that the roots were functionally more efficient both for pulling in nutrients and water. Further studies using isotopic techniques can only answer this vital question.

A factor at the genetic entity level also has a bearing on the better yield and earliness of large corms. The large corms initiated the secondary corm slightly at a higher level though the plantings were at uniform depths. The primary corm being larger accommodated such a situation with better anchorage and development. The root bearing zone (RBZ) thus which lies mainly in the 4-7 cm depth should have become shallow, permitting a more effective foraging of the roots at the top horizons of the soil profile that accounts for more nutrients.

All these factors individually and in combination should have acted to the better effect of the larger planted corms favouring better and earlier bunches.

5.3 Studies using growth regulators

The studies using growth regulators have to be analysed from two major angles 1) Earliness and 2) Bunch yields. In the case of the former, NAA and IAA were the earliest to bunch in corm dip treatments, whereas in the corm injection it was PCBA at 500 and 250 ppm followed by NAA and IAA. The longest time taken in the case of corm dip was that of PCBA whereas in the case of corm injection, it was ABA 500 ppm.

The above results can be logically explained on the basis of absorption on one side and regulation and release on the other side. In the case of corm dip method, the corms were dipped in known concentration of the phytohormones. The relative amount absorbed is based on solubility and physiologically active surface area. The NAA and IAA were dissolved as per standard procedures and should have been absorbed at a faster rate leading to better growth parameters like height, collar girth, leaf area and number of leaves retained at harvest. As a definite number of leaves and area were satisfied, the crop came to harvest early. On the other hand, the relative solubility of PCBA in water is low and secondly, there is normally a delay between the time the chemical is absorbed into the plant and the exhibition of growth retardation. The extent of time depend on a number of factors

i. Method of application
ii. Transportation rate
iii. Degree of vascular binding
iv. Amount reaching the leaf *vs.* the growing point
v. Level of endogenous gibberellins at the time of treatment
vi. Time of treatment

Hence it should be concluded that the applied PCBA would not have been absorbed in the right quantities to affect growth retardation. The morphological characteristics of the plant confirm this point. On the other hand, when it comes to corm injection, PCBA 500 was the earliest to yield. PCBA is a compound known to inhibit GA biosynthesis and a compound with nitrogen containing heterocycle. The actions of PCBA was categorized as an inhibitor of GA biosynthesis which could take place at any of the three steps from ent-courene to ent-couronic acid. Further studies have also shown that there should be a threshold concentration of PCBA available in the shoot apex to maintain GA biosynthesis. The vascular system behind the growing point may act as a reservoir if the PCBA concentration there remains relatively high. A sufficiently high concentration is required to be maintained in that portion of vascular system if a continuous supply is being translocated from root or stem application. It is also proven that the PCBA is reversibly bound to the vascular tissues.

When it came to corm injection levels, the 500 ppm should have been sufficiently enough to maintain PCBA concentration that was probably reversely bound to vascular bundles and 250 ppm was not enough to act in this manner.

The high yields obtained in corm dip with PCBA 250 ppm also support this concept as it came to harvest in 296 days as against 309 in the case of PCBA 500 ppm. This again shows that at 500 ppm, the concentration was high to retard growth and was maintained in the vascular system for a continuous cycle. Whereas the effects of 250

ppm was for a relatively lower period thus pushing the crop to productivity and satisfying the maximum number of leaf production thereby realizing best yields.

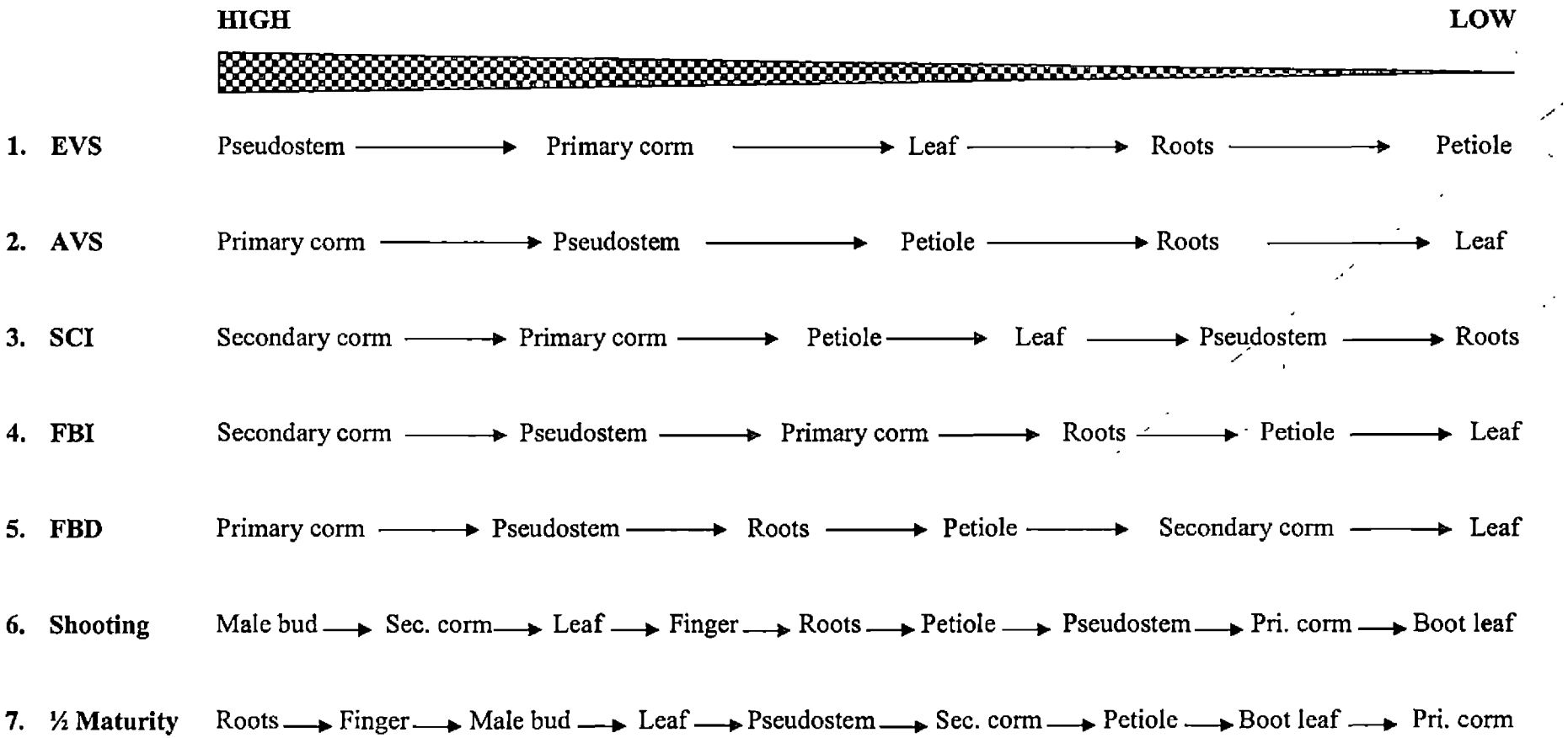
When it came to corm injection, IAA gave the best yields. As the PCBA given goes into the vascular system, its effects were highly manifested owing to the binding to the vascular tissues and also providing a steady stream of GA biosynthesis. Thus the yields were affected as observed in the morphological characters such as dwarfness, reduced collar girth, minimum leaf area, least number of leaves produced and least number of leaf retention at harvest. On one side, the picture reveals the long lasting effects of PCBA & ABA in growth retardation and yields. On the other more important side, it confirms the differential level of activity with the method of application.

5.4 ^{32}P uptake and nutrient translocation to different tissues

The differential nature of ^{32}P uptake at the various biotic phases is evident in the studies. In the EVS, maximum allocation was observed in the pseudostem and primary corm in different samplings (fig 73). Towards the last sampling, activity was observed in all tissues revealing that the nutrient was translocated at a very fast rate as it had reached almost every part of the plant, with the lowest being observed in the entry point tissue – the roots.

This suggests that phosphorus is translocated very fast and points to the basic mobility of the nutrient besides its requirement in the regulatory pathway. The very basic

Fig 73. Percentage accumulation of ^{32}P in various tissues on the 15th day after application



principle of root activity studies using ^{32}P is that the nutrient is highly immobile in soil and highly mobile in plant tissues (Atkinson, 1998; Ancy and Kurien, 2000; Kurien *et al.*, 2002, 2006 a&b).

At AVS again, the picture was almost the same with the primary corm and pseudostem showing maximum activity. Still lower levels were observed in petiole and very low levels in roots and leaves suggesting that the corm and the pseudostem were the primary units of accumulation. At the SCI stage, in early samplings, the uptake was nil. In the mid sampling, it was low but appreciable in the last sampling, the latter two showing that the secondary corm was the major site of accumulation. The roots too showed a sizeable uptake. Further, activity was observed in all tissues revealing that there was requirement from all tissues.

At the FBI and FBD stages, secondary corm and primary corm accounted for maximum activity. At these stages, the roots were also a major source of mobilization. At shooting, the male bud was the major sink in the early sampling and the fruit in the later two samplings. At half maturity, the fruits, the pseudostem and roots in the early sampling followed by the secondary corm, the roots and the petiole in the mid sampling and the roots, fingers, male bud, leaf and petiole were the major sinks in the last sampling.

Initially, at the EVS and AVS, accumulation was more confined to the pseudostem and primary corm showing that the ^{32}P is already in the translocatory stage.

At the SCI and FBI stages, it was more confined to the secondary corm – the major centre of activity. At FBD, contrary to the normal lines of thinking, it was more observed in the primary corm. At shooting, it was more in the male bud and at half maturity it was in the secondary corm, finger and male bud. The prioritization of accumulation of nutrients as per Cannell's findings is in the seed and fruit. As far as ^{32}P is concerned, Kurien *et al.* (1999) reported that the priority of mobilization to various tissues in banana is in the order male bud followed by corm, followed by fruit. This report is based on the study undertaken in the shooting stage of the plant. The split-up of the present study during various biotic stages in the peak phase of accumulation (15^{th} day) is presented as models and prioritizes the specific activity (cpm/g) in the order from high to low. The split-up conclusively shows the differential prioritization of ^{32}P to various tissues during various biotic phases.

In the initial stages, if it is geared towards the structural makeup, at the SCI stage it is focused to the development of the new corm. At FBI and FBD, the secondary corm and primary corm ranked high in the order. The high accumulation of ^{32}P in the corm (at FBI and FBD) conclusively proves that at the transformation stage, the most critical stage in the development of the bunch, there is a high pull into the corm which is at that stage the nerve centre of all activities. This has been conclusively proven in a full fledged four year study of an Indian Council of Agricultural Research *(ICAR)* supported project (Kurien, 1997). The intensity of activity of roots compared at various biotic phases of the crop also trickles to the level of this critical phase of the crop. The roots at FBI/FBD stage has been reported to show the maximum intensity of root activity (Kurien *et al.*,

2002; 2006 a&b). The above studies were also using isotopic techniques involving ^{32}P. The present study also supports this concept and drives home the point in clear terms that at FBI/FBD stage, the requirement of the corm is very high.

At shooting, it is again male bud, leaf and finger in the order, which is in tune with the early findings of Kurien *et al.,* (1999). This shows that the male bud in the early stage is a very high competing sink. This can be argued from three major angles. Firstly, as the utilization of energy otherwise lost for opening of flowers for finger development (Simmonds, 1959; Simpaio and Simao, 1970; Meyer, 1975; Jaramillo, 1982; Amma *et al.*, 1986). Secondly, it supports the findings of Danniells *et al.* (1994), who opined that the dry weight analysis indicated that the male bud represents a competing photosynthetic sink and thirdly, the sink activity of the male bud is high though its size is small (Walker and Ho, 1977).

At the half maturity stage, the secondary corm, followed by the finger, male bud ranked in the order of priority of accumulation. This can be logically interpreted as a necessity driven concept, primarily the bunch stalk which starts as a cylinder from the corm and the developing propagules, which is a sucker situated on the corm should have necessitated more nutrients. ^{32}P allocation between suckers from the mother plant have been reported in the ICAR project (Kurien *et al.,* 1997). Further, prioritization in the allocation of ^{32}P from the mother plant to various developing suckers in an orderly fashion with age has been reported by Kurien *et al.,*(1999). The above finding of high requirement of the corm can be argued based on the above studies. The male bud is the

third most competing sink and has moved down from the first at shooting stage because the development of male bud is almost complete (Stover, 1972). The lowest accumulation (traces) has been observed in the primary corm. This is supported by the excavation anatomical studies, which show that practically only a small patch of live tissue is present at this stage and hence this aspect needs no further explanation.

5.5 Carbon assimilation studies

The essence of the study on carbon assimilation explained in the previous chapter throws light on three major characters a) regulation at source level b) regulation at transport level c) regulation at sink level.

At the EVS, more than 50 percent of the activity was observed at the level of the photosynthetic apparatus *viz.* the leaf and the remaining lesser share spread between the petiole and the pseudostem. It should be presumed that at this stage, it is a case of regulation at the source level with a lesser share being apportioned for phloem loading.

At the AVS level, in addition to the three tissues wherein accumulation was observed, the primary corm also accounted for more than 12 percent of the carbon assimilated. Here again, the over dominance of the source level of partitioning is very evident with more than 62 percent being observed at the level of source itself. The whole accumulation is centered in the leaf petiole, pseudostem and primary corm.

At the SCI stage, the accumulation in the corm is completely in the secondary corm. Besides, the other three tissues as above also accounts for fairly high accumulation. A critical analysis point to the level that the release from the source level to a regulation at the transport level has already occurred as is evidenced in the highest accumulation in the pseudostem.

The FBI and FBD stages show a complete regulation at the transport level, with the secondary corm and the pseudostem in the order accounting for the full carbon accumulation. This stage is a complete dominance of the regulation at the transport level, probably a switchover to the requirements of the flow of the initiated floral meristem thereby establishing a sink load.

It is apparent that some balance exists between vegetative and reproductive development of any plant species. A plant could be considered as a collection of individual sinks which compete with each other. During plant growth, these sinks will change in their competitive ability leading to the diversion of assimilates towards the stronger sinks. Yield tissue in most crop species including trees consist of the reproductive organ except for a few crops with a predominant vegetative sink like the sugar beet potato, cassava etc. Flower initiation and subsequent floral development clearly depend on both assimilate and nutrient availability (Jenner, 1985; Monselise and Goldschmidt, 1982) and are known to be regulated hormonally (Looney and Pharis, 1986). In agronomic and many horticultural crops, the final productivity does not seem to be limited by flower initiation and development, as more flowers are formed than the

plant can support. The situation of fruit trees is however more complicated by the fact that the floral meristems are initiated during the period when cell division and enlargement of the current yield tissue is occurring (Monselise and Glodschmidt, 1982; Coombe, 1976).

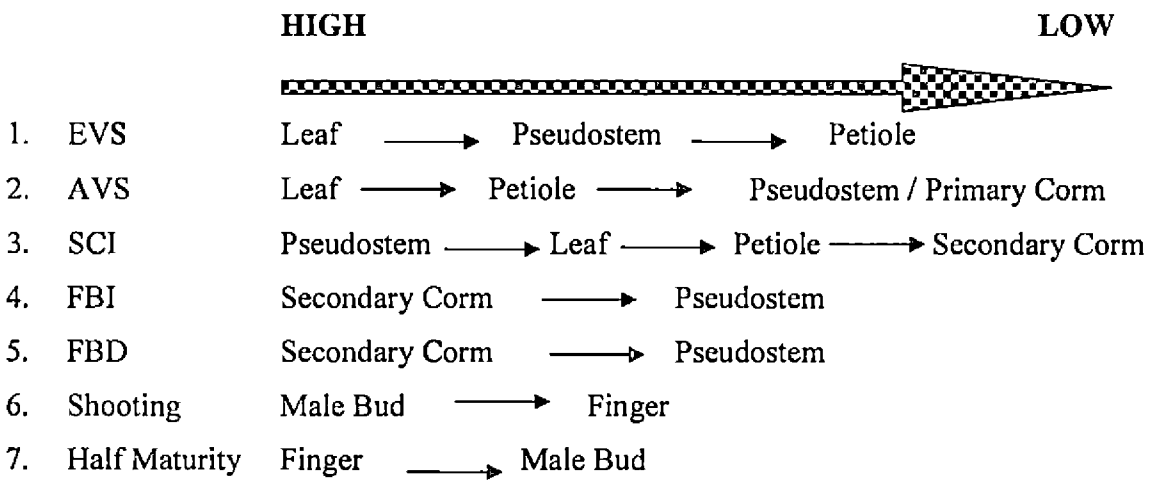
There occurs a marked stimulation of ovary growth shortly after pollination and fertilization, leading to fruit set. The roles of Auxins, Gibberellins and ethylene in fruit set are also well established. However, this initial fruit set does not necessarily lead to fruit retention till fruit maturity. It is being controlled by multifarious factors involving both assimilate supply and hormonal regulation. We need to identify the initial triggering factor which makes a particular fruit a better competitor for the available assimilates than the other fruits (Wright, 1989). Thus once sink load and distribution are set, the relative ability of various competing sinks, both vegetative and reproductive within the same plant, will determine the final patterns of assimilate partitioning (Daie, 1991).

The carbon assimilation at shooting and half maturity stages point to the overwhelming dominance of the regulation at sink level. In the former, the male bud accounts for nearly $3/4^{th}$ of the carbon assimilated, whereas in the latter, the finger accounts for more than $3/4^{th}$ of the carbon assimilated. Both the above cases point to the absolute sink control of assimilates partitioning. The male bud develops earlier than the fruits and hence it should be presumed that in the initial stages of bunch development, the giant's share of the photosynthates goes into the development of the male bud. Once this competing sink which is small in sink size is developed, paves way for the developing

fingers. Again growth rate of banana fruits varies with the source-sink ratio during fruit growth. Practical approaches of removal of hands (decreasing sink size – Meyer, 1975; Danniells *et al.,* 1994; Johns, 1996), leaf shading (reducing resource availability – Israeli *et al.,* 1995), bunch bagging (increasing sink demand by elevating temperature – Trupin, 1959; Perumal and Adam, 1968; Turner, 1970; Ganry, 1983; Walker, 1975; Israeli *et al.,* 1980; Daniells *et al.,* 1987; Johns and Scott, 1989; Daniells *et al.,* 1994; Jannoyer and Chillet, 1998; Turner, 1972) modify fruit growth rates and consequently even commercial harvest dates.

Thus the concept proposed by Cannell (1985) that the seeds are the most competing sinks applies only to seeded plants at the seed formation stage. The modified priority in nutrient partitioning based on ^{32}P studies in banana which is a parthenocarpic fruit has revealed that the male bud is the biggest competing sink (Kurien *et al.,* 2002). This is based on the study of the plant at an early shooting stage. The present study which is much more elaborate in banana points into the differential level of partitioning of carbon assimilates at various biotic phases. The order being as in fig 74.

Fig 74. Differential level of partitioning of carbon assimilates at various biotic phases



The above models can also be explained at the level of requirement of the plant. The initial stages of EVS and AVS go into the structural build-up of the plant, primarily for the development of the canopy. The highest accumulation in leaf and lower levels in petiole and the enclasping leaf bases (pseudostem) are at these levels. The later phases of SCI again re-emphasize the concept of the structural build-up. The stage of FBI and FBD wherein maximum accumulation is seen at the secondary corm is a shift in the requirement as the plant marches to its reproductive stage. Thus the bud at the centre of the developed secondary corm harbours the maximum mobilization of photosynthates. The next two biotic stages of shooting and bunch maturity is a case of competition between sinks at the floral level. The models proposed for all the seven biotic phases fixed from the present study given above show the differential photosynthates mobilized to various tissues, which has never been examined as much as in this study in banana.

5.6 Altered response to depth of planting

The superficial planting at 10 cm depth gave the earliest and better bunches. The planting coincides with the worst season or namely the season of summer bananas so that any improvement will be a big game. The better influence of superficial planting as per the Package of Practices (KAU, 2007) can be explained from four or five angles. The first aspect is that the upper horizons of the soil are the most fertile and planting at shallow depths should have permitted better absorption of nutrients and water. The favourable effect of soil temperature in the top 10 cm recorded during the course of the growth of the crop is another important congenial factor. The rooting habit of the clone

under study is another factor to be recorded. The Root Bearing Zone (RBZ) is in the range of 5-7 cms and the shallow planting gave a condition most optimum for foraging the most fertile horizons of the soil. Some of the studies available on this line are from the works of Swennen *et al* (1987) who reported that the apical meristem of a sucker planted at 30 cm depth is 12-13 cm and at 4-5 months stage is at 6 cm depth. In the present study, the depth of planting was taken in such a way that the top cut portion was at 10 cm, 20 cm and 30 cm depth at planting. Thus as time progressed, the clump should have pushed up along with apical meristem and the root bearing zone should have moved negatively geotropic as reported by Champion and Oliver (1961). The various flushes of roots thus functioned to a higher potential only in the shallow planting. The term higher potential is being used as it was summer bananas. The effective foraging capacity was promoted by the aeration of the roots as well.

Another important factor was at the SCI stage. The SCI studied at this stage showed that at deeper plantings the corm tends to be cylindrical to push the growing apical primordial to the upper surface; thus again proving that clump lifting is a genetic factor of bananas. Thus lifting means that the first and second flushes of roots of the deeper planting could not function effectively as the roots lie buried in deeper profiles of soil. The timing of the planting to coincide with summer was deliberate and intentional so that any altered effects on crop growth are visible or shown by the plant. Further studies involving translocation of both nutrients and photosynthates of bananas planted at various depths could give better reasoning concepts of productivity in relation to depth of planting.

5.7 Effects of Retention *Vs* Detachment of Primary Corm

The profound influence of the primary corm on photosynthate accumulation is evident at EVS and AVS. Thereafter accumulation *per se* is not observed till harvest. The carbohydrate translocated to the corm at these stages should have acted as a reserve even upto the final stages of harvest. The live portions, though fractionally small observed even at the final stage are an indication in this direction. The reserve material should have been a source for both the structural buildup and for determining the yields.

The picture becomes all the more clear and explicit, when we look at the scenario of ^{32}P absorbed. The primary corm which starts deterioration from SCI stage as observed in the excavation studies is functionally very active as far as ^{32}P is concerned. In the initial EVS, AVS and SCI stages, the counts retrieved show that it ranks first or second in accumulation among the different tissues. Again, at the FBI stage, the order of ranking is third and in FBD stage it is number one. In the terminal stages of shooting and half maturity, it is low in the order. What is important is that even in the critical stages of FBI and FBD, ^{32}P accumulated in a unit mass was very high in the primary corm. At this stage, phosphorus should have been an important factor due to its active role in phosphorylation and respiratory pathways as the crop has just moved into the reproductive phase.

The amount of ^{32}P which have been absorbed till this stage should have acted as a resource pool for satisfying the requirements in the later stages. From both the studies

involving radiotracers, it is evidently clear that at various stages the primary corm has accumulated either the photosynthates or the nutrients. The reduced yield observed with detachment of primary corm at secondary corm initiation stage is certainly due to the non-supply of the reserves maintained in the primary corm.

Secondly, the complementary functions served by the primary corm in the translocatory pathway should have been halted. Another major aspect is that the third flush of roots are produced at SCI stage and are seen both on the primary and secondary corm. Hence detachment should necessarily alter both water and nutrient requirement as a portion of the third flush of roots are removed. The study conclusively proves that the primary corm lying buried under the lowermost portion in the soil definitely influences the physiology of crop production, even though both in size and volume it reduces from the stage of SCI. A detailed study involving injections of isotopes into the primary corm at various biotic phases will give the best answer and is suggested as a future line of work.

Summary

SUMMARY

Banana is the major fruit crop of India ranking first in world production (FAO, 2006). The state of Kerala is a natural home to many cultivars particularly those belonging to the 'AAB' genomic group. Among them, the cultivar Nendran is the pick of the varieties, maximum in preference and is normally cultivated as a monocrop. The banana plant comprises essentially of three major regions – the massive rhizome or corm, the pseudostem and the inflorescence. In the orderly cycle of development, the plants undergo complex patterns of change. In the case of banana, the physiological changes beginning from sucker production, juvenility, maturity and flowering cannot be signed out as separate entities. They are closely related to one another and influenced by various weather elements.

Initial studies conducted at Regional Agricultural Research Station, Kumarakom for salinity resistance and varietal reaction led to the development of basic studies aimed at corm and roots. To identify the effects of salinity, the plants were uprooted to study the causes at the corm and root levels. At this stage, the varieties showed an induction of a new corm and the succeptibility / resistance to salinity was found to be governed by the earliness of the new corm. The present study which is a part of the fully supported and funded by the Ministry of Science and Technology, Govt. of India was taken up at RARS, Kumarakom from August 2005. The salient findings emanating from this study are summarized below.

i. Secondary corm (SC) formation is an integral part of crop cycle of banana crop raised from suckers and it is ***being reported for the first time.*** The new corm was observed to develop above the planted corm. This planted corm gradually becomes necrotic, deteriorates and falls off towards the time the crop comes to maturity. All the six plantings in the calendar year prove this beyond doubt. The crop duration in sucker planted bananas are dependent on the SC formation.

ii. The earliness of secondary corm initiation (SCI) is a factor of corm size. The study using graded corm size as treatments conclusively prove this beyond doubt.

iii. The time taken from SCI to Flower Bud Initiation (FBI), Flower Bud Differentiation (FBD), Shooting and Maturity is almost same. Hence the change in crop duration of *Nendran* can be explained on the basis of time taken to reach SCI.

iv. A definite GDD is required for the planted sucker to reach the SCI stage depending on corm size. The thermal units required for each biotic event was worked out. The thermal units requirement is based on the corm size and this explains the reasons for earliness in bunch production of large sized corms.

v. Another finding emanating from the study is the efficiency factor of the corms (heliothermal units /photothermal units). The larger corm size had a greater efficiency of realization of thermal units.

vi. High mat condition is dependant on the development of new corm over the planted corm. The more the superficial the planting is, higher the chance of an early mat conditions. Depth of planting upto 30 cm also showed high mat conditions as the secondary corm development tends to take place towards the soil surface but at a later stage proving that clump lifting is a more a genetic factor. Increasing depth of planting delays harvest as the stage to SCI took longer time.

vii. Root production was confirmed to be in five flushes with distinct overlapping of the successive flushes. The study reports for the first time that root production is not cyclic and not continuous. It was found to be closely associated with biotic events.

viii. Hormone dipping treatment of suckers prior to planting and by corm injection after establishment revealed that early growth was suppressed by PCBA with drastic reduction in internodal length. Dwarfening of plant stature could be attained by using PCBA and ABA. This would pave the way for further research to mitigate the effects of wind or avoid staking which is a costly input. SCI was observed to be earliest in treatments involving IAA. However control treatment was the earliest to bunch showing the modified influence of hormones on time taken to reach harvest.

ix. In the Early Vegetative Stage (EVS) and Active Vegetative Stage (AVS), the nutrient uptake was more translocated towards the structural components – the pseudostem (Ps) and corm. At SCI and FBI stage, the focus shifted to the secondary corm. At FBD stage in the early and late sampling the primary corm accounted for maximum localization of applied ^{32}P, whereas in the mid sampling it was in the secondary corm. At shooting in the early two samplings maximum accumulation was seen at SC and roots whereas in the last sampling the fingers and male bud accounted for full uptake of applied isotope. At half maturity stage, the roots and fingers in the early two samplings and roots fingers and male bud in the late sampling accounted for maximum localization of nutrients.

x. The first report on Carbon assimilation and transport in banana is also from the study. The results from the studies involving ^{14}C showed a holistic picture on the photosynthate translocation and assimilation to the various plant parts at different stages of its growth. During the initial stages (EVS & AVS), the accumulation was found to be the maximum at the source level itself. At SCI stage it was found to be more in the leaf petiole and pseudostem with no recovery in the primary corm. At the reproductive transformation stage of the plant (FBI & FBD), the entire assimilates were found to be translocated to the SC and Ps. At the shooting stage and the half maturity stage, the finger and male bud together account for the whole photosynthates whereby giving a marked reflection and manifestation of the functional requirement of the plant with the entire shifts focused at the sink level.

xi. Studies using the detached primary corm reveal that the primary corm also has a complimentary role in the crop cycle and detachments certainly affects crop growth and productivity.

To conclude, the study has generated results both at the fundamental and applied aspects. The studies on corm and root - ***The Hidden Half of the Plant*** - are first of its kind. The generated results have immense field applications. A humble beginning has been made for further research.

References

REFERENCES

Aguilar, E.A., Turner, D.W., Gibbs, D.J., Sivasithamparam, K. and Amstrong, W. 1998. Response of banana (Musa sp.) roots to oxygen deficiency and its implication for Fusarium wilt. *Acta Horticulturae* 490:223-228.

Amma, S.P., Babylatha, A.K., Pushkaran, K., Kurien, T.M., 1986. Studies on the effect of removing terminal hands and male bud on yield and fruit size of banana Musa (AAB group) Palayankodan. *S. Indian Hort.* 34 (4), 204-209.

Ancy, T.K., Kurien, S., 2000. Bunch stalk feeding of urea in Banana Musa (AAB group) 'Nendran'. *Scientia Horticulturae* 84:205-212.

Araya, M. and Blanco, F. 2001. Changes in the stratification and spatial distribution of the banana (Musa AAA cv. Grand Naine) root system of poor, regular, and good developed plants. *J. Pl. Nutr.* 24: (11) 1679-1693

Araya, M., Vargas, A. and Cheves, A. 1998a. Changes in distribution of banana (Musa AAA cv. 'Valery') roots with plant height, distance from the pseudostem and soil depth. In: Proceedings of the First International Symposium on Banana in the Subtropics -GalÃ¡n SaÃºco, V. (ed.), Puerto de la Cruz, Tenerife, Espaniol. pp. 201-207.

Araya, M., Vargas, A. and Cheves, A. 1998b. Changes in distribution of roots of banana (Musa AAA cv. Valery) with plant height, distance from the pseudostem, and soil depth. *Journal of Horticultural Science and Biotechnology.* 73: (4) 437-440

Atkinson, D. 1998. The optimisation of the supply of mineral nutrients to fruit trees through diagnosis. Proceedings of the third international symposium on mineral nutrition of deciduous fruit trees, Zaragoza, Spain, 27-31 May 1996. (ed. Val, J., Montanes, L. and Monge, E. *Acta-Horticulturae.* 448: 307-315

*Bassoi, L.H., Moura-e-Silva, J.A., Silva, E.E.G-da., Ramos, C.M.C., Targino, E-de-L., Maia, J.L.T., Ferreira, M-de-NL. and Ferreira, M. 2001. Data on spread of banana roots for irrigation practices. Comunicado Tecnico da Embrapa Semi Arido. 105: 3 pp.

Biju, S.V. and Kurien, S. 1994. Morphological characters in relation to flower bud initiation and differentiation in banana; INFO*MUSA*, 3(2):19-21 INIBAP, France.

Biju, S.V., Kurien, S. and Mohanakumaran, N. 1997. The changes in the growing point of 'Red Banana' during various physiological phases. INFO*MUSA* 6(2):19-21

Blomme G., R. Swennen, A. Tenkouano, R. Ortiz & D. Vuylsteke. 2001. Estimation of root development from shoot traits in plantain and banana (Musa spp). INFO*MUSA* 10(1):15-17.

Blomme, G., Swennen, R. and Tenkouano, A. 2000. Assessment of variability in the root system characteristics of banana (Musa spp.) according to genome group and ploidy level. INFO*MUSA*. 9: 2, 4-7

Blomme, G., Swennen, R. and Tenkouano, A. 2002. The effect of soil bulk density on root and overall plant development in six banana varieties. INFO*MUSA*. 11: 2, 38-40

Blomme, G., Tenkouano, A. and Swennen, R. 2001. Influence of leaf removal on shoot and root growth in banana (Musa spp.). INFO*MUSA*. 10: 2, 10-13

Braide, J and Wilson, G. 1980. Plantain Decline: a look at the possible causes. *Paradisiaca* 4:3-7

Calvo, C. and Araya, M. 2001. Quantity of roots on the ten bananas producer regions of Costa Rica. *CORBANA*. 27:(54) 47-64

Cannell, M.G.R. 1985. Dry matter partitioning in tree crops. Attributes of Trees as Crop Plants (eds. Cannell M.G.R. and Jackson, J.E.). National Environmental Research Council, New York. 265 p.

Chakrabarthy, B.K and Rao, N. 1984., Studies on the flower bud initiation and development in some banana Gultivars. *J. Res*, Assam University 5(1): 1-10.

Chakrabarthy, B.K. and Madhava Rao, V.N. 1980. Influence of planting seasons on certain growth and morphological characters of banana. Proc. of the National seminar on banana production technology. (eds: Muthukrishnan, C.R.; Abdul Khader, J.B.M.M.), p. 73-78 TNAU, Coimbatore (IND).

Champion, J and Olivier, P 1961. Etudes preliminiares sur les raciness de bananier. *Fruits,* 16:371-374

Chan, LitFu, Lu, ChunTang, Lu, Wei, MengLi, Lu, HsiuYing, Chan, L.F., Lu, C.T., Wei, M.L. and Lu, H.Y. 1998. Effect of planting seasons on accumulation of dry matter and nitrogen in wetland taro (Colocasia esculenta (L.) Schott). *Journal of Agricultural Research of China*. 48: (3) 32-46

Chan, LitFu., Lu, ChunTang., Lu, HsiuYing., Chan, L.F., Lu, C.T. and Lu, H.Y. 1999. Growth analysis of wetland taro (Colocasia esculenta (L.) Schott) under various cropping seasons. *Journal of Agricultural Research of China*. 47: (3) 220-241

Chattopadhyay, P.K., Maiti, S., Sen, S.K. and Bose, T.K. 1980. Effect of time of planting and type of planting material in growth and yield of banana. Proc. Nat. Sem. on banana Prod. Technol. pp 79-84

Coombe, B.G. 1976. The development of fleshy fruits. *Ann. Rev. Pl. Physiol.* 27: 507-528

Daie, J. 1991. Biochemical regulation of source-sink relationships. Biochemical Regulators. Harold Gautman, Dekkar INC, Madison Avenue, New York, 362 p.

Daniells, J.W., Lisle, T.T. and Bryde, N.J. 1994. Effect of bunch trimming and leaf removal at flowering on maturity bronzing, yield and other aspects of fruit quality on bananas in North Queensland. *Aust. J. Crop Agric.* 34 (2): 259-265

Daniells, J.W., O'Farell, P.J., Mulder, J.C., Campbell, S.J., 1987. Effect of bunch covering and bunch trimming on bananas in North Queensland. *Qd. J. Agric. Anim. Sci.* 44(2), 101-105.

Das, P.K and Sen, H. 1995. Effect of time of planting on growth and corm yield of elephant foot yam in eastern India. *Trop. Agric.* 72(1) 13-17

Eckstein, K. and Robinson, J.C. 1995. Physiological responses of banana (Musa AAA, Cavendish subgroup) in the subtropics. I. Influence of internal plant factors on gas exchange of banana leaves. *Journal of Horticultural Science* 70: 147-156.

FAO. 2006. http://www.fao.org/docrep/004/ad452e/ad452e1q.html

FAO. 2003. FAOSTAT statistics database, Agriculture, Rome, Italy. 218 p.

*Ganry, J. 1983. Ecophysiological approach to banana floral development relations with yield. IRFAI GERDAT, BP 5035, 34032.

*Gousseland J. 1983. Etude de l'enracinement et de l'émission racinaire du bananier 'Giant Cavendish' (Musa acuminata AAA, sous-groupe Cavendish) dans les andosols de la Guadeloupe. *Fruits* 38: 611-623.

Gowen, S. 1995. Bananas and Plantains. Chapman & Hall, New York. 189 p.

Hottum, R.E. 1955. Growth habits of monocotyledons - variations on a theme. *Phytomorph.* 5: 399-438

INIBAP. 2002. musalit.inibap.org/pdf/IN060568_en.pdf

Israeli, T., Gazit, S., Blumenfield, A., 1980. Influence of relative humidity on the type of flower in the cavendish banana. *Fruits* 35(5), 275-279.

Israeli, Y., Plaut. Z. and Schwartz, A. 1995. Effect of shade on banana morphology, growth and production. *Scientia Horticulturae.* 62(1-2): 45-56

Jannoyer, M. and Chillet, M. 1998. Improving banana growing conditions with the Katryx R bag. *Fruits* 53(4): 219-228

*Jaramillo R. 1982. Las principales características morfológicas del fruto de banano, variedad Cavendish Gigante (Musa AAA) en Costa Rica. Unión de Países Exportadores de Banano (UPEB). 42 p.

Jenner, C.F. 1985. Control of accumulation of starch and protein in cereal grains. *Pl. Growth Regulator Monograph.* 12: 195-209

Johns G. 1996. Effects of bunch trimming and double bunch covering on yield of bananas during winter in New South Wales. *Australian Journal of Experimental Agriculture* 36: 229-235.

Johns, G.G., Scott K.J., 1989. Delayed harvesting of bananas with sealed covers on bunches. 2. Effect on fruit yield and quality. *Aust. J. Exp. Agric.* 29(5), 727-733.

Kerala Agricultural University 2001. Package of Practices Recommendations : Crops 12th edition. Kerala Agricultural University, Trichur, P 216

Kerala Agricultural University 2007. Package of Practices Recommendations : Crops 13th edition. Kerala Agricultural University, Trichur, P 334

Koshy, M. 1989. Flower bud differentiation in banana. M.Sc. (Hort) thesis, KAU, Vellayani, 328 p.

Kumar, N. and Nalina, L. 2001. Research on high density planting of banana in Tamil Nadu - a resume. Changing scenario in the production systems of horticultural crops. Proceedings of a National Seminar, Coimbatore, Tamil Nadu, India, 28-30 August 2001. South-Indian-Horticulture. 49: Special, 1-5

Kurien, S. 1997. Annual report of the I.C.A.R Adhoc Project On "Intermat, Intramat and crop Competitions in Banana using Radiotracer techniques. Submitted to the Indian Council of Agricultural Research. 125 p.

Kurien, S. 2004. Annual report of the DST Project On "Yield Prediction Models in Banana". Submitted to the Department of Science and Technology, Ministry of Science and Technolgy, Govt. of India. 88 p.

Kurien, S. 2006. Annual report of the DST Project On "Yield Prediction Models in Banana". Submitted to the Department of Science and Technology, Ministry of Science and Technolgy, Govt. of India. 115 p.

Kurien, S. 2008. Annual report of the DST Project On "Yield Prediction Models in Banana". Submitted to the Department of Science and Technology, Ministry of Science and Technolgy, Govt. of India. 132 p.

Kurien, S., Anil, B.K., Kumar, S.P., and Wahid P.A. 1999. Nutrient studies in banana using ^{32}P. Musa news, *Infomusa* 8(1): 35-36

Kurien, S., Kumar, P.S., Kamalam, N.K. and Wahid, P.A. 2002. Nutrient cycling from the Musa mother plant at various physiological stages to suckers as affected by spacing and sucker retention using tracer techniques. *Fruits* 57(3): 143-151

Kurien, S., Kumar, S.P., Kamalam, N.V. and Wahid P.A. 2006a. Intermat and intramat competition in banana studied using ^{32}P. *Fruits* 61: 225-235

Kurien, S., Kumar, S.P., Kamalam, N.V. and Wahid P.A. 2006b. Relative efficiency of ^{32}P uptake in banana-based intercropping system. *Fruits* 61: 353-366

*LassoudieÁ re, A., Maubert, P., 1971. Evolution des dimensions des bananas entre l'eÂ mission de l'inflorescence et la reÂ colte du reÂ gime. *Fruits* 26, 321-333.

*Lavigne, C. 1987. Contribution à l'étude du système racinaire du bananiere. Mise au point de rhizotrons et premiers résultats. *Fruits* 42: 265-271.

Lecompte, F. and Pagès, L. 2007. Apical diameter and branching density affect lateral root elongation rates in banana. *Environ. Exp. Bot.* 59:243-251.

Lecompte, F., Ozier-Lafontaine, H. and Pages, L. 2001. The relationships between static and dynamic variables in the description of root growth. Consequences for field interpretation of rooting variability. *Plant and Soil.* 236: (1) 19-31

Lecompte, F., Ozier-Lafontaine, H. and Pages, L. 2003. An analysis of growth rates and directions of growth of primary roots of field-grown banana trees in an andisol at three levels of soil compaction. *Agronomie.* 23: 3, 209-218

Lecompte, F., Vaucelle, A., Pages, L. and Ozier-Lafontaine, H. 2002. Number, position, diameter and initial direction of growth of primary roots in Musa. *Annals of Botany.* 90: 1, 43-51

Lehmann, J. and Abe, J. 2003. Subsoil root activity in tree-based cropping systems. *Plant and Soil.* 255:1 319-331

Looney, N.E. and Pharis, R.P. 1986. Gibberellins and reproductive development of tree fruits and grapes. *Acta Horticulturae* 179: 59-72

McMichael, B.L. and Burke, J.J. 1998. Soil temperature and root growth. *HortScience* 33(6): 947-950.

*Meyer, J.P., 1975. Influence de l' ablation de mains sur le rendement en poides des regimes de bananas par categories etc. conditionnement aux antilles. *Fruits* 30, 663-668.

Mohan, N.K. and Madhava Rao, V.N. 1984. The effect of plant density on the banana root system. *S. Ind. Hort.* 32 (5): 254-257

*Mohan, N.K. and Madhava Rao, V.N. 1988. Tracer studies to determine the active root zone in banana. In: Memoria de la IV Reunion sobre agrofisiologia del banano - GuzmÃ¡n Chaves, J.A. (ed.); Romero Calderon, R. (ed.), p. 79-83 Meeting: Reunion sobre Agrofisiologia del Banano, San JosÃ

Monselise, S.P. and Goldschmidt, E.E. 1982. Alternate bearing in fruit trees: a review. *hort Rev.* 4: 128-173

Murthy, S.V.K. and Iyengar, B.R.V. 1996. Kinetics of phosphorus absorption in banana (Musa paradisiaca) as influenced by growth and root morphology. *Indian Journal of Agricultural Sciences.* 66(10): 567-572

Murthy, S.V.K., Iyengar, B.R.V. 1997. Root distribution and morphology in some banana (Musa paradisiaca) varieties. *Indian Journal of Agricultural Sciences.* 67 (11): 495-499

Pages, L., Asseng, S., Pellerin, S. and Diggle, A. 2000. Modeling root system growth and architecture. In Root methods: a handbook (eds. Smith, A.L., Bengough, A.G., Engels, C. van Noordwijk, M., Pellerin, S. and van de Geijn, S.C.). Springer-Verlag, Berlin, pp. 113-146.

Panse, V.G., Sukhatme, P.V., 1985. Statistical methods for agricultural workers. ICAR New Delhi, pp. 154-168

Perumal, A., Adam, A.V., 1968. Bagging of Giant Cavendish banana stems in Honduras. Effect on number of days from flower emergence to fruit harvest, *Trop. Agric.* 45, 101-110

Ping, Lu., KamChau, Woo., ZhuTian, Liu., Lu, P., Woo,K.C. and Liu, Z.T. 2002. Estimation of whole-plant transpiration of bananas using sap flow measurements. *Journal of Experimental Botany* 53(375): 1771-1779

Ramcharan, C., Ingram, D.L., Nell, T.A. and Barrett, J.E. 1991. Fluctuations in leaf carbon assimilation as affected by root-zone temperature and growth environment. *HortScience.* 26: 9, 1200-1202

Rao, G.S.L.H.V.P. 2008. Agricultural Meteorology. Prentice Hall of India Pvt. Ltd., New Delhi. pp 61-62

Riopel, J.L. and Steeves, T.A. 1964. Studies on the roots of Musa accuminata'Gros Michael' 1. The anatomy and development of main roots. *Annals of Botany* 28:475-494.

*Robinson, J.C. 1993. Mulching. Inligtingsbulletin -Instituut-vir-Tropiese-en-Subtropiese-Gewasse. Special Edition, 10-11

Robinson, J.C. 1995. System of cultivation and management. in Bananas and Plantains. (Gowen, S. ed.). Chapman and Hall. Pp. 15-65

Robinson, J.C. and Alberts, A.J. 1989. Seasonal variation in the crop water-use coefficient of banana (cultivar 'Williams') in the subtropics. *Scientia Horticulturae* 40:215-225.

Sancho V.H. 1994. Root distribution of 'CurrarÃC' false horn plantain (Musa AAB) at different phenological stages. *Informe Anual.* 1993. 31-32

Schaffer, B., Searle, C., Whiley, A.W. and Nissen, R.J. 1996. Effects of atmospheric CO_2 enrichment and root restriction on leaf gas exchange and growth of banana (Musa). *Physiologia Plantarum.* 97: 4, 685-693

Simmonds, N.W. 1959. Bananas. Longman, New York, pp. 188-189.

Simmonds, N.W. 1966. Bananas. Orient Longman Publishing Co. Ltd., London, 389 p.

Simmonds, N.W., 1982. Bananas. Longman, New York, pp. 205-252.

Simpaio, R., Simao, S., 1970. Removal of male flowers from new banana inflorescences. *Rev. Agric. Picicaba*, 95, 93-95.

*Sioussram, D. 1968. Observations preliminaries sur 1" enrtacinement de la variete du bananiers dans les sols de la station de Neuf chateeau. Guadeloupe. *Fruits* 23 : 473-479

Skutch, F. 1932. Anatomy of the axis of banana. *Botanical gazette XCIII*: 222-258

Sobhana A., Aravindakshan, M. and Wahid P.A. 1989. Root activity patterns of banana (var. Nendran) under irrigated and rainfed conditions. J. Nucl. Agric. Biol. 18(2): 117-123

Stover, R. 1979. Pseudostem growth leaf production and flower initiation in the Grand Nain banana. Bulletin. *Tropical Agrl. Research Service* 8:37

Stover, R. and Simmonds, N.1987. Bananas. Third edition. Tropical Agriculture Series. Orient Longman Publishing Company Ltd., London, 468p

Stover, R.H. 1972. Banana, Plantain and Abaca diseases. Commonwealth Mycological Institute, Kew, Surrey, England. p. 245.

Summerville, W.A.T. 1944. Studies on nutrition as quantified by development in Musa cavendishii. *Queensland. J. Agric* 1:126-:127

Swennen, R. 1984. A physiological study of the suckering behaviour in Plantain (Musa cv. AAB). Dissertationes de Agricultura No 132. Faculty of Agriculture, Catholic University of Leuven, 180p.

Swennen, R., De Langhe, E.A., Janssen, J. and Decoene, D. 1986. Study of the root development of some Musa cultivars in hydroponics. *Fruits* 41(9): 515-524.

Swennen, R., Wilson, G.F. and Decoene, D. 1987. Priorities for future research on the root system and corm in plaintains and bananas in relation to nematodes and the borers. Proc. of the INIBAP workshop on nematodes and the borer weevil in bananas – status of research and outlook, Byumbra, Burundi, pp 91-96

*Tixier, P., Ris`edeb J.M., Dorel, M. and Mal´ezieuxc, E. 2006. Modelling population dynamics of banana plant-parasitic nematodes: A contribution to the design of sustainable cropping systems. *Ecological Modelling* 198: 321–331

*Trupin, F., 1959. Coupe du bourgeon male sur la inflorescence due bananier Gros Michel. *Fruits* 14: 389-390.

Turner D.W. 1970. The growth of the banana. *J. Aust. Inst. Agric. Sci.* 36:102-111

Turner, D.W. 1972. Banana plant growth - L: Gross Morphology. *Aust. J. Exp. Agric. Anim. Husb.* 12(55);209-224

Turner, D.W. and Lahav, E. 1983. The growth of banana plants in relation to temperature. *Australian Journal of Plant Physiology* 10:43-53.

Turner, D.W. and Thomas, D.S. 1998. Measurements of plant and soil water status and their association with leaf gas exchange in banana (Musa sp.); a lacticiferous plant. *Scientia Horiculturae* 77:177-193

Valsamma, M., Arvindakshan, M., Valsalakumari, P.K. and Parameswaran, N.K. 1987. Root distribution of banana cultivars under rainfed condition. *South Indian Horticulture*. 35 (5). 334-338

Verma, P.K., Sen, H., Roychoudhury, N. and Mukhopadhyay, S.K. 1992. Corm production of elephant foot yam as affected by planting dates. *Horticultural Journal* 5(1): 49-54

Walker, A.J. and Ho, L.C. 1977. Carbon translocation in tomato, carbon import and fruit growth. *Ann. Bot.* 41: 813-823

Walker, L., 1975. The effect of debudding and preharvest dehanding on bunch weight and fruit quality. Annual Report. 1974. Jamaica Banana Board, Research and development department, pp. 31-33.

Wendericks, D. 1985. Effect of pH and temperature on the root system in banana and plantain (In dutch). Faculty of Agriculture, Catholic University of Leuven, 162p.

Wright, C.J. 1989. Interactions between vegetative and reproductive growth. Manipulation of Flowering (ed. Wright, C.J.). Butterworth and Co. (Pub) Ltd., London, pp. 15-27

*Originals not seen

DEVELOPMENTAL PHYSIOLOGY OF BANANA CORM (*Musa* AAB NENDRAN) IN RELATION TO PHENOLOGY, YIELD AND QUALITY

By

BINU JOHN SAM

(2004-22-01)

ABSTRACT OF THE THESIS

Submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Horticulture

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF POMOLOGY AND FLORICULTURE
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM–695 522
KERALA, INDIA

2011

ABSTRACT

The study on "Developmental physiology of banana corm (Musa AAB Nendran) in relation to phenology, yield and quality" was taken up as a part of the fully funded DST project of the Ministry of Science and Technology, Government of India at the RARS, Kumarakom from 2004 to 2008. The study was basically centered on the corm and roots. The objectives of the study were to have a basic idea of the origin and development of the secondary corm as influenced by various factors, to identify and fix the stages of corm development and rooting in relation to biotic events (bud initiation, differentiation, shooting and suckering), to establish the root production pattern (continuous or cyclic), characterize the roots (pioneers or feeders), study the relationship of carbon assimilation and nutrient uptake on corm development, to have a basic understanding on origin and development of suckers, to study the genetic differences in corm and sucker development and finally to hasten out secondary corm formation thereby reducing crop duration without affecting post-harvest quality parameters.

The major findings emanating from the studies are presented aspect-wise under different paragraphs.

Planting was taken up at bimonthly intervals. Each planting consisted of fifty plants and observations on all characters were taken up. The height of the plant in the June planting was the highest followed by that in April, October and August. The December and February planting recorded the least height. April followed by February and August planting had the highest girth. December, followed by October and June recorded the lowest girth in the order. The number of leaves produced by the plant was in the range of 27-28 with very minor subtle difference between months of planting. The pattern of leaf production is very explicit, an increasing number of leaves are found to produce from upto FBD stage in case of June planting and in October planting this is found to increase upto shooting whereas in December and February, leaf production is very erratic and a small fall in production is observed in April.

Number of new leaves emerging in a fortnight is found to increase in June and October planting upto FBI and is at the maximum. Whereas the December, February and April planting has revealed a very low number of leaf production and the maximum number of leaves produced is found to be in between SCI and FBI which could be one of the major reason for the low productivity. A critical analysis of the data reveals that an increasing number of leaves retained is observed upto FBD stage in case of October and April planting. In April planting this trend is observed only upto FBI stage whereas in December and February the maximum number of leaves retained is seen at the SCI stage. This reveals that number of leaves retained in the critical phases of FBI and FBD have a direct impact on the yield and yield components. The length of the 'D' leaf is found to increase upto the last phase in all the six crops. The maximum leaf length of leaf is observed in June planting. An increase in the breadth of leaf upto shooting is observed in October and December planting but thereafter the leaf width is found to decline from FBD to shooting. However in case of leaf area the June, October and December planting showed progressive increment in area. However maximum area in case of February and April were at FBD and FBI stage.

The study confirms that June planting gave the highest yield and was over 10kg. This is due to water shortage in Early Vegetative, AVS and SCI and high water table as good as flooding at the stage of FBI due to heavy South West Monsoon experienced in the area. On the contrary, June planting received showers from planting and after shooting received adequate sunshine hours. The finger characters were more or less a reflection of the bunch weight. However the finger in August planting appeared straighter on maturity than June planting.

One of the major findings emanating from the study is the efficiency factor heliothermal units/ photothermal units. The factor gives the concept of efficiency as it is a function of realized sunshine duration to the potential maximum at a location. The study confirms that when this factor is very near or exceeds 0.5 the yield tends to increase with inputs not being a limiting factor. The photothermal units (PTU) and heliothermal Units

(HTU) requirement were almost a reflection of the same as that of GDD. A split up of the requirement from one biotic phase to the other again revealed an identical trend.

The base temperature at which growth starts in banana was identified to be 14^0C. Secondary corm formation is an integral part of crop cycle of banana crop raised from suckers and it is being reported for the first time. The new corm was observed to develop above the planted corm. This planted corm gradually becomes necrotic, deteriorates and falls off towards the time the crop comes to maturity. All the six plantings in the calendar year prove this beyond doubt. The crop duration in sucker planted bananas are dependent on the secondary corm formation.

Secondary corm formation is found to be a factor of corm size. This has been conclusively proved by the experiment using suckers of graded corm size. The time taken from SCI to FBI, FBD and Shooting and Maturity is almost same. Hence the change in crop duration of Nendran bananas can be explained on the basis of time taken to reach SCI. A definite GDD is required for the planted sucker to reach the SCI stage depending on corm size. The thermal unit requirement is based on the corm size and this explains the reasons for early bunch production of large sized corms

The study has confirmed that the root production in banana is in flushes. Five flushes of roots are observed in a crop cycle. Overlapping of successive flushes of roots is observed giving a false appearance of continuous root production. Overall, the production of a flush of root takes place in about a fortnight's time. Qualitative & quantitative differences are observed in the production of different flushes of roots.

The study has confirmed that the flushing of roots is more dependant on the biotic events of the crop. The first flush of roots is observed in the early vegetative phase (EVS), about 3-4 weeks after planting ie. up to the production of four numbers of leaves. Thereafter, the root grows. The second flush of roots coincides with the active vegetative growth and from approximately the eighth or ninth leaf onwards. The third flush of roots is observed at the secondary corm initiation phase. The first and second flushes are

observed purely on the primary planted corm whereas, the third is observed partly on the newly developing corm *ie:* the Secondary Corm and partly on the primary corm and on the constricted interphase part. The fourth flush of roots is observed at the flower bud initiation stage and the fifth flush at shooting or early bunching phase. These two flushes of roots carry the banana bunch to maturity.

In the orderly cycle of development of banana, five distinct physiological phases such as Vegetative Phase, Flower Bud Initiation (FBI), Flower Bud Differentiation (FBD), Shooting and Bunch Maturity are normally described. In no literature has the corm ever been emphasized or even mentioned in the developmental physiology. The formation of the secondary corm was studied anatomically and the physiological factors governing the secondary corm formation was also studied by analyzing the mother corm tissues. The study has conclusively proven that a new corm develops on the planted corm and it is this new corm or the ***Secondary Corm*** which further carries the plant to bunching and harvest.

Another observation is that the shooting or bunching is observed to be a factor of maturity of the new corm and the crop cycle or crop span or crop duration is found to be dependant on satisfaction of three main phases

a) Primary corm to early secondary corm formation
b) Secondary corm formation, maturation of secondary corm to bunching
c) Bunch maturity and harvest

During the second year, the experiments were focused on hastening of secondary corm development and early replacement of original corm of the sucker. For this, suckers of a medium corm size were fixed based on the first year's experiment.

In the study involving hormonal application, IAA, NAA, PCBA and ABA each at 250 and 500 ppm were advocated by corm dip method and corm injection method

Hormone dipping treatment of suckers prior to planting and by corm injection after establishment revealed that early growth was suppressed by PCBA with drastic

reduction in internodal length. Dwarfening of plant stature could be attained by using PCBA and ABA. This would pave the way for further research to mitigate the effects of wind or avoid staking which is a costly input. SCI was observed to be earliest in treatments involving IBA. However the control treatments were the earliest to bunch. The crop is yet to be harvested. The study has proven that maturity of secondary corm can be manipulated by exogenous application of growth regulators.

The studies on root activity revealed spatial distribution of root activity and differential accumulation in various tissues which could be explained at tissue level and with time The importance of secondary corm and its accumulation in tune with the development physiology. On the fifth day after application recovery of activity was observed in the primary corm only at the FBD stage. On the 10^{th} day after application (DAA) maximum recovery of activity was obtained in the primary corm at FBI stage. Sufficiently higher amounts were observed at Early Vegetative Stage (EVS), Active Vegetative Stage (AVS) and Half Maturity stage. On the contrary at 15^{th} DAA the relative concentration was very much high in primary corm at EVS and AVS stage. The relative concentrations were six times that observed at SCI (third highest) in the former and double in the latter. As the crop advanced the concentration has decreased with single digit recovery at Half Maturity.

In case of secondary corm (SC) on the fifth day, recovery of activity was only observed at FBD stage, whereas on the 10^{th} day it was maximum observed at FBI stage. Highest recovery in SC is observed at shooting followed by Secondary Corm Initiation (SCI) stage, Half Maturity and FBI. At all stages a fairly good concentration is observed explaining for the growth of secondary corm. The relative levels in roots in the earliest and second sampling were observed at FBI stage whereas in the final sampling it was observed to peak at half maturity and shooting stage.

The maximum recovery of radioactivity in the pseudostem were observed in the early two stages in the first sampling ie. FBI & SCI and AVS in the second and in early three stages in final sampling, revealing that nutrient absorbed is the maximum utilized

for structural make up. In the final sampling, recovery was observed in the pseudostem in all the stages.

In the case of recovery form the 'D' Leaf in early sampling, maximum recovery could be traced at FBI stage followed by that at half maturity and FBD. In this sampling recovery was not observed at any other stage. On the 10^{th} DAA maximum recovery was observed at FBI followed by SCI, FBD and half maturity. No recovery was observed at any other stage.

In case of the concentration in petiole of 'D' leaf maximum recovery was observed at FBI, Shooting, SCI and Half maturity on the second sampling. No radioactivity was recovered at any phase on the 5^{th} DAA. However in the final sampling maximum recovery was observed at EVS, Shooting, SCI and Half Maturity. Recovery was observed at all stages in the 15^{th} DAA.

The boot leaf which subtends the bunch showed fairly good concentration at Half Maturity on the 15 DAA emphasizing the importance of the leaf with advance in fruit maturity. Lower levels were recovered at the shooting stage. On the 5^{th} and 10^{th} DAA no recovery were observed. In the case of 'D' finger the maximum recovery was observed at shooting stage on the first, second and third sampling. The levels being fairly high in the final sampling.

In case of male bud increasing levels of recovery are observed with samplings. The levels being the highest in case of last sampling and being the highest sink per unit weight of tissue. At Half Maturity no recovery was observed at 5^{th} and 10^{th} DAA but in the final sampling again high level of recovery is observed. The study overwhelmingly emphasizes the need to debud the male inflorescence on the one hand and on the other major and important side it highlights this part as a vegetable with high P nutrient content.

The first report on Carbon assimilation and transport in banana is also from the study. For this an innovative apparatus for the dissemination of ^{14}C was fabricated after many a trial and error method. The apparatus is simple in design but accurate in its practicality and the first of its kind to be used in banana plants. The results from the studies involving ^{14}C showed a holistic picture on the photosynthate translocation and assimilation to the various plant parts at different stages of its growth. During the initial stages (EVS & AVS), the accumulation was found to be the maximum at the source level itself. At SCI stage it was found to be more in the leaf petiole and pseudostem with no recovery in the primary corm. At the reproductive transformation stage of the plant (FBI & FBD), the entire assimilates were found to be translocated to the SC and Ps. At the shooting stage and the half maturity stage, the finger and male bud together account for the whole photosynthates whereby giving a marked reflection and manifestation of the functional requirement of the plant with the entire shifts focused at the sink level.