PRE- HARVEST FORECASTING MODELS AND INSTABILITY IN PRODUCTION OF CASSAVA

(*Manihot esculenta* Crantz.)

by

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(2015-19-003)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Pre-harvest forecasting models and Instability in production of cassava (*Manihot esculenta* Crantz.)"** 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, associateship, fellowship or other similar title, of any other University or Society.

Place :Vellayani
Date:28/07/2017

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CERTIFICATE

Certified that this thesis entitled **"Pre-harvest forecasting models and Instability in production of cassava (*Manihot esculenta* Crantz.)"** is a record of research work done independently by Ms. Neethu S Kumar under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

ANOVA	Analysis of Variance
CAGR	Compound Annual Growth Rate
C.V	Coefficient of Variation
C_p	Mallow's C_p
CTCRI	Central tuber crops Research Institute
df	Degrees of freedom
ESS	Error sum of square
et al.	Co- workers/ Co-authors
Fig.	Figure
FAO	Food and Agriculture Organization
fl	Functional leaves
hb	Height of branching
i.e.	that is
in	Inter nodal length
KAU	Kerala Agricultural University
LAI	Leaf Area Index
MAP	Month after planting
MLR	Multiple Linear Regression
pb	Primary branches
pl	Plant height
R^2	Coefficient of Determination
R^2_{adj}	Adjusted R^2
RSS	Residual sum of square

S.D	Standard Deviation
S.E	Standard Error
TSS	Total sum of square
VIF	Variance Inflation Factor
viz.,	Namely

Introduction

1. INTRODUCTION

Cassava (*Manihot esculenta* Crantz.) is an important tuber crop which is mainly cultivated in the tropic and sub tropic regions of the world over a wide range of soil and environmental conditions. It grows and produces best under warm humid condition where rainfall is available and can be grown in areas with low rainfall if irrigation is possible. Crop grows well in well drained laterite, sandy loam and gravelly soils and tolerant of drought and heat stress. It is generally grown on marginal lands with a minimum of agricultural inputs (Hillocks *et al.*, 2002). Once established, the crop needs a little attention but it is in capable of tolerating weed competition, as well as competition from insect, pests and disease.

Cassava is an important dietary staple in many countries within the tropical regions of the world (Perez and Villamayor, 1984). It provides the staple food for an estimated 800 million people worldwide (FAO, 2007), grown almost exclusively by low-income, smallholder farmers, produced efficiently on a small scale, without the need for mechanization.

Cassava is considered as the third most important food source of carbohydrate in the tropics after rice and maize and it provides more than 60 per cent of the daily calorie needs of the population. It plays an important role in alleviating poverty as it thrives and produces stable yield under conditions in which other crops fail. It can also be considered as a versatile crop which can be processed into a wide range of products such as starch, flour, tapioca, beverages and chips etc.

Cassava is also gaining significance as an important crop for the emerging bio fuel industry and as a potential carbohydrate source for ethanol production (Ziska *et al.,* 2009). A well formulated plan for the improvement and utilization of cassava and cassava products will help to provide incentives for farmers, crop vendors and food processors to increase their family income and profit. It also provides food security for households by producing and consuming cassava and cassava products (Plucknett *et al.*, 1998).

Cassava which was believed to have originated from Brazil introduced into India by the Portuguese during the 17th century was now cultivated in about thirteen states of India with major production in the South Indian states of Kerala (71100 ha) and Tamil Nadu (120600 ha) in 2013-14. In India 60 per cent of production is used for the production of sago, starch and chips and we have a demand - supply gap of 1.5×10^6 tons of tapioca production (Sreenivas,2007). However, major production of cassava is used for house hold consumption in Kerala. Kerala state accounted for 45.5 percent in area, 58.74 per cent in production to all India area and production in 2001-02 (Edison *et al.*, 2006). However, states contribution in area and production to all India was reduced to 29.90 percent and 27.75 per cent in 2012-13. The productivity of 37.59 t ha^{-1} was highest in Kerala among the major cassava growing states in 2001-02. In recent years the productivity of cassava has increased with the introduction of high yielding short duration varieties but the trend in production and area was downward in India.

Recently, a number of short duration varieties of cassava were developed by Central Tuber Crops Research Institute (CTCRI) and Kerala Agricultural University (KAU). These varieties are generally distinguished from each other by their morphological characteristics such as leaf, stem and tuber color, leaf shape and number of storage roots per plant. It can be easily propagated by stem cuttings but the lack of sufficient quality planting material is considered as a major constraint for the improvement of a viable cassava production system.

Forecasting of crop yield is a challenge. Main factors affecting crop yield are soil characteristics, inputs supplied and weather parameters. Crop yield estimation before harvest is important to the farmers and consumers to determine the price and stability in the market especially in a crop like cassava where the economic part is the root tuber which is perishable. Yield prediction models can be developed using climatic factors to study the effect on crop yield with the help of secondary data. Moreover, forecasting model can be developed using plant characters also. Crop yield forecasting methods are used to improve agriculture and rural statistics. Deterministic crop models can be developed by taking observations throughout the growing period which give a precise measure of yield before the harvest of the crop. Difference between forecast and final production are analyzed after harvest.

Reliable and accurate pre-harvest forecast estimates of crop production help as a basis of decision making policy of the government, agro -based industries, traders and agriculturalists. Government demands a reliable and valid pre-harvest forecast of production of crops for their policy decision in regard to procurement, distribution, buffer stocking, import-export, price fixation and marketing of agricultural commodities. The agro based industries and traders need them for proper planning of their operations, while agriculturalists use them as a basis for deciding the cultivation of a crop and its acreage during the subsequent season. Hence, the yield data obtained by reliable forecasts techniques will be very much helpful for the country like India whose economy is mainly based on agriculture.

In this context, an attempt is made to develop pre-harvest forecasting model for tuber yield of cassava using biometric characters of the plants. Linear and non-linear regression models which are estimated by regressing yield as a function of the biometric characters can be used for predicting yield. Pre- harvest models based on primary data were scarce in Cassava. This study make an attempt to develop pre- harvest yield prediction models in five popular short duration varieties of cassava in Kerala, with the following objectives:

- To develop early forecasting models for yield of five major short duration varieties of cassava.

- To carry out trend and instability analysis on area and production of cassava in Kerala.

1.1 NATURE AND SCOPE OF THE STUDY

The present work is an attempt to analyze the inter relationship between yield and biometric characters and to develop pre- harvest forecasting of cassava yield based on which appropriate management practices can be adopted to obtain better returns to farmers as compared to traditional practices. The time series data on area, production and productivity over a period of 25 years incorporating additional information like price and climatic factors will help to find the behavior of the cassava production system quantitatively.

1.2 LIMITATION OF THE STUDY

The study has been conducted as a part of the M.Sc. (Ag. Stat) programme and is limited to only one season and location. Also the study is limited in the sense that the model will be developed only by using the biometric characters and without incorporating the weather parameters.

1.3 ORGANIZATION OF STUDY

For analytical convenience and clear exposition of the present study, the thesis has been organized into six chapters including the introduction chapter which deals with the importance of the topic, objectives, scope and limitations of the study. Second chapter elucidates with the review of literature including the findings of related studies to throw some insight in developing yield forecasting model. Third chapter delineates the methodology adopted, including the description of the experimental site, nature of the variables and their measurements, source of secondary data and the analytical technique used in the study. Results of the study are presented in the fourth chapter and the discussion of major findings is highlighted in fifth chapter. Summary are presented in the sixth chapter.

Review of Literature

2. REVIEW OF LITERATURE

A number of studies have been undertaken on pre-harvest forecasting of different crops such as cereals, oilseeds, commercial and fruit crops by different institutions and also on trend and instability analysis. The present chapter attempts a brief review of the important related studies with different methodology. This would enable the researcher to lead the study in the right direction, collect the appropriate data and to draw meaningful results out of it. Keeping in view the objective of the study, the reviews are presented under the following headings.

2.1 Pre- harvest forecasting models

2.2 Trend analysis

2.3 Instability analysis

2.1 PRE-HARVEST FORECASTING MODELS

A pilot study was conducted by Singh *et al.* (1976) in 120 villages of 4 selected blocks in Aligarh District for estimating pre-harvest forecasting model of wheat yield. Multistage random sampling method was used and observation on biometric characters such as number of tillers plant^{-1}, height of the main tiller, length of ears, number of green leaves plant^{-1} and diameter of the main tiller at the base were recorded. The correlation coefficient was found to be positive and highly significant between yield and number of tillers, while correlation between yield and other biometrical characters varied from block to block over different intervals of time. The amount of variation in tuber yield explained by the biometric variables ranges from 26 to 36 per cent.

Singh *et al.* (1979) tried to improve the forecasting yield of jute crop with the help of biometric characters. This analysis was based on the data collected from a pilot study for four years in the state of Bihar and West Bengal. A multiple linear regression model between yield and biometric characters was considered because of its simplicity, variance of the prediction and lesser magnitude of measurement error. The results of multiple regression analysis revealed that the multiple correlation coefficients between crop yield and the biometric characters were highly significant while the partial regression coefficients of yield with height and diameter of the plants varied from year to year. The results of the study indicated that the prediction of jute yield based on plant density and plant height was highly satisfactory with an explanatory power of the predictor biometric variables ranging from 30 to 50 per cent.

An attempt for forecasting rice yield in Raipur was done by Jain *et al.* (1980) using climatic factors based on data at different stages of crop growth. Secondary data on weekly weather variables such as maximum temperature, total rainfall, relative humidity and number of rainy days for twenty five years was used for developing yield prediction models. Statistical methods such as principal component method and regression analysis were performed and the results of the analysis revealed that yield forecasting in rice was possible using weekly climatic variables.

Jain *et al.* (1981) carried out a pilot survey in Meerut district (U.P) to estimate the pre-harvest sugarcane yield by developing suitable forecasting model. The samples were selected by using multistage random sampling technique and data on yield and biometric characters were collected. Correlation coefficient was found to be positive and significant for the characters like number of canes and height with the yield parameter except for the first stage. The results of the study indicated that when the crop was about 7 to 8 months old, these characters could explain the variation in yield using multiple regression technique and it was possible to predict the yield using these explanatory variables about 2 to 3 months before harvest.

A forecasting model for pre-harvest estimate of sugarcane yield was made by Jha *et al.* (1981). The biometric characters included in the analysis were number of shoots, height, girth of shoot and width of the third leaf from the top. The results of the analysis revealed that number of canes and their height had significant effect on yield and these variables were incorporated in multiple regression models to predict the yield, 2 to 3 month before harvest.

Chandrahas *et al.* (1983) developed a pre-harvest model for predicting sugarcane yield using plant biometric characters taken at various stages of crop growth. Correlation analysis was carried out between crop yield and biometric characters and suitable model was fitted using multiple regression technique.

Multiple regression models were developed for forecasting cotton yield by Aneja and Chandrahas (1984). The per cent of variation in yield explained by plant population and number of bolls was 35 to 40 and it was increased to 80 per cent by the addition of first picking yield as a predictor variable.

A study was conducted by Jain *et al.* (1985) for forecasting the yield of hybrid jowar using growth indices of biometrical characters for two or more periods. Growth indices were developed by taking correlation coefficient between yield and plant characters as weights of the variables included in the study. The biometrical characters included were number of plants, height of plants, number of leaves per plant, length and breadth of flag leaf and length of ear head. About 50 per cent variation in yield was explained by the characters at 10-12 weeks growth stage. New models were developed to improve the variation explained by the biometrical characters of 2 or more periods have been utilized and it was observed that new model was superior to linear model.

Multiple linear regression models were developed by Bapat and Singh (1987) to predict the yield of groundnut crop in Rajkot district (Gujarat) using data on biometric characters and weather parameters. The different biometric characters included in the analysis were number of flowers plant^{-1}, plant population, length of main axis and number of pods per plant at the pegging stage after sowing. The plant population and length of main axis showed positive and significant correlation with yield in all periods of crop growth while rainfall during pod development stage was found to be significantly correlated with yield. About 54 per cent of variation in yield was explained by biometric characters. It was observed that the forecasting models developed using the biometric characters at flowering, pegging and pod development stages of crop growth were good in predicting the crop yield.

A pilot study was conducted in Kolhapur district of Maharashtra by Bapat and Singh (1988) to develop an appropriate forecast model for pre-harvest of sugarcane yield. This study adopted multi-stage stratified random sampling and multiple regressions for selection of fields and forecasting of crop respectively. It was found that the biometric characters showed a positive and significant correlation with yield and it contributes a variation of 51-73 per cent.

A pilot study on pre-harvest forecasting of apple yield in Shimla District was done by Chandrahas and Prem Narain (1993). Statistical methods such as regression analysis was performed using data on yield as the dependent variable and tree characters such as height, girth and canopy spread as independent variables. About 59, 65 and 40 per cent variation in yield were explained by the model at 6-10 years, 11-15 and above 15 years old stage respectively and the results revealed that forecasting the yield in apple was possible at about two month before harvest using tree characters.

Three year data on tobacco crop was analyzed by Chandrahas *et al.* (1993). This study utilized data on biometric parameters such as plant height, breadth, plant population per plot and number of curable leaves per plant along with yield. It was found that when the crop attains more than 10 weeks old, correlation of cured leaf yield with number of curable leaves and plant population were significant and the correlation between yield and height was significant when the crop was at 12-17 weeks old. Regression output has shown that, 40-70 and 50 per cent variation in yield was explained by biometrical parameters when it was grown in black and red soil respectively. The results of the study concluded that pre-harvest forecasting of crop yield was feasible when the crop was at 12 weeks old.

Banana yield was predicted using regression models by Rao *et al*. (1993). The result of regression analysis using data on biometric characters of ten cultivars has shown that the morphological characters were positively correlated with yield and yield prediction was possible during the early stages of the crop.

Agrawal *et al*. (1994) made an attempt to develop an integrated forecasting model for rice using spectral data at New Delhi. Analysis was done according to split plot design where soil treatment was taken as main plots and nitrogen level in subplots. Statistical methods such as correlation and regression were performed for the observation taken from 18 plots. The estimated multiple regression was possible with 95 per cent variation in rice yield and rice yield could be forecasted a month before harvest using the spectral data.

A forecast model was developed for predicting wheat yield using multiple linear regression based on data collected from experimental plots by Onkar *et al*. (1998). Biometric parameters collected were number of tillers, height of plants and length of ear head and the design adopted was split plot design with tillage in main plots and treatments in subplot. Linear and quadratic functions were fitted to the data and observed that linear model was more adequate than quadratic.

Shamasundaran *et al*. (2002) used multiple regression models for predicting the yield of banana based on plant characters such as plant height, plant girth and number of suckers plant^{-1} for seven commercial varieties of banana at five stages of growth. The results of the study indicated that model prediction was found to be better during the later stages.

The yield forecasting model in cardamom, growing under intensive management practice using thirteen plant characters was attempted by Priya *et al.* (2003). The explanatory variables included in the analysis were tillers clump^{-1}, tiller height, leaves tiller^{-1}, vegetative buds clump^{-1}, bearing tillers clump^{-1}, panicle clump^{-1}, panicle length, capsule racemes $^{-1}$, leaf breadth and recovery percentage and these variables contributed a precision of about 82 per cent variation in yield. Step down multiple regressions was appropriate and it was found that four characters such as panicle clump^{-1}, racemes panicle $^{-1}$, capsules racemes $^{-1}$ and leaf breadth contribute about 77 per cent precision in yield.

Tittonell *et al.* (2005) estimated crop yield using multiple linear regression models in cereals with explanatory variables as plant height, ear length and ear diameter and the results of the study concluded that simple linear regression using plant height was appropriate for estimating the yield.

Anuradha *et al.* (2007) conducted a study with thirty genotypes of pigeon pea and found that characters such as number of pods plant^{-1}, per plant, number of secondary branches plant^{-1}, harvest index and dry matter plant^{-1} had a significant positive correlation with yield plant^{-1}. Path analysis was performed to estimate direct and indirect effect of biometric characters on yield and it revealed that harvest index had a highly positive direct effect on seed yield plant^{-1} along with dry matter plant^{-1}, seeds pod^{-1}, and primary branches plant^{-1}.

An attempt was made to develop a regression model to forecast rice yield over central Punjab by Kaniska *et al.* (2007). Correlation analysis was carried out between rice yield and weather data for 29 years and sensitive period for rice yield with respect to weather parameters were identified. Linear, exponential and power regression models were developed and they were found to be significant at 1 per cent level of significance. The yield predicted using power regression was more accurate than linear and exponential models.

Kumar *et al.* (2007) performed regression studies on plantain and found that vegetative growth and fruit characters could effectively be used for yield forecasting. These characters were treated as independent predictor variables for developing the model. Growth parameters predicted the yield up to 89.29 per cent while fruit characters could predict yield up to 99.57 in main crop and 78.69 per cent and 86.54 per cent respectively, in ratoon crop.

Ram *et al.* (2007) conducted a study to predict yield in plantain using multiple regression models by considering observations on both growth and fruit characters at the time of harvest as separate predictor variables. The analysis on ten plantain varieties showed that vegetative growth and fruit characters could effectively predict the yield. Growth factors contribute about 89.29 per cent of variation in yield while fruit characters contribute about 99.57 per cent in yield.

A field experiment was conducted by Pramila and Rajireddy (2008) to identify the relationship between growth and yield attributes of soybean cultivated in various cropping systems. Correlation coefficients were determined between weather parameters, crop growth and yield attributes. A regression model was developed by considering the weather parameters, which had significant effect on the seed yield.

Regression analysis was carried out by Sharma *et al.* (2008) to predict crop yield of Apple using morphological parameters such as trunk girth, tree volume, spur content, fruit set and nutritional parameters. The results of the analysis confirmed that yield prediction using multiple linear regressions was highly satisfactory.

A statistical model for predicting sugarcane yield was made by Suresh and Priya (2009) using weather parameters as explanatory variables. The estimated model was able to explain 87 per cent variation in yield and it was helpful in predicting the yield at 2 month before harvest.

Pandey *et al*. (2013) made an attempt to develop models for forecasting rice yield on the basis of weather variables. Weekly data on weather parameters and annual rice production had been collected. Statistical procedure such as stepwise regression was used to find out the important variables and the parameter estimation was done using multiple linear regression analysis.

Statistical models have been developed by Annu *et al*. (2014) for prediction of wheat yield based on biometric characters under normal and late sowing condition. Several forecasting models were estimated by using explanatory variables as original biometric characters and different forms of original variables in the model and the results of the analysis concluded that in both cases the multiple regression model with biometric characters in the original form were found to be the best forecasting model.

A pre-harvest forecasting model for predicting *Kharif* rice yield in coastal Karnataka was developed by Geetha and Sridhara (2014). It has been found that the forecasting models estimated were able to explain annual variation in rice production and to predict pre-harvesting estimates of rice yield with greater accuracy.

Singh *et al*. (2014) performed regression analysis in wheat to predict the crop yield at different stages of crop growth. The simulated model for prediction of crop yield at 45 days before harvest using studies up on weather indices could successfully predict the pre-harvest yield under semi arid region. The deviation between observed yield and predicted yield was determined and it ranged from 5-11 per cent.

Agrawal (2015) conducted a study to analyze the effect of weather parameters and inputs on the crop yield and to estimate appropriate forecasting model for crop yield. Two types of forecasting models such as within year and between year models were used in this work. The between year models were developed by taking data from previous years while within year model used data from the current period. The result of the analysis revealed that logistic model having yield as dependent variable and time as independent variable fits a suitable model for predicting the yield.

Bhatt *et al.* (2015) in their study used regression models for forecasting of mustard yield in Punjab .Three different statistical models have been developed for predicting crop yield using weather parameters. In the basic model, multiple regressions were performed using weather parameters and in the modified model an extra variable of technology trend were taken and in the third model, regression analysis was done using Statistical Package for Social Science (SPSS). The results of the study indicated that modified model was the best fit for Ludhiana and Patiala region while SPSS fits for Amritsar region.

Garde *et al.* (2015) discussed different multiple linear regression models for predicting wheat yield in Uttar Pradesh for a period of 27 years from 1982-83 to 2008-09 using weather parameters. They concluded that stepwise regression can effectively be used for predicting yield.

Chaudhari *et al.* (2016) developed a forecasting model for prediction of yield in mustard using weather parameters in Gujarat.Various models were estimated using all weather parameters and step wise regression was performed to increase the forecasting power of the model. Model which has provided the earliest forecast with high coefficient of determination, t value and minimum percentage deviation from the observed average yield was found to be the best forecasting model.

Goyal (2016) made an attempt to estimate the yield of wheat using different multivariate techniques. A trend based yield model was developed using weather parameters and the model was found to be suitable for predicting the yield. Three types of regression models were performed.

1. Weather parameters and trend yield as regressors

$$Y=12.96+1.069TY-0.21GDD-0.11GDD-0.17\,ARF$$

$$\text{Adj } R^2 = 0.84 \quad SE = 2.77$$

2. Principal component scores and trend yield as regressors

$$Y=1.26+.967TY+0.77PC+0.61PC$$

$$\text{Adj } R^2 = 0.86 \quad SE = 2.57$$

3. Discriminant scores and trend yield as regressors

$$Y=1.20+.965TY-0.30DS-1.12DS$$

$$\text{Adj } R^2 = 0.87 \quad SE = 2.42$$

Y: model predicted yield

TY: trend yield

PC_i : i^{th} principal score

DS^i : i^{th} discriminant score

S.E : standard error of the estimate

2.2 TREND ANALYSIS FOR AREA, PRODUCTION, PRODUCTIVITY AND PRICE

Subramaniyan (1982) analyzed the growth of area, production and productivity of banana using secondary data in different states of India for a period of 15 years. Study revealed that trend in area was increasing for this period.

A study was conducted in Andhra Pradesh for analyzing the growth and distribution of fruit crops such as mango, citrus, grapes, papaya and other fruits for a period of 13 years by Raju *et al*. (1989). Statistical methods such as compound growth rate and simple regression were employed for carrying out the analysis.

Angles and Hosamani (2002) analyzed the growth rate in area, production and productivity of turmeric in certain states of South India for a period of 20 years from 1979-80 to 1998-99. An exponential growth function was used for the analysis and concluded that there was significant growth in area, production and productivity except, area in Tamil Nadu and Kerala, production in Tamil Nadu and productivity in Karnataka.

The trend in area, production, productivity and export of cashew in India was analyzed by Mamatha *et al.* (2002). The study revealed that growth rate in area, production and productivity were found to be positive.

Navadkar *et al.* (2004) examined the trend in area, production and productivity of fruits and vegetables in Himachal Pradesh. The estimated growth rates indicated that there was a significant increase in area under fruits and vegetables by 3.1 and 1.5 per cent per annum respectively while production increased by 2.6 and 4.4 per cent annually.

Sebastian *et al.* (2004) analyzed the growth rates in area, production and productivity of cashew in Kerala for a period of 48 years (1952-53 to 1999-2000). The period of study was subdivided into two the periods; such as period 1 from 1952-53 to 1975-76 and period II from 1976-77 to 1999-2000. The study concluded that area showed positive and significant growth while production had a stagnant rate and productivity had a decreasing trend for the study period.

Rao and Reddy (2005) computed the growth rates of area, production and productivity of groundnut for two periods; period 1 from 1988-89 to 2002-03 and period II from 1953-56 to 2002-03 for three geographical regions of Andhra Pradesh. The results of the study indicated that area had negative significant growth rate in period 1 and had positive significant effect in period II, while production and productivity was significant during both periods.

Varghese (2007) conducted a study on trend analysis in area, production, productivity and price behavior of cardamom in Kerala. The study revealed that there was a significant decline in area by 1.21 per cent and a significant increase in production and productivity by 4.14 and 5.51 per cent per annum respectively.

Aparna *et al.* (2008) made an attempt to analyze the trend in growth rates of major vegetables using compound annual growth rates (CAGR) in Vishakhapatnam district. CAGR was calculated using exponential growth function and the result revealed that there was significant decline in area while production and productivity showed a non- significant positive growth rate.

Trends in area, production and productivity of major fruit crops were examined by Kalita *et al.* (2008) using secondary data for a period of 25 years in Jammu and Kashmir. The study concluded that area, production and productivity showed a significant positive growth rate during the study period and instability index was found to be low.

Jaypatre *et al.* (2010) analyzed the trends in area, production and productivity of mango in south Gujarat region. Secondary data on time series was collected from General Statistical Information of Agricultural Department. Study was mainly pertained with two sub periods. The results of the analysis revealed that linear growth rate was non- significant while compound growth rate was significant in both periods. Instability index of area, production and productivity were found to be higher in second period.

An attempt was made by Jayasree *et al.* (2012) on analysis of price behavior of cassava in Kerala for a period of 12 years from January 1999 to June 2011. Study revealed that the growth in cassava prices was slow and had a price instability index of 36.97 per cent.

Ramandeep *et al.* (2015) examined the trends in area, production and productivity of important crops such as cotton, castor and banana. Data pertaining to area, production and productivity of these crops were collected for a period of 12 years. The study concluded that trend in area, production and productivity of these crops showed an increasing trend at country level.

Sharma (2015) made an attempt to analyze the trends in area, production and productivity of banana crop in India. A time series data from 2001-02 to 2013-14 (13 years) and from 2005-06 to 2010-11 (6 years) regarding the area, production and productivity of banana crop in India was collected. It is observed that there was significant decline in area in India while there was a significant increase in area under banana in the district of Kaushambi by 9.51 per cent but the production has decreased by 26.38 per cent and productivity was increasing at the rate of 1.3 per cent per annum.

2.3 INSTABILITY ANALYSIS FOR AREA, PRODUCTION, PRODUCTIVITY AND PRICE

Anuradha and Reddy (2005) analyzed the growth and instability in cotton area, production and productivity during the period from 1951-52 to 2010-11. CGR were estimated using exponential function and instability measures such as coefficient of variation was computed. It was found that growth of area, production and productivity was significant and instability was found more on production followed by productivity and area.

Ganeshan (2015) made an attempt to examine the growth and instability in turmeric production in terms of area, production and productivity in selected states of India. Secondary data for a period of 32 years were collected. Result revealed that there was a significant increase in area, production and productivity with a low instability index.

Ashok and Yelledhalli (2016) conducted a study to analyze the growth and instability in area, production and productivity of different crops in Bangalore division. Statistical measures such as coefficient of variation and Coppock index were calculated to obtain the instability measure. Study revealed that area and production of cereals had a negative growth while productivity had positive growth and found that area, production and productivity of pulses had been increased significantly.

It is evident from the review of literature that multiple linear and non-linear regressions were suitable for developing the pre-harvest forecasting of crop yield. Moreover, correlation analysis provides the most appropriate method to or establish the interrelationship between the variables. The review of literature on trend and instability emphasize the need of comparing various methods and to determine the trend and instability.

Materials and Methods

3. MATERIALS AND METHODS

It is important to discuss about the materials and methods used in the present study to prove or disprove the various hypothesis developed as part of finding an answer to the objectives. This chapter gives an idea about the source of the data, variable of measurement and statistical procedures adopted in the study and the details are presented under the following headings.

3.1 Description of Experimental Site

3.2 Materials: Collection of Primary and Secondary Data

3.3 Methods: Statistical Tools and Techniques Employed

3.1 DESCRIPTION OF EXPERIMENTAL SITE

The present study uses both primary and secondary data. The primary data for the study was taken from a field experiment conducted at Instructional Farm, College of Agriculture, Vellayani as part of an ongoing project on 'Performance of short duration varieties of cassava in low lands'.

A general awareness about the characteristics of the study area is vital to understand the background of research. The field experiment was conducted in the instructional farm, College of Agriculture, Vellayani in Randomized Block Design with three replications. All Cassava varieties were planted during March 2016 and harvested during August 2016 with a spacing of 90 cm x 90 cm. All cultural practices were followed during the cultivation, as per Kerala Agricultural University Package of Practices Recommendations (KAU, 2016).

3.1.1. Climate: Vellayani had a warm humid tropical climate. The weekly averages of maximum and minimum temperature, relative humidity and rainfall received during the cropping period collected from the observatory of College of Agriculture, Vellayani are given in Appendix 1.

3.1.2. Cropping Period: The field experiment was conducted during the period from March to August 2016.

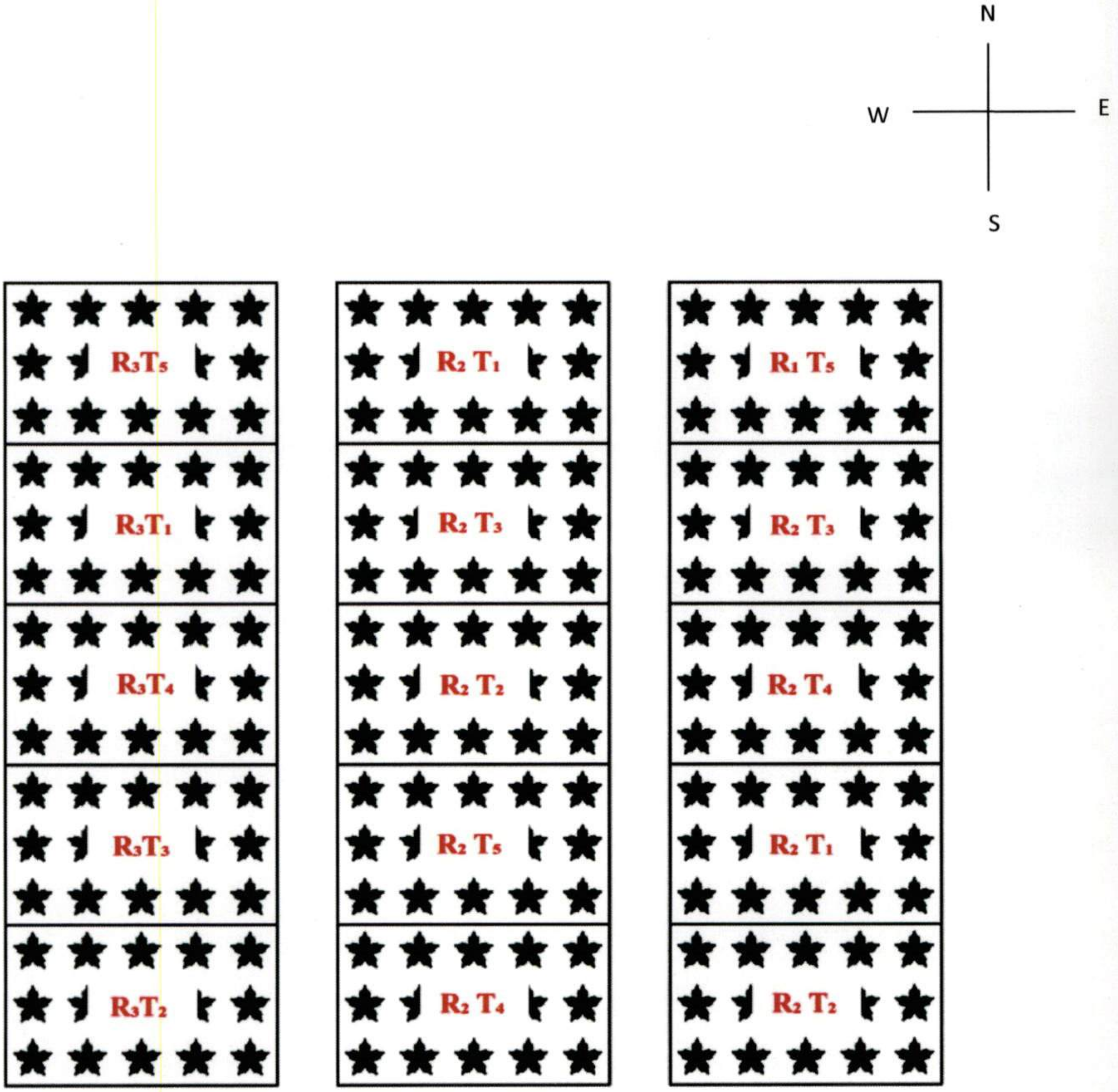

Fig. 1 Lay out of the field experiment

Fig 2: General view of the experimental site

3.1.3. Cropping History of the Experimental Site: The experimental site was under a bulk crop of upland rice during the previous season.

3.1.4. Soil: Soil of the experimental site was sandy clay loam belonging to the taxonomical order oxisol.

3.2. MATERIALS

3.2.1. Crop Variety

The varieties selected for the present study were 5 short duration cassava varieties *viz*., Sree Jaya, Sree Vijaya, Sree Swarna which are released from Central Tuber Crops Research Institute (CTCRI), Sreekariyam, Trivandrum, Vellayani Hraswa from College of Agriculture, Vellayani and a local variety Kantharipadarppan.

3.2.2. Selection of Samples

The number of plants in each replication was 15 so that the total number of plants for each variety was 45. Among the number of total plants, a sample of 25 plants were selected at random for each variety. The total sample size for the present study was 125. To develop a pre-harvest forecasting model using the biometric characters, observation on biometric characters at monthly interval and yield and yield attributes taken at harvest were considered as the major items of observation.

3.3. OBSERVATIONS ON CROP

3.3.1. Biometric Characters

3.3.1.1. Plant Height: Height of the plant from bottom to top of the plant measured in cm, was taken as plant height and observations were recorded at monthly interval. The plant height at first month, second, third, fourth and fifth month are denoted as pl_1, pl_2, pl_3, pl_4 and pl_5 respectively.

3.3.1.2. Inter nodal Length: Distance between two nodes measured in cm and was considered as inter nodal length. The inter nodal length at first, second, third, fourth and fifth month are denoted as in_1, in_2, in_3, in_4, and in_5 respectively.

3.3.1.3.Number of Functional Leaves plant^{-1}: The number of leaves which are photo synthetically active was taken as number of functional leaves and the observations were taken monthly and they are denoted as fl_1, fl_2, fl_3, fl_4, and fl_5 respectively.

3.3.1.4. Total Number of Leaves plant^{-1}: Total numbers of leaves in each plant was counted, every month.

3.3.1.5. Leaf Area Index: Length, width and number of lobes were measured for 3 leaves (top, middle and bottom portion) from each plant and leaf area (A) was calculated using the equation

A= length * width* number of lobes*constant value (0.44) and expressed in cm^2. LAI was calculated using the equation,

$$\text{LAI} = \frac{leaf\ area\ \mathbf{plant^{-1}}\ (\mathbf{cm^2})}{leaf\ area\ occupied\ by\ the\ plant\ (cm^2)}$$ (Ramanujam and Indira, 1978)

3.3.1.6. Number of Primary Branches plant^{-1}: Number of primary branches was taken at monthly interval and is denoted as *pb*.

3.3.1.7. Height of First Branching: Height of first branching was measured in cm from base of the stem, at soil level to the top of branch and it is denoted as *hb*.

3.3.2. Yield and Yield Parameters

The tuber yield and yield parameters were measured at harvest stage of each sample plant separately.

3.3.2.1. Number of Tubers plant^{-1} : Number of tubers was counted from each sample plant.

3.3.2.2. Average Tuber Weight: Weight of the tuber was measured in grams (g) from each plant and average worked out.

3.3.2.3. Average Tuber Length: Length was measured in cm for each tuber from each plant and average worked out.

3.3.2.4. Average Tuber Girth: Girth was measured in cm for each tuber from each plant and average worked out.

3.3.2.5. Tuber Yield: Tuber yield from each plant was weighed and recorded in kg.

3.3.3. Collection of Secondary Data

The data pertaining to area in ha, production in tones, productivity in kg ha $^{-1}$ and price in rupees were collected for a period of 25 years (1991-2016), from the publications of Department of Economics and Statistics, Thiruvananthapuram, Kerala to elicit the trends and instability in area production, productivity and price of cassava. The rainfall data was also collected to study its effect on the trends in production of cassava in Kerala.

3.4. METHODS OF STATISTICAL ANALYSIS AND DEVELOPMENT OF FORECAST MODEL FOR PRIMARY DATA.

The appropriate statistical methods used for the analysis of primary data were discussed in detail in this section.

3.4.1. Summary Statistics

The average, standard deviation, minimum and maximum of all items of measurements of all varieties were determined.

3.4.2. Pearson's Correlation Coefficient

Pearson's product moment correlation coefficient was computed to study the association between tuber yield and biometric characters and yield and yield attributes. The analysis was done for each variety.

$$r = \frac{covariance\ (X,Y)}{Standard\ deviation\ (X)\ standard\ deviation\ (Y)} = \frac{cov\ (X,Y)}{\sqrt{v(X)v\ (Y)}}$$

$$r = \frac{\Sigma(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\Sigma(x_i - \bar{x})^2\ \Sigma(y_i - \bar{y})^2}}$$

Where, $cov\ (X,Y) = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})$

$v(X) = \frac{1}{n-1}\Sigma(X_i - \bar{X})^2$

$v\ (Y) = \frac{1}{n-1}\Sigma(Y_i - \bar{Y})^2$

$r \in [\,0,1]$

The significance of correlation coefficients was tested using critical value (Fisher and Yates, 1963) of 'r' for n-2 degrees of freedom (df) at the probability at p= 0.05 and p= 0.01 level of significance, n is the number of samples.

3.4.3. Multiple Linear Regressions (MLR)

Linear regression is a technique of estimating the conditional expected value of variable Y given the value of variable X. The variable Y is called the dependent or predicted variable (tuber yield) and variable X is called explanatory or predictor variable (biometrical observations). MLR is a statistical tool which helps to examine how multiple predictor variables are related to a predicted variable and used it to have an accurate prediction and to identify the best model.

3.4.3.1. The Model

The multiple linear functional form of Y relating to the explanatory variables (biometrical characters) is given as

$$Y = X\beta + \varepsilon$$

where $\beta' = (\beta_0, \beta_1, \beta_2, \beta_3, \ldots, \beta_p)$ is the coefficient matrix or matrix of regression coefficients, $Y' = (Y_1, Y_2 \ldots Y_n)$ is the vectors of values of the dependent variable (tuber yield) and $\varepsilon' = (\varepsilon_1, \varepsilon_2 \ldots \varepsilon_n)$ is the error vector, E (ε) = 0, V (ε) = σ^2 and Cov (ε_i, ε_j) =0, error vector ε is distributed as N [0, σ^2] and , Cov (X_i,X_j)=0 and X is given by

$$X = \begin{matrix} 1 & X_{11} \dots & X_{1P} \\ 1 & X_{21} \dots & X_{2P} \\ 1 & X_{n1} \dots & X_{np} \end{matrix}$$

is n x (p+1) matrix of observations on the explanatory variables (biometrical characters).

Multiple linear regression model of tuber yield for predicting pre-harvest was estimated using biometrical characters at every month and by combining the biometrical characters in different time periods for each variety.

3.4.3.2. Estimation of Parameters in Multiple Linear Regression Model

Method of least squares was used to estimate the coefficients and the least squares estimator of the parameter vector β is given by

$$\hat{\beta} = b = (X^1X)^{-1}X^1Y$$

and its sampling variance is given by $V(b) = (X'X)^{-'}\sigma^2$, where σ^2 is estimated error variance. (MSE from ANOVA table)

3.4.3.3. Overall Significance of Regression Using Analysis of Variance

In regression analysis, the total sum of square (TSS) is partitioned into regression sum of squares (SSR) or explained sum of squares and error sum of squares (SSE) and the ratio of mean sum of squares of regression to mean sum of squares error to test the overall significance regression. In matrix notation,

$TSS = Y'Y - n\bar{y}^2$

SSR= $\beta'X'Y - n\bar{y}^2$

SSE = $Y'Y - \beta'X'Y$

The overall significance of regression is tested using ‘F’ ratio

$$F = \frac{(\hat{\beta}^1 X^1 Y - n\overline{Y}^2)/(p)}{Y^1 Y - \hat{\beta}^1 X^1 Y /(n-p-1)}$$

Where, p is one less than total number of parameters in the model and n is the sample size and R^2 is multiple coefficient of determination.

The analysis of variance table (ANOVA) for overall significance of regression is given below.

ANOVA

Sources of Variation	d.f	Sum of squares	Mean Sum of Squares	F
Regression	p	$\beta' X' Y - n\bar{y}^2$	$(\beta' X' Y - n\bar{y}^2)\frac{1}{p}$=MSR	MSR/MSE
Error	n-p-1	$Y'Y - \beta' X' Y$	$(Y'Y - \beta' X' Y)/(n-p-1) = MSE$	
Total	n-1	$Y'Y - n\bar{y}^2$		

3.4.3.4. Test of Significances of Regression Coefficient

Null hypothesis is denoted by H_0 and is defined as there is no relationship between the variables.

Significance of partial regression coefficient was tested using t statistic with *(n-2)* df

$$t = \frac{estimate}{S.E\ (estimate)} = \frac{b}{S.E\ (b)}$$

$$\text{S.E (b)} = \sqrt{var(b)}$$

3.4.4. Model Adequacy Checking

Adequacy of a model depends on the validity of assumptions underlying the model. Violations of the assumptions may yield an unstable model. We cannot detect departures from the underlying assumptions by examination of the summary statistics such as t or F statistics or R^2 (Draper and Smith, 1981).

3.4.4.1. Coefficient of Determination (R^2)

The statistic R^2 indicates proportion of variance in the dependent variable accounted by regression. It is computed using sum of squares.

$$R^2 = \frac{\beta' X'Y - n\bar{y}^2}{Y'Y - n\bar{y}^2}$$

$$R^2 = 1 - \frac{Y'Y - \beta' X'Y}{Y'Y - n\bar{y}^2}$$

The value of R^2 ranges from 0 to 1 indicates the extent to which the dependent variable can be predicted. An R^2 value of 0 indicates that the dependent variable cannot be predicted from the independent variables while value in between 0 to 1 indicates that the dependent variable can be predicted from the independent variable without an error.

3.4.4.2. Adjusted R^2

$$R^2_{adj} = 1 - (1 - R^2)\frac{n-1}{n-p-1}$$

R^2_{adj} should always be less than R^2 and it shows how the R^2_{adj} will increase if 't' value of the added variable is greater than one (Draper and Smith, 1981). R^2_{adj} is a better measure than computed R^2 for comparative purposes. It is a modified version of R^2 which has been adjusted for the number of predictors in the model. Here, p is the number of regressor variable and n is the number of observations (Theil, 1971).

3.4.4.3. Mallow's C_p Criterion

Mallow's C_p criterion is used to find whether the model consisting of p regressors selected from k regressors is adequate or not or whether it suffers from lack of fit.

$$C_P = \frac{RSS_P}{\sigma^2} - (n-2p)$$

where RSS_P is the residual sum of square of p regressors and n is the number of observations. Models with small C_P value have small total variance of prediction. If the C_P value is near to p it indicates that bias is small and it is much greater than p indicates error is substantial and while it is below p which may due to sampling error and should be considered as no bias.

3.4.5. Detection of Multicollinerity

Multicollinerity deals with presence of linear relationship among the explanatory variables. Perfect multicollinerity means high degree of collinerity between explanatory variables. When explanatory variables are perfectly correlated, method of usual least square procedure cannot be applied in the estimation of regression coefficient. It causes serious problem in estimation, prediction and inference. Variance Inflation Factor (VIF) is an appropriate tool used for the detection of multicollinerity. VIF measures how much the variance of the estimated regression coefficients are inflated as compared to when the predictor variables are not linearly related. VIF of the i^{th} variable is given as

$$VIF_i = \frac{1}{1-R_i^2}$$

where R_i^2 is the coefficient of determination obtained when X_i is regressed on the remaining regressors.VIF are the diagonal elements of the inverse of the correlation matrix of regressors. If the estimated VIF is greater than 10, it indicates the presence of multicollinerity. If R_i^2 is very close to zero, VIF will be one and which means there is no correlation among the explanatory variables while R_i^2 is very close to one, VIF will be very large and which indicate high multicollinerity among the variables. Most important strategy to overcome multicollinerity is to remove the variables having high VIF value. If a variable has high VIF, it has to be removed from the list of predictor variables.

3.4.6. Multiple Non Linear Regression Analysis

Non linear regression analysis is a form of regression analysis in which data are modeled by a function which is a non linear combination of parameters and depends on independent variables. Cob- Douglas production function of the form $y = A\, {X_1}^{b_1} {X_2}^{b_2} {X_3}^{b_3} {X_4}^{b_4} {X_5}^{b_5} {X_6}^{b_6} \times e$ is performed by taking the logarithmic value of observations.

3.4.7. Stepwise Regression Analysis

An important issue in regression analysis with large number of variables in the model is the selection of significantly contributing variables to the yield. There are so many methods available for the selection of explanatory variables. Most common one is the stepwise regression analysis; forward and backward stepwise. In this method, selection of independent variables is done with the help of an automatic process, which involves no human intervention. The selection of significant variables is achieved by observing some statistical values like R^2, t-statistic, C_p and VIF. Stepwise regression basically fits the regression model by adding/dropping the variables one at a time based on a specified criterion. It adds or removes predictors as needed for each step and thus it is known as forward and backward step wise regression. In forward regression, selection starts with most significant predictor variable and adds variable in each step. However, in backward regression, elimination starts with all predictors in the model and removes the least significant variable in each step. The decision to add or drop a variable is usually made on the basis of the contribution of that variable to the error sum of square (SSE), as judged by the F test. (Montgomery, *et al*. 2003)

3.3.8. Analysis of Variance (ANOVA)

ANOVA was performed to compare varietal effect on yield and biometric characters.

3.3.9. Analysis of Secondary Data

3.3.9.1. Trend Analysis

Trend analysis in area, production, productivity and price of cassava was studied using Compound Annual Growth Rate (CAGR). The compound annual growth rate was estimated using the exponential function of the following form

$$y = a\, b^t e$$

Take the logarithm, it becomes *log y = log a + t log b+ error*, and it can be written as

$ln(Y) = ln(b_0) + b_1 t$, where

t – is used to represent the time variable, Y- variable for which growth rate is calculated and b_1- regression coefficient of t on Y. Student's t test was adopted to find the significance of regression coefficients (Dhindsa and Sharma, 1995).

The Compound Annual Growth Rate (CAGR) is obtained as

$$\text{CAGR (\%)} = (\text{Antilog } b_1 - 1) \times 100$$

In order to find the effect of climatic factors on the growth of area, production and productivity of cassava, rainfall adjusted growth rate was also determined using exponential growth model by taking rainfall as an independent variable (Cummings and Ray, 1969).

3.3.9.2. Instability Analysis

Instability analysis in area, production and productivity of cassava for the past 25 years were found out. Instability measures such as coefficient of variation, Cuddy-Della Valle index (Cuddy and Della Valle, 1978) and Coppock instability index (Coppock, 1962) were used to estimate the instability.

3.3.9.2.1. Coefficient of Variation (C.V) $= \frac{standard\ deviation}{mean} * 100$

3.3.9.2.2. Cuddy-Della Valle Index = C.V $\times \sqrt{(1-\bar{R})^2}$

3.3.9.2.3. Coppock Index = (Antilog) $\sqrt{(V \log - 1)}$ $* 100$

$$\text{V log} = \frac{1}{(N-1)} \sum (\log p_{t+1} - \log p_t - M)^2$$

$$\text{M} = \frac{1}{(N-1)} \sum (log p_{t+1} - \log p_t)$$

3.3.10. Statistical Software used for Analysis

STATA.12 and MS Excel-07 statistical packages are used for tabulation, correlation analysis, multiple linear regression, instability analysis and trend analysis.

Results

4. RESULTS

The review of literature, the details of experiment conducted, the items of observations recorded for the study and the various statistical procedures adopted have been discussed in the previous chapters. The results of statistical analysis of the data pertaining to the study of five short duration varieties of cassava *viz.*, Sree Jaya, Sree Vijaya, Sree Swarna, Vellayani Hraswa and Kantharipadarppan during the course of investigation are presented in this chapter under the following headings.

4.1 Summary Statistics of Biometric Characters and Yield Characters.

4.2 Comparison of Tuber Yield and Biometric Characters by ANOVA

4.3 Inter Correlations between Yield and Biometric Characters.

4.4 Pre-Harvest Yield Prediction Using Multiple Linear and Non-Linear Models.

4.5 Trends in Area, Production, Productivity and Price of Cassava in Kerala.

4.6 Instability in Area, Production and Productivity of Cassava in Kerala.

4.1 SUMMARY STATISTICS OF BIOMETRIC CHARACTERS AND YIELD ATTRIBUTES

4.1.1 Biometric Observations of variety Sree Jaya

The mean, standard deviation (S.D), minimum and maximum of the biometric parameters *viz.*, plant height, inter node length, total leaves plant^{-1}, number of functional leaves plant^{-1}, height of first branching and number of primary branches plant^{-1} and LAI of the variety Sree Jaya taken at monthly interval were found out and the results are presented in Table 1, 2, 3, 4 and 5 respectively. The summary statistics of yield parameters at harvest time were also worked out and the results are presented in Table 6.

4.1.1.1 Summary Statistics of Plant Height

It is evident from Table 1 that, the height of the cassava plant increased from 1 MAP (119.24 cm) to 4 MAP (223.44 cm) and the growth was stagnant after fourth month. The mean height increased from 119.24 cm at 1 MAP to 224.88 cm at 5 MAP with a minimum height of 99 cm at 1 MAP to 199 cm at 5 MAP. The maximum height recorded at 1 MAP and at 5 MAP were 139 cm and 259 cm, respectively. The variation in plant height was less in 1 MAP to 4 MAP but highest was (44.75 cm) at fifth month.

Table 1.Summary statistics of plant height of variety Sree Jaya

Plant Height(cm)	Mean (cm)	Standard Deviation (cm)	Minimum (cm)	Maximum (cm)
1MAP	119.24	11.94	99.00	139.00
2MAP	160.60	13.61	130.00	180.00
3MAP	195.84	18.89	151.00	220.00
4MAP	223.44	21.68	184.00	250.00
5MAP	224.88	44.75	199.00	259.00

4.1.1.2 Summary Statistics of Inter nodal Length

Table 2. Summary statistics of inter nodal length of variety Sree Jaya

Inter nodal length (cm)	Mean (cm)	Standard deviation (cm	Minimum (cm)	Maximum (cm)
1 MAP	3.66	0.82	3.00	6.00
2 MAP	3.86	0.77	3.00	6.00
3 MAP	4.32	0.69	3.00	6.00
4 MAP	4.64	0.64	4.00	6.00
5 MAP	4.88	0.66	4.00	6.00

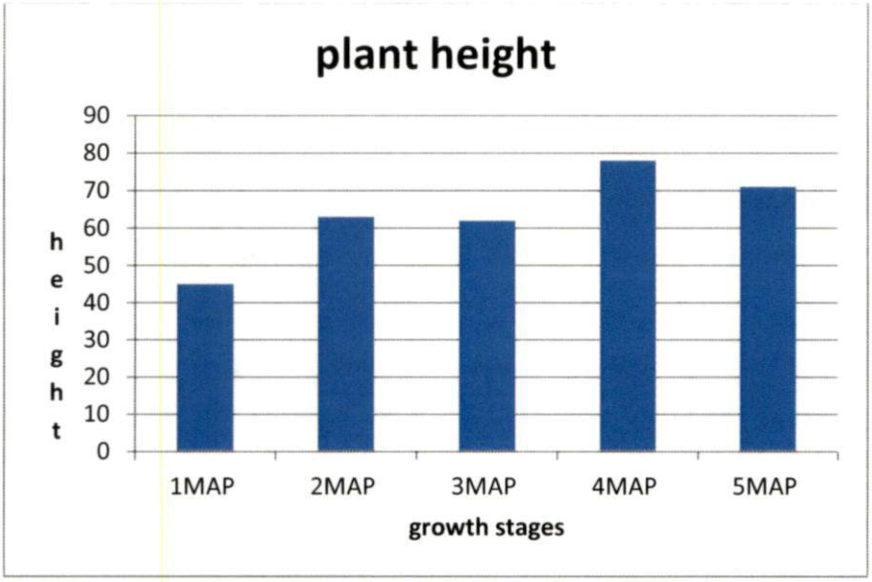

Fig 1. Average plant height of variety Sree Jaya at different growth stages

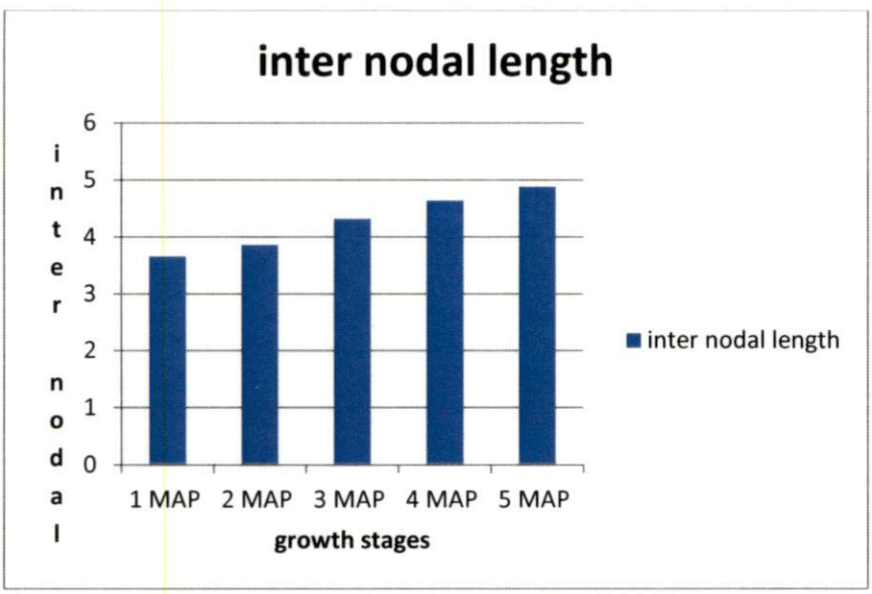

Fig 2. Average inter nodal length of Variety Sree Jaya at various growth stages

The average inter nodal length increased from a mean value of 3.56 cm at 1 MAP to 4.88 cm at 5 MAP (Table 2). The minimum value of 3 cm and a maximum value of 6 cm were recorded at 1 MAP itself and the estimated standard deviation was less than one in all months.

4.1.1.3 Summary Statistics of Number of Leaves

It is evident from Table 3 that the total number of leaves plant^{-1} increased from 1 MAP (66) to 3 MAP (95) and there after it started to decline, however the maximum number of leaves (182) was recorded at 4 MAP. The minimum number of leaves varied from 47 at 1 MAP to 58 at 5 MAP. The worked out standard deviation was highest in 4 MAP (38) and least at 2 MAP (17).

Table 3. Summary statistics of number of leaves of variety Sree Jaya

Number of leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	66	20	47	153
2 MAP	79	17	50	136
3 MAP	95	22	59	166
4 MAP	94	38	61	182
5 MAP	85	36	58	176

4.1.1.4 Summary Statistics of Number of Functional Leaves

It was found from Table 4 that the trend in number of functional leaves plant^{-1} also was similar to that of total number of leaves, but the average number of functional leaves was highest at 3 MAP (91) and 4 MAP (91). The percentage contribution of number of functional leaves to total number of leaves was found to be high at 4 MAP (96.81) and 3 MAP (95.78).

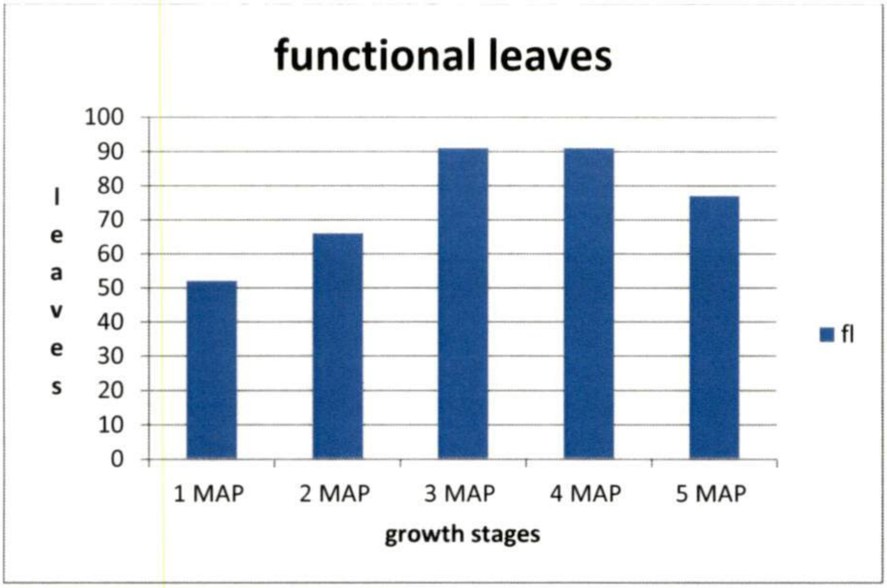

Fig 3. Average number of functional leaves of Sree Jaya at different growth stages

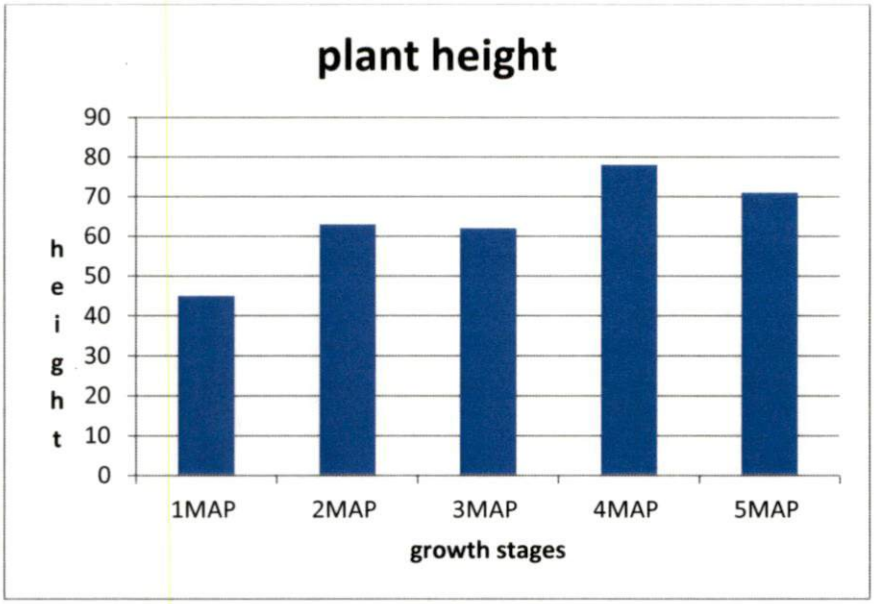

Fig 4. Average plant height of variety Sree Vijaya at various growth periods

Table 4.Summary statistics of number of functional leaves of variety Sree Jaya

Number of functional leaves $plant^{-1}$	Mean	Standard deviation	Minimum	Maximum
1 MAP	52 (78.79)*	12	35	105
2 MAP	66 (83.54)	15	42	124
3 MAP	91 (95.78)	22	57	164
4 MAP	91 (96.81)	38	59	178
5 MAP	77 (90.59)	37	50	167

* Values in the brackets were per cent of functional leaves to total leaves.

4.1.1.5 Summary Statistics of Number of Primary Branches, Height of First Branching and LAI

Table 5. Summary statistics of number of primary branches, height of first branching and LAI of variety Sree Jaya

Variables	Mean	Standard deviation	Minimum	Maximum
Number of primary branches $plant^{-1}$	2.23	1.09	1.00	4.00
Height of first branching (cm)	206.05	37.09	125.00	250.00
LAI	3.94	2.20	2.00	9.23

The number of primary branches in the plant was noticed from second month onwards. It was found that only a few number of plants had branches at 2 and 3 MAP and branching was continued until fifth month. The summary statistics of number of primary branches and height of first branching were calculated using data at 5 MAP and results are presented in Table 5. A perusal of data indicated that the average number of branches at 5 MAP was 2.23. The number of branches varied from 1 to 4 for this variety. It was also found that height of branching at 5 MAP was 206.05 cm with a minimum height of 125 cm to 250 cm. The leaf area index was determined for each plant using the methodology given in chapter 3 and the result is present in Table 5. The mean leaf area index obtained was 3.94 with a minimum value of 2.00 and a maximum value of 9.23. The extent of variation in LAI was 2.20.

4.1.1.6 Summary Statistics of Yield Attributes

Average number of tubers obtained for Sree Jaya was 8 per plant with an average tuber yield of 2.90 kg and average tuber weight of 330.73 g. The average tuber length and tuber girth were 21.82 cm and 15.62 cm, respectively. The variety Sree Jaya had a minimum yield of 1.25 kg and a maximum yield of 5.6 kg with a standard deviation of 1.01 kg. The minimum tuber weight was 214.28 g and the maximum was 493.75 g, with the coefficient of variation (C.V) of 22.59 indicating less variation in tuber weight.

Table 6. Summary statistics of yield attributes of variety Sree Jaya

Summary statistics	No.of tubers plant^{-1}	Tuber yield plant^{-1} (kg)	Average tuber weight(g)	Length of tuber (cm)	Girth of tuber (cm)
Mean	8.08	2.90	330.73	21.82	15.62
Standard Deviation	2.70	1.01	74.73	3.17	2.03
Minimum	4.00	1.25	214.28	15.00	10.10
Maximum	13.00	5.60	493.75	27.99	18.72
C V	33.41	34.82	22.59	14.52	12.99

4.1.2 Biometric Observations of variety Sree Vijaya

The mean, standard deviation (S.D), minimum and maximum of the observations on biometric parameters *viz.,* plant height, inter nodal length, total number of leaves plant^{-1}, number of functional leaves plant^{-1}, height of first branching, number of primary branches plant^{-1} and LAI included in the study, supposed to have influence in developing pre-harvest yield prediction model for the variety Sree Vijaya, taken at monthly interval were found out and the results are presented in Tables 7, 8, 9, 10 and 11 respectively. The summary statistics of yield parameters at harvest time were also worked out and the results are presented in Table 12.

4.1.2.1 Summary Statistics of Plant Height

It is evident from Table 7 that, the height of the plant was increased from 1 MAP (79.72 cm) to 5 MAP (164.08 cm). The mean height increased from 79.72 cm at 1 MAP to 164.08 cm at 5 MAP with a minimum height of 62 cm at 1 MAP to 110 cm at 5 MAP. Some of the plants reached a height of 105 cm at 1 MAP, but the minimum was 62 cm. The maximum height recorded at 5 MAP was 201 cm with a S.D of 28.75 cm. The variation in plant height from 1 MAP to 4 MAP varied from 9.20 cm to 29.38 cm.

Table 7. Summary statistics of plant height of variety Sree Vijaya

Plant Height(cm)	Mean	Standard Deviation	Minimum	Maximum
1MAP	79.72	9.20	62.00	105.00
2MAP	98.04	12.96	76.00	124.00
3MAP	120.88	19.83	89 .00	144.00
4MAP	154.84	29.38	102.00	194.00
5MAP	164.08	28.75	110 .00	201.00

4.1.2.2 Summary Statistics of Inter nodal Length

The average inter nodal length increased from a mean value of 3.56 cm at 1 MAP to 5.88 cm at 5 MAP (Table 8). The minimum recorded value of inter nodal length was 2 cm at 1 MAP and 5 cm at 5 MAP. But the maximum inter nodal length at 1 MAP and at 5 MAP were 5 cm and 8 cm respectively. The estimated standard deviation was less than one in all months.

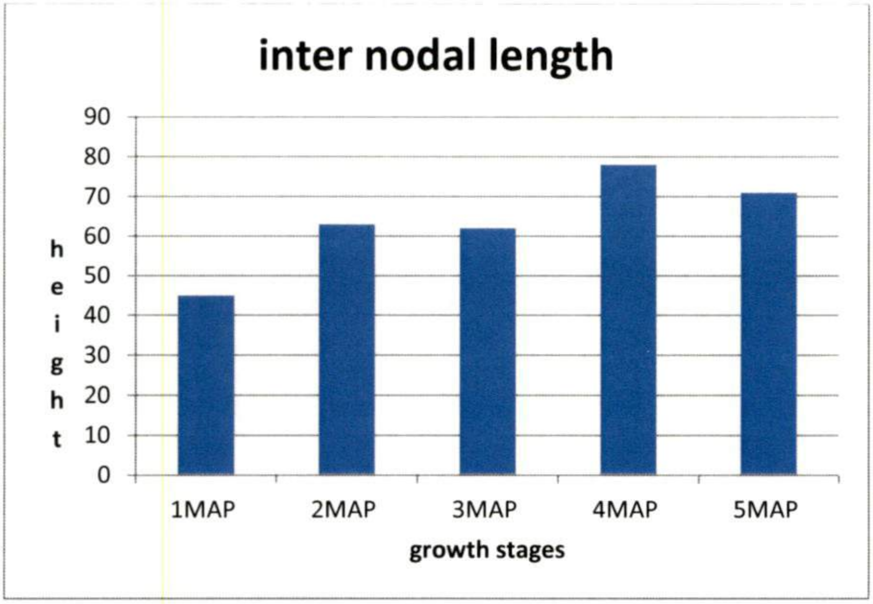

Fig 5. Average inter nodal length of variety Sree Vijaya at various growth stages

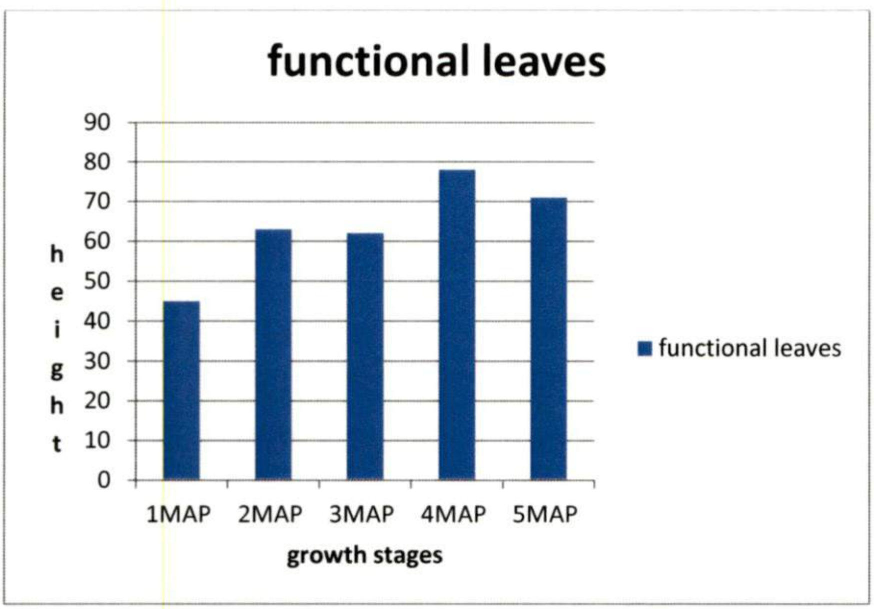

Fig 6. Average number of functional leaves of variety Sree Vijaya

Table 8. Summary statistics of inter nodal length of variety Sree Vijaya

Inter nodal length (cm)	Mean	Standard deviation	Minimum	Maximum
1 MAP	3.56	0.96	2.00	5.00
2 MAP	4.04	0.67	3.00	5.00
3 MAP	4.68	0.55	4.00	6.00
4 MAP	4.96	0.53	4.00	6.00
5 MAP	5.88	0.83	5.00	8.00

4.1.2.3 Summary Statistics of Number of Leaves

The total number of leaves plant^{-1} was increased from 1 MAP (54) to 4 MAP (98) and there after it started to decline, however the maximum number of leaves (130) was recorded at 4 MAP (Table 9). The minimum number of leaves varied from 36 at 1 MAP to 61 at 3 MAP. The worked out standard deviation was highest in 4 MAP (23) and least at 2 MAP (8).

Table 9. Summary statistics of number of leaves of variety Sree Vijaya

Number of leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	54	9	36	72
2 MAP	63	8	49	80
3 MAP	81	13	61	102
4 MAP	98	23	44	130
5 MAP	95	21	38	125

4.1.2.4 Summary Statistics of Number of Functional Leaves

It was found from Table 10 that the trend in number of functional leaves plant^{-1} also was similar to that of total number of leaves, but the average number of functional leaves was highest at 4 MAP (94). However, the per cent of functional leaves to total number of leaves was highest (98.83 %) at 3 MAP.

Table 10. Summary statistics of number of functional leaves of variety Sree Vijaya

Number of functional leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	42 (77.78)	5	33	56
2 MAP	54 (85.71)	7	45	70
3 MAP	76 (98.83)	12	56	93
4 MAP	94 (95.92)	24	30	126
5 MAP	86 (90.53)	20	30	119

Values in the brackets were per cent of functional leaves to total leaves.

4.1.2.5 Summary Statistics of Number of Primary Branches, Height of First Branching and LAI

The number of primary branches in the plant was noticed from first month onwards. It was found that most of the plants had branches at 2 MAP. The summary statistics of number of primary branches plant^{-1} and height of first branching were calculated using data at 2 MAP and results are presented in table 11. It was found that the average number of branches at 2 MAP was 2.04 with a standard deviation of 0.37. The number of branches varied from 1 to 3 for this variety with average height of branching of 78.86 cm and it varied from 67 to 90 cm. The average leaf area index obtained was 2.23 with a minimum value of 0.64 and a maximum value of 3.74 with a very low standard deviation of 0.77.

Table 11. Summary statistics of number of primary branches and height of first branching and LAI of variety Sree Vijaya

Variable	Mean	Standard deviation	Minimum	Maximum
Number of primary branches plant^{-1}	2.04	0.37	1.00	3.00
Height of first branching (cm)	78.86	7.39	67.00	90.00
LAI	2.23	0.77	.64	3.74

4.1.2.7 Summary Statistics of Yield Attributes

It was observed from Table 12 that the average number of tubers plant^{-1} obtained for the variety Sree Vijaya was 10 with an average tuber yield of 2.88 kg and average tuber weight of 285.73 g. The average length and girth of tubers were 20.43 cm and 13.43 cm respectively. The variety Sree Vijaya had a minimum yield of 1.27 kg and a maximum yield of 4.90 kg with a standard deviation of 1.0 indicating that there was not much variation in tuber yield. The number of tubers plant^{-1} varied from 5.00 to 13.00 and the range of tuber weight was from 147.50 g to 381.81 g.

Table 12. Summary statistics of yield attributes of variety Sree Vijaya

	No.of tubers plant^{-1}	Tuber yield plant^{-1} (kg)	Average tuber weight (g)	Length of tuber (cm)	Girth of tuber (cm)
Mean	10.00	2.88	285.73	20.43	13.43
Standard Deviation	2.53	1.00	62.67	2.92	2.16
Minimum	5.00	1.27	147.50	12.57	8.30
Maximum	13.00	4.90	381.81	25.76	10.30

4.1.3 Biometric Observations of variety Sree Swarna

The mean, standard deviation (S.D), minimum and maximum of biometric parameters *viz*., plant height, inter nodal length, total number of leaves plant^{-1}, number of functional leaves plant^{-1}, height of first branching, number of primary branches plant^{-1} and LAI of the variety Sree Swarna taken at monthly interval were recorded and the data are presented in Table 13, 14, 15, 16 and 17 respectively. The summary statistics of yield parameters at harvest time were also worked out and the results are presented in table 18.

4.1.3.1 Summary Statistics of Plant Height

It is evident from Table 13 that, the height of the cassava plant increased from 1 MAP (83.48 cm) to 5 MAP (153.24 cm). The mean height increased from 83.48 cm at 1 MAP to 153.24 cm at 5 MAP with a minimum height of 64 cm at 1 MAP to 130 cm at 5 MAP. The maximum height recorded at 1 MAP and at 5 MAP were 105 cm and 200 cm respectively. The variation in plant height was less in 1 MAP and the highest variation of 28.7 cm was noticed at 5 MAP.

Table13. Summary statistics of plant height of variety Sree Swarna

Plant Height(cm)	Mean	Standard Deviation	Minimum	Maximum
1MAP	83.48	13.29	64.00	105.00
2MAP	101.56	22.06	71.00	145.00
3MAP	120.96	28.70	87.00	170.00
4MAP	143.60	22.20	109.00	188.00
5MAP	153.24	21.71	130.00	200.00

4.1.3.2 Summary Statistics of Inter nodal Length

It was found from Table 14 that the average inter nodal length increased from a mean value of 3.88 cm at 1 MAP to 4.76 cm at 5 MAP. The minimum length of 2 cm and a maximum length of 6 cm were recorded at first month itself and the estimated standard deviation was less than one in all months.

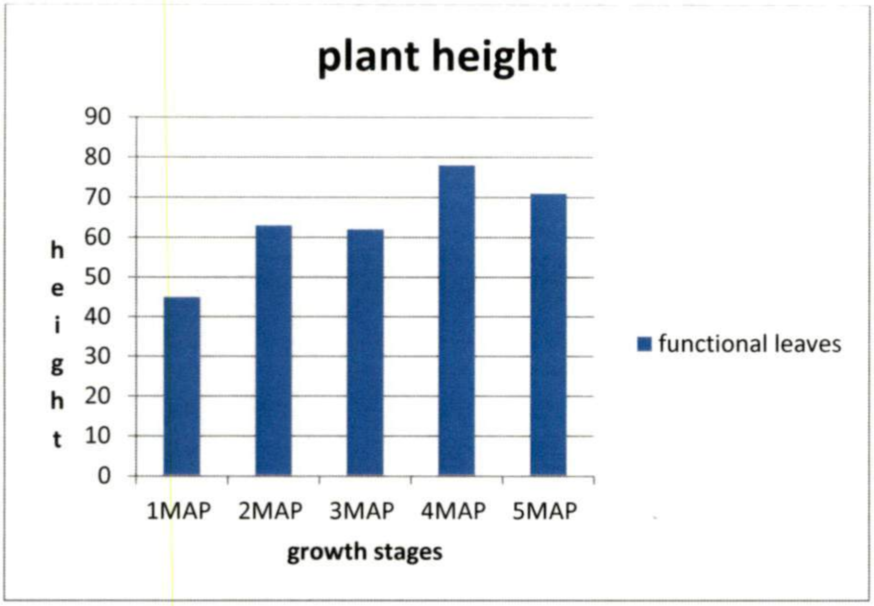

Fig 7. Average plant height of variety Sree Swarna

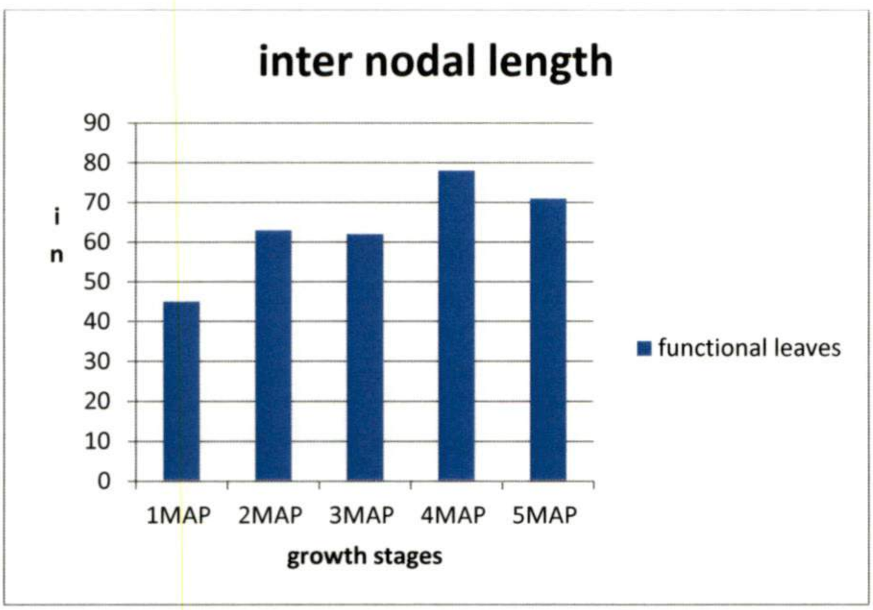

Fig 8. Average inter nodal length of variety Sree Swarna

Table14. Summary statistics of inter nodal length of variety Sree Swarna

Inter nodal length (cm)	Mean	Standard deviation	Minimum	Maximum
1 MAP	3.88	0.88	2.00	6.00
2 MAP	3.92	0.86	2.00	6.00
3 MAP	4.24	0.72	3.00	6.00
4 MAP	4.60	0.57	4.00	6.00
5 MAP	4.76	0.52	4.00	6.00

4.1.3.3 Summary Statistics of Number of Leaves

The total number of leaves plant^{-1} increased from 1 MAP (62) to 3 MAP (76) and there after it started to decline. However, the maximum number of leaves was recorded at 4 MAP *i.e.*, 119 (Table 15). The minimum number of leaves varied from 41 at 1 MAP to 56 at 3 MAP and there was a reduction in total number of leaves. There was not much variation in number of leaves at all the months.

Table15. Summary statistics of number of leaves of variety Sree Swarna

Number of leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	62	13	41	88
2 MAP	70	14	50	98
3 MAP	76	14	56	101
4 MAP	75	19	41	119
5 MAP	71	17	36	116

4.1.3.4 Summary Statistics of Number of Functional Leaves

It was found from Table 16 that number of functional leaves plant^{-1} also followed a similar trend as that of total number of leaves plant^{-1} and the average

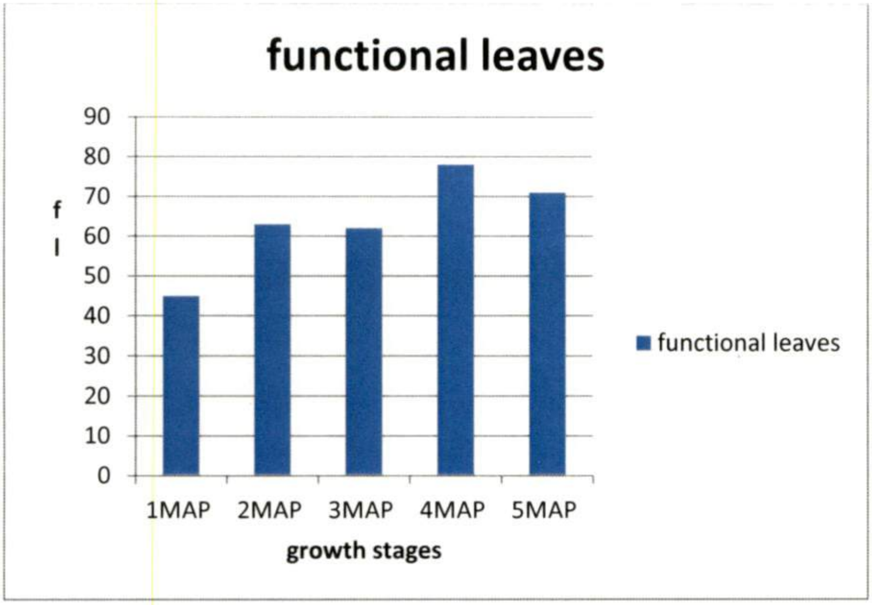

Fig 9. Average number of functional leaves of variety Sree Swarna

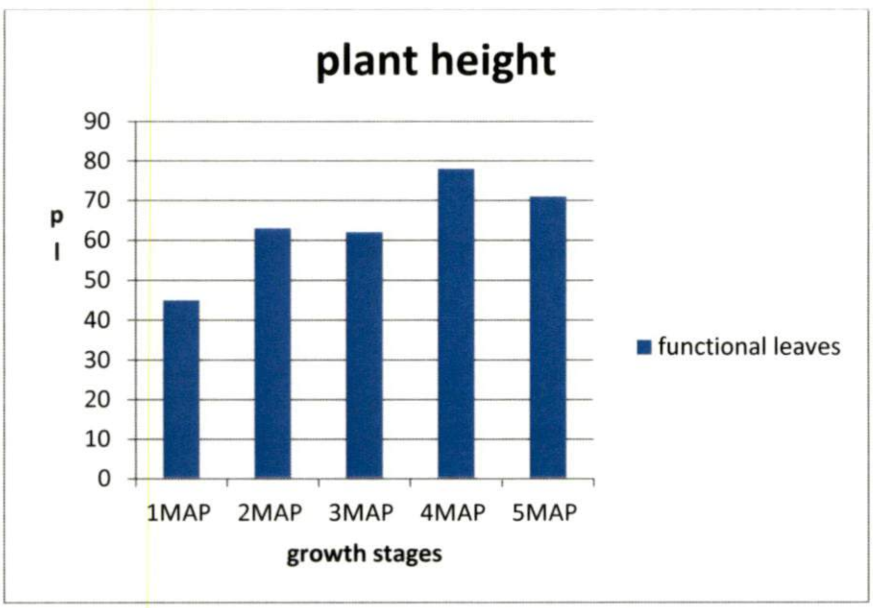

Fig 10. Average plant height of variety Vellayani Hraswa

number of functional leaves was the highest at 3 MAP (74) followed by 4 MAP (72).

Table 16. Summary statistics of number of functional leaves of variety Sree Swarna

Number of functional leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	48 (77.41)	13	32	79
2 MAP	57 (81.42)	11	44	84
3 MAP	74 (97.36)	13	51	94
4 MAP	72 (96)	18	39	110
5 MAP	65 (91.54)	18	30	110

Values in the brackets were per cent of functional leaves to total leaves.

4.1.3.5 Summary Statistics of Number of Primary Branches, Height of First Branching and LAI

Table 17. Summary statistics of number of primary branches and height of first branching and LAI of variety Sree Swarna

Variable	Mean	Standard deviation	Minimum	Maximum
Number of primary branches plant^{-1}	2.50	0.65	2.00	4.00
Height of first branching (cm)	79.08	20.55	57.00	132.00
LAI	1.10	0.43	0.44	1.99

The number of primary branches plant^{-1} was noticed from first month onwards. It was found that only a few number of plants had branches at 1 and 2 MAP and branching was continued until fourth month. The summary statistics of number of primary branches plant^{-1} and height of first branching were calculated using data at 4 MAP and results are presented in Table 17. It was found from Table 17 that the average number of primary branches plant^{-1} having a mean of

2.50. The number of branches varied from 2 to 4 for this variety. The mean height of first branching was 79.08 cm and varied from 57 to 132 cm. The LAI of this variety varied from 0.44 to 1.99 with a very low standard deviation of 0.43. The average leaf area index was 1.10.

4.1.3.7 Summary Statistics of Yield Attributes

The summary statistics of yield and yield parameters of variety Sree Swarna are presented in Table 18. Average number of tubers plant^{-1} obtained for Sree Swarna was 8.00 with an average tuber yield of 2.63 kg plant^{-1}, average tuber weight of 308.78 g. This variety registered a minimum yield of 1.15 kg and a maximum yield of 4.75 kg plant^{-1} and the average tuber weight varied from 212 g to 467.85 g. The average length and girth of tuber were 21.31 cm and 13.21 cm respectively.

Table 18. Summary statistics of yield attributes of variety Sree Swarna

Summary statistics	No.of tubers plant^{-1}	Tuber yield plant^{-1} (kg)	Average tuber weight	Length of tuber (cm)	Girth of tuber (cm)
Mean	8.00	2.63	308.78	21.31	13.21
Standard Deviation	3.36	1.01	70.00	3.01	2.24
Minimum	3.00	1.15	212.00	15.90	10.31
Maximum	15.00	4.75	467.85	26.66	17.60

4.1.4 Biometric Observations of variety Vellayani Hraswa

The summary statistics including mean, standard deviation (S.D), minimum and maximum of the observations of biometric parameters gives an overall idea about the plant characters. The estimated values of biometric characters of Vellayani Hraswa taken at monthly interval are presented in Table 19, 20, 21, 22, and 23 respectively. The summary statistics of yield parameters at harvest time were also worked out and the results are presented in Table 24.

4.1.4.1 Summary Statistics of Plant Height

The height of cassava plant normally increases at a faster rate during early stages of crop growth and the magnitude of increase in height reduced at later stages. It is evident from Table 19 that height of Vellayani Hraswa has shown a similar trend with an average height of 94.32 cm at 1 MAP to 184.52 at 5 MAP. The maximum height recorded at 1 MAP and at 5 MAP were 131 cm and 215 cm respectively. The variation in plant height was less in 1 MAP to 3 MAP and highest variation of 23.95 was noticed at 4 and 5 MAP.

Table 19. Summary Statistics of plant height of variety Vellayani Hraswa

Plant Height(cm)	Mean	Standard Deviation	Minimum	Maximum
1MAP	94.32	12.03	72.00	131.00
2MAP	108.60	11.67	84.00	146.00
3MAP	128.28	13.49	98.00	174.00
4MAP	174.80	23.95	136.00	204.00
5MAP	184.52	23.95	144.00	215.00

4.1.4.2 Summary Statistics of Inter nodal Length

Table 20. Summary statistics of inter nodal length of variety Vellayani Hraswa

Inter nodal length (cm)	Mean	Standard deviation	Minimum	Maximum
1 MAP	3.40	0.91	2.00	5.00
2 MAP	3.60	0.76	3.00	5.00
3 MAP	4.24	1.12	3.00	6.00
4 MAP	4.68	0.85	4.00	6.00
5 MAP	4.92	0.81	4.00	6.00

The average inter nodal length increased from a mean value of 3.40 cm at 1 MAP to 4.92 cm at 5 MAP (Table 20). The minimum value of 2 and a

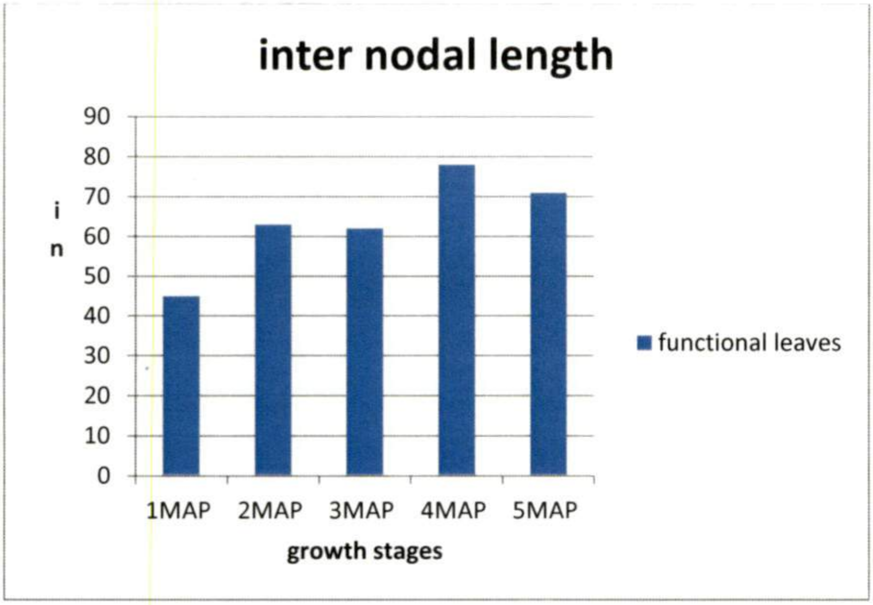

Fig 11. Average inter nodal length of variety Vellayani Hraswa

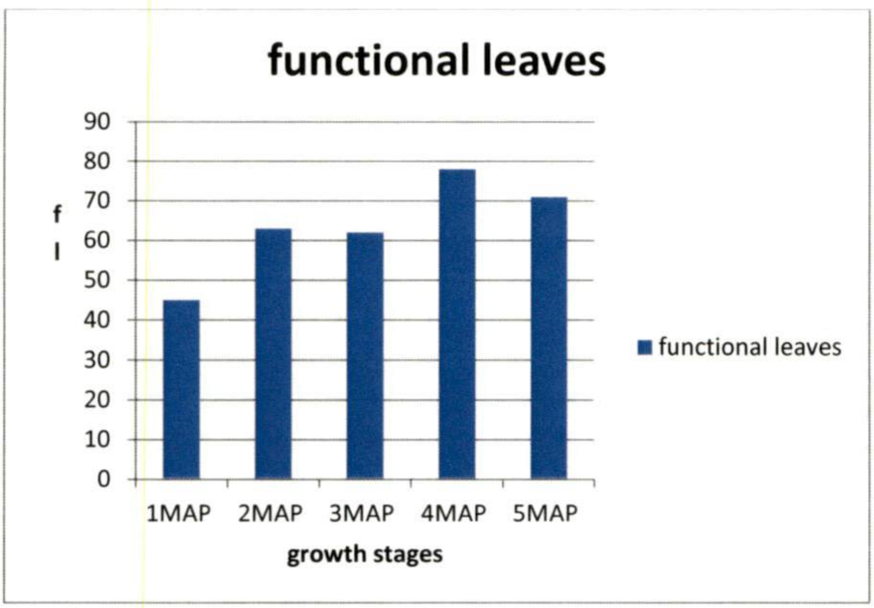

Fig 12. Average number of functional leaves of variety Vellayani Hraswa

maximum value of 5 were recorded at first month itself and the estimated standard deviation was greater than one at 3 MAP. It was also noticed that, the range of variation from 1 MAP to 5 MAP was only 2 to 6.

4.1.4.3 Summary Statistics of Number of Leaves

The total number of leaves plant^{-1} increased from 1 MAP (81) to 4 MAP (174) and there after it started to decline and the maximum number of leaves was recorded at 4 MAP (Table 21). The minimum number of leaves varied from 40 at 1 MAP to 116 at 4 MAP. Here also, the total number of leaves was maximum at 4 MAP. The worked out standard deviation was highest at 5 MAP (43) and least at 1 MAP (18).

Table 21. Summary statistics of number of leaves of variety Vellayani Hraswa

Number of leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	81	18	40	144
2 MAP	100	21	64	128
3 MAP	114	25	76	144
4 MAP	174	22	116	209
5 MAP	159	43	104	205

4.1.4.4 Summary Statistics of Number of Functional Leaves

It was found from Table 22 that the trend in number of functional leaves plant^{-1} also was similar to that of total number of leaves and the average number of functional leaves was highest at 4 MAP (165) and 5 MAP (156). However, the maximum number of functional leaves was recorded at 4 MAP and it was declined to 185 per plant at 5 MAP. This indicates that growth of the plant at 4 MAP was crucial for this variety. The variation among the observation at each growth stage was almost same.

Table 22. Summary statistics of number of functional leaves of variety Vellayani Hraswa

Number of functional leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	68 (83.95)*	20	27	136
2 MAP	77 (77)	16	44	110
3 MAP	107 (93.85)	25	68	136
4 MAP	165 (94.82)	27	91	206
5 MAP	156 (98.11)	27	91	185

Values in the brackets were per cent of functional leaves to total leaves.

4.1.4.5 Summary Statistics of Number of Primary Branches, Height of First Branching and LAI

Table 23. Summary statistics of number of primary branches, height of first branching and LAI of Vellayani Hraswa

Variable	Mean	Standard deviation	Minimum	Maximum
Number of primary branches plant^{-1}	3.08	0.70	2.00	4.00
Height of first branching (cm)	60.24	11.84	47.00	90.00
LAI	3.89	0.66	2.42	4.95

Primary branching was noticed at the first month itself for this variety. It was found that all of the plants had branches at first and second month. The summary statistics of number of primary branches and height of first branching were calculated using data at 2 MAP and results are presented in Table 23. It was found from Table 23 that the average number of branches at 2 MAP was 3.08. The number of branches varied from 2 to 4 for this variety and average height of branching was with a mean height of 60.24 cm and varied from 47 to 90 cm. Leaf area index has an average value of 3.89 with a minimum value of 2.42 and maximum value of 4.95 and having standard deviation of 0.66.

4.1.4.7 Summary Statistics of Yield Attributes

Summary statistics of yield and yield attributes provide an idea about the production capacity of each variety. The average number of tubers per plant obtained for Vellayani Hraswa was 7 which varied from 2 tubers per plant to 14 tubers per plant. The average tuber yield per plant was 2.80 kg with minimum yield of 0.5 kg to maximum yield of 8 kg. The average tuber weight was 358.18 g and having minimum weight of 180 g to maximum weight of 639.28 g. The estimated tuber length and girth was 22.85 and 14.73 cm respectively (Table 24). The estimated variance was high in tuber yield per plant.

Table 24. Summary statistics of yield attributes of variety Vellayani Hraswa

	No. of Tuber/ plant	Tuber yield/plant (kg)	Average tuber weight (g)	Length of tuber (cm)	Girth of tuber (cm)
Mean	7.68	2.80	358.18	22.85	14.73
Standard Deviation	3.23	1.67	130.73	5.13	2.11
Minimum	2	.5	180	13.45	11.3
Maximum	14	8	639.28	37.52	19.82

4.1.5 Biometric Observations of variety Kantharipadarppan

The mean, standard deviation (S.D), minimum and maximum of the observations of biometric parameters *viz*., plant height, inter nodal length, total number of leaves plant^{-1}, number of functional leaves plant^{-1}, height of first branching, number of primary branches plant^{-1} and LAI included in the study, supposed to have influence in developing pre-harvest yield prediction model of the variety Kantharipadarppan taken at monthly interval were found out and the results are presented in Table 25, 26, 27, 28 and 29 respectively. The summary statistics of yield parameters at harvest time were also found and the results are presented in Table 30.

4.1.5.1 Summary Statistics of Plant Height

It is evident from Table 25 that, the height of the cassava plant was increased from 1 MAP (96.92 cm) to 4 MAP (161.48 cm) and the growth was stagnant after fourth month. The mean height increased from 96.92 cm at 1 MAP to 172.8 cm at 5 MAP with a minimum height of 66 cm at 1 MAP to 119 cm at 5 MAP. The maximum height recorded at 1 MAP and at 5 MAP was 130 cm and 201 cm respectively. The variation in plant height was less in 1 MAP and highest variation of 28.84 was noticed at 4 MAP.

Table 25. Summary Statistics of plant height of variety Kantharipadarppan

Plant Height(cm)	Mean	Standard Deviation	Minimum	Maximum
1MAP	96.92	17.60	66.00	130.00
2MAP	115.80	19.72	82.00	145.00
3MAP	140.80	27.27	90.00	170.00
4MAP	161.48	28.84	105.00	190.00
5MAP	172.80	26.67	119.00	201.00

4.1.5.2 Summary Statistics of Inter nodal Length

Table 26. Summary statistics of inter nodal length of variety Kantharipadarppan

Inter nodal length (cm)	Mean	Standard deviation	Minimum	Maximum
1 MAP	2.88	0.72	2.00	4.00
2 MAP	2.88	0.72	2.00	4.00
3 MAP	3.20	0.81	2.00	5.00
4 MAP	3.36	0.81	2.00	5.00
5 MAP	4.00	1.04	3.00	8.00

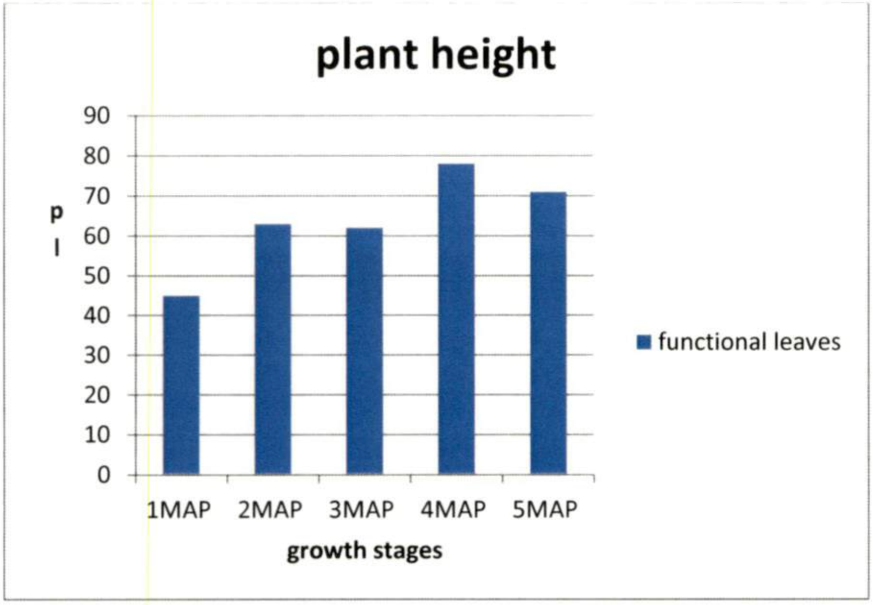

Fig 13. Average plant height of variety Kantharipadarppan

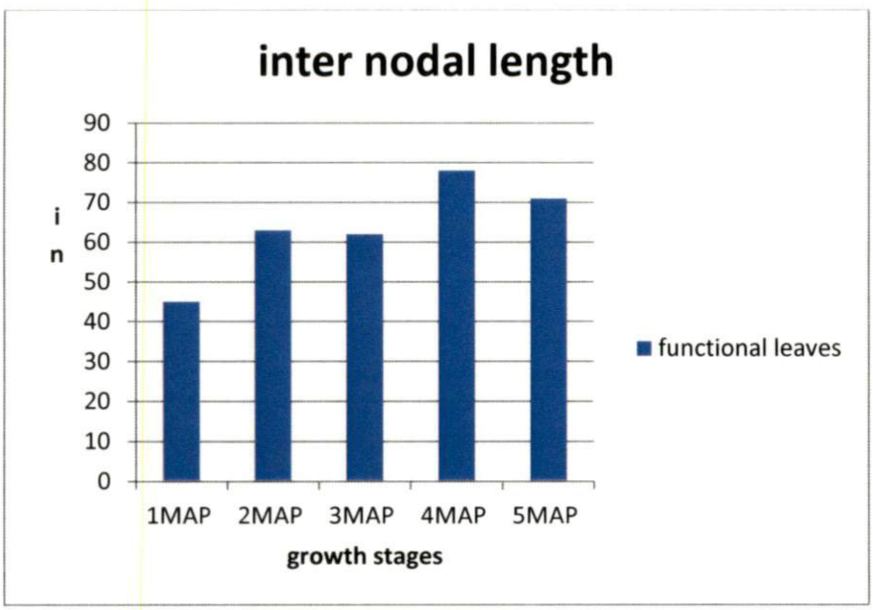

Fig 14. Average inter nodal length of variety Kantharipadarppan

The average inter nodal length increased from a mean value of 2.88 cm at 1 MAP to 4 cm at 5 MAP (Table 26). The minimum value of 2 cm and a maximum value of 4 cm were recorded at first month itself and the estimated standard deviation was found to be greater than one in 5 MAP.

4.1.5.3 Summary Statistics of Number of Leaves

The total number of leaves was increased from 1 MAP (60) to 4 MAP (82) and there after it started to decline and the maximum number of leaves was recorded at 4 MAP (Table 27). The minimum number of leaves varied from 43 at 1 MAP to 44 at 2 MAP and 3 MAP. The worked out standard deviation was highest in 4 MAP (35) and least at 1 MAP (9).

Table 27. Summary statistics of number of leaves of variety Kantharipadarppan

Number of leaves plant^{-1}	Mean	Standard deviation	Minimum	Maximum
1 MAP	60	9	43	86
2 MAP	68	12	44	91
3 MAP	67	14	44	94
4 MAP	82	35	43	154
5 MAP	77	34	40	140

4.1.5.4 Summary Statistics of Number of Functional Leaves

It was found from Table 28 that the trend in number of functional leaves plant^{-1} also was similar to that of total number of leaves and the average number of functional leaves was highest at 4 MAP (145) and 5 MAP (128). However, the maximum number of functional leaves was recorded at 4 MAP and it declined to 128 per plant at 5 MAP.

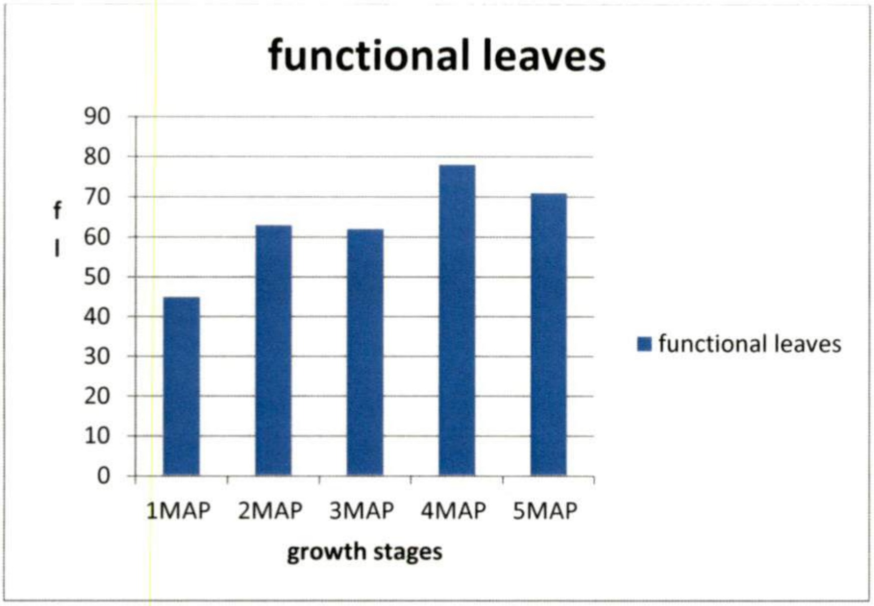

Fig 15.Average number of functional leaves of variety Kantharipadarppan.

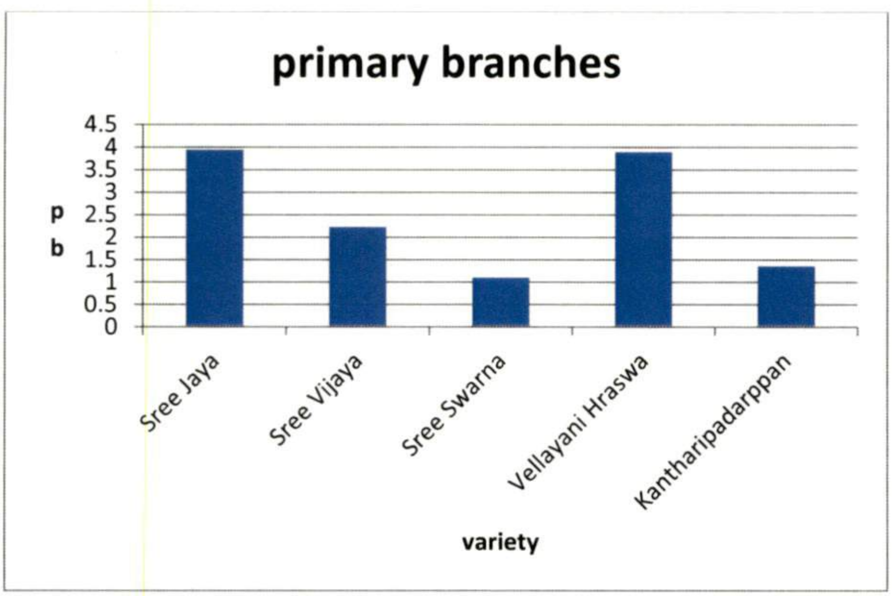

Fig 16. Average number of primary branches of all varieties

Table 28. Summary statistics of number of functional leaves of Kantharipadarppan

Number of functional leaves $plant^{-1}$	Mean	Standard deviation	Minimum	Maximum
1 MAP	45 (75)	6	34	62
2 MAP	63 (92.64)	11	40	90
3 MAP	62 (92.53)	15	40	92
4 MAP	78 (95.12)	34	40	145
5 MAP	71 (92.20)	32	34	128

Values in the brackets were per cent of functional leaves to total leaves.

4.1.5.5 Summary Statistics of Number of Primary Branches, Height of First Branching and LAI

Table 29. Summary statistics of number of primary branches, height of first branching and LAI of variety Kantharipadarppan

Variable	Mean	Standard deviation	Minimum	Maximum
Number of primary branches $plant^{-1}$	1.87	0.34	1.00	2.00
Height of first[t] branching (cm)	107.31	19.86	70.00	140.00
LAI	1.36	0.63	0.69	2.61

The number of primary branches in the plant was noticed from second month onwards. It was found that only a few number of plants had branches at second month and branching was continued until fourth month. The summary statistics of number of primary branches and height of first branching were calculated using data at 4 MAP and results are presented in Table 29. It was found that the average number of branches at 4 MAP was with a mean of 1.87. The number of branches varied from 1 to 2 for this variety. The average height of

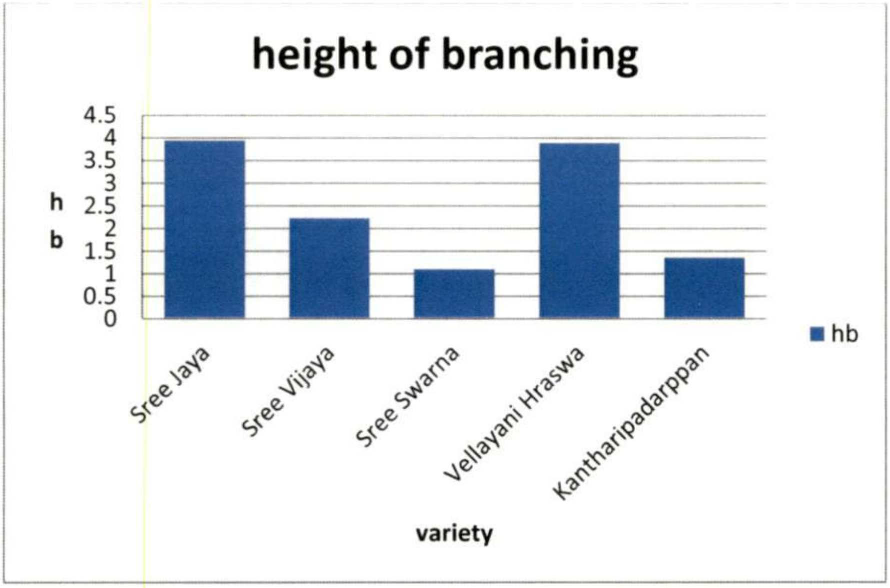

Fig 17. Average height of branching of all varieties

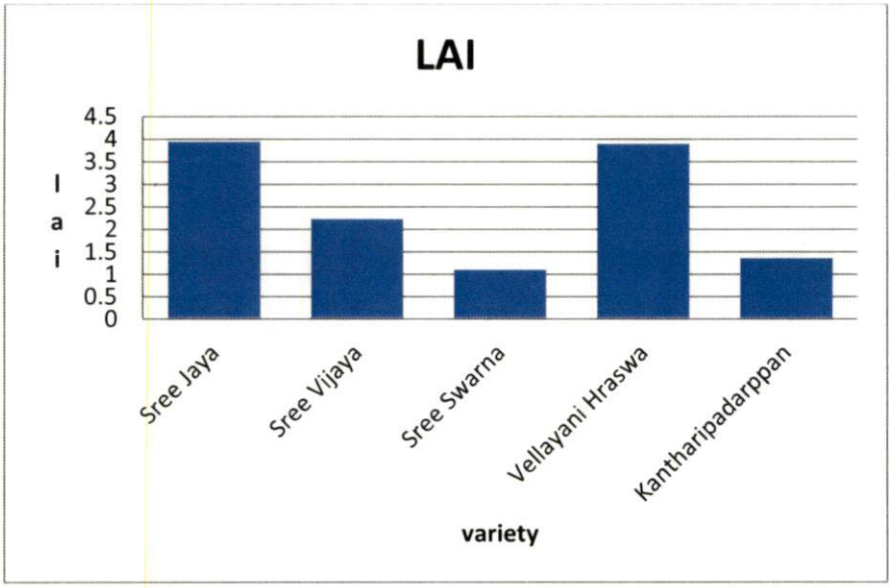

Fig 18. Average leaf area index of all varieties

branching was 107.31 cm and it varied from 70 to 140 cm. Leaf area index has an average value of 1.36 with a minimum value of 0.69 and maximum value of 2.61.

4.1.5.7 Summary Statistics of Yield Attributes

The average number of tubers per plant obtained for Kantharipadarppan was 9 which varied from 5 tubers per plant to 15 tubers per plant (Table 30). The average tuber yield per plant was 3.40 kg with minimum yield of 1.6 kg to maximum yield of 5.75 kg. The average tuber weight was 354.73 g and having minimum weight of 190 g to maximum weight of 646.87 g. The estimated tuber length and girth was 21.51 and 15.96 cm respectively.

Table 30. Summary statistics of yield attributes of variety Kantharipadarppan

	No.of tubers plant^{-1}	Tuber yield plant^{-1} (kg)	Average tuber weight (g)	Length of tuber (cm)	Girth of tuber (cm)
Mean	9.12	3.41	354.73	21.51	15.96
Standard Deviation	2.60	1.03	95.74	3.07	1.03
Minimum	5.00	1.60	190.00	17.45	13.07
Maximum	15.00	5.75	646.87	28.20	19.56

4.2 COMPARISON OF TUBER YIELD AND BIOMETRIC CHARACTERS OF FIVE VARIETIES OF CASSAVA

The comparison between tuber yield and plant biometric characters of five varieties was made using Analysis of Variance (ANOVA) and the results are presented in Table 31. It is revealed from Table 31 that there was no significant difference in tuber yield, but there was significant difference in all biometric characters of five varieties of cassava. There was significant difference in plant height at each growth stage of all the varieties and the average plant height was highest for Sree Jaya at 5 MAP (224.88 cm) followed by Vellayani Hraswa (184.52 cm). The average height at 5 MAP was low in Sree Swarna (153.24 cm).

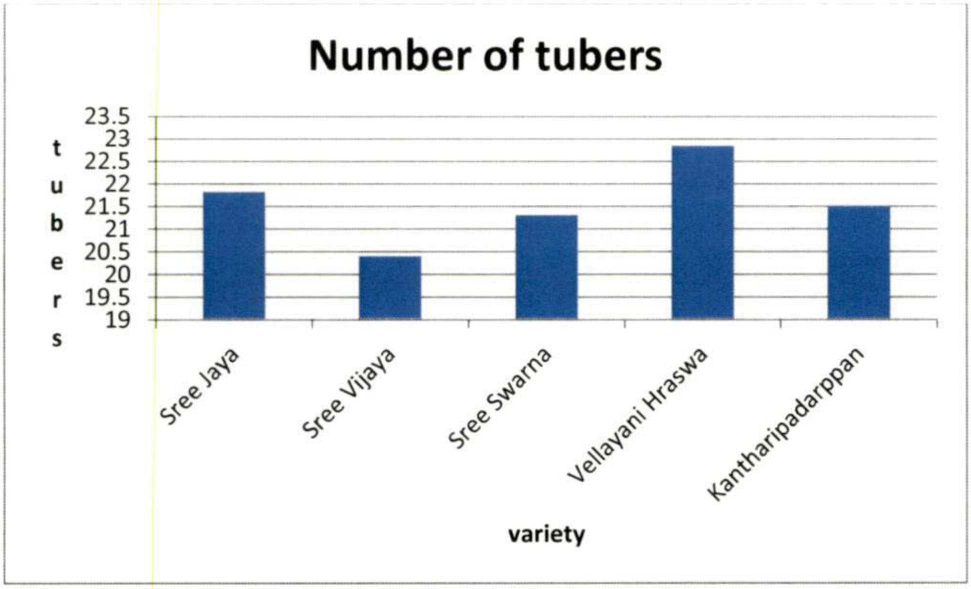

Fig 19. Average number of tubers of all varieties

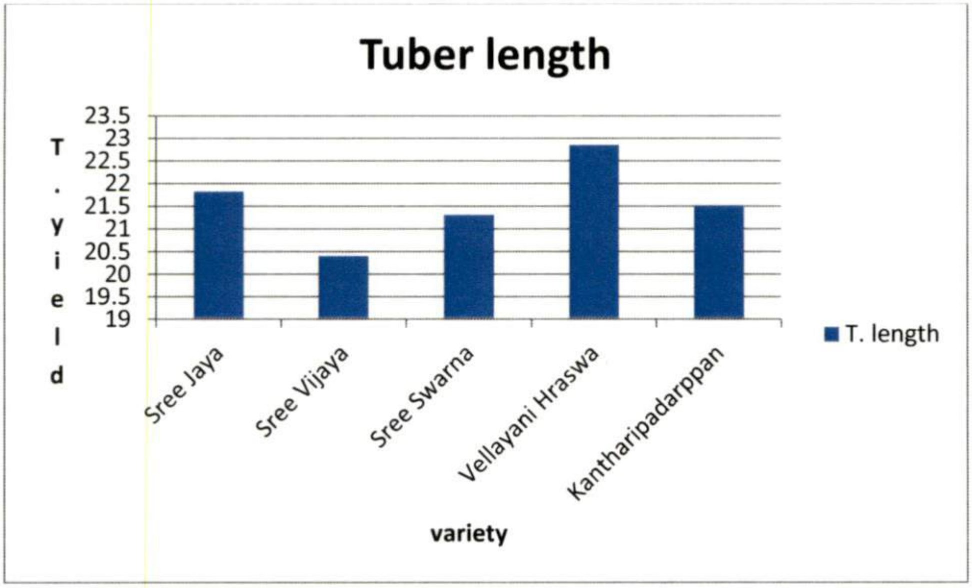

Fig 20. Summary statistics of tuber yield of all varieties

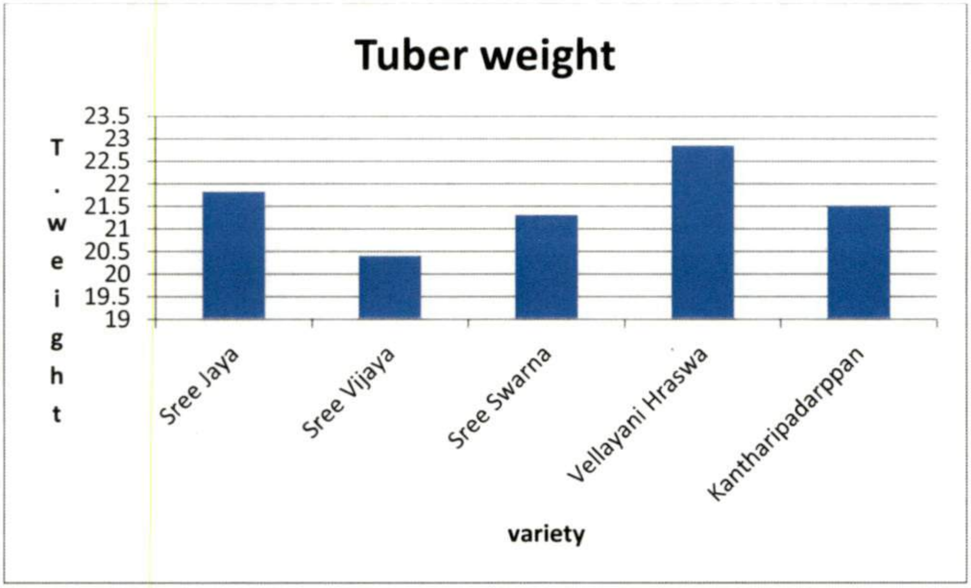

Fig 21. Summary statistics of tuber weight of all varieties

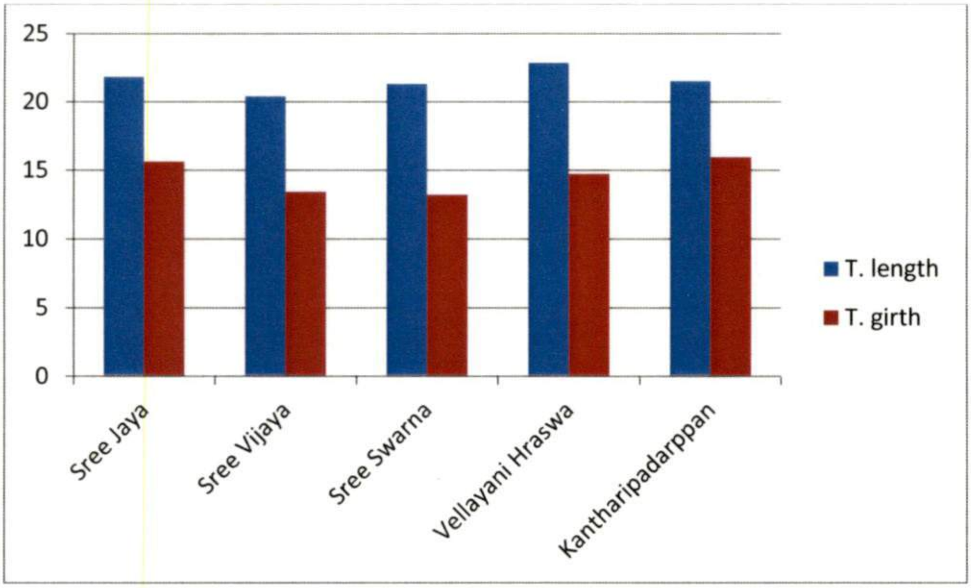

Fig 22. Summary statistics of tuber length and tuber girth of all varieties

Table 31. Comparison of Tuber yield and biometric characters of five varieties of Cassava

Variety	Tuber yield	pl3	pl4	pl5	in3	in4	in5	fl3	fl4	fl5	hb	pb	LAI
Sree Jaya	2.91	195.84	223.44	224.88	4.32	4.64	4.88	91.4	91.2	77.6	206.05	2.23	3.95
Sree Vijaya	2.89	120.88	154.84	164.08	4.68	4.96	5.88	76.68	94.16	86.76	78.86	2.04	2.23
Sree Swarna	2.64	120.96	143.6	153.24	4.24	4.6	4.76	70.56	72.52	65.16	79.08	2.5	1.102
Vellayani Hraswa	2.80	128.28	174.8	184.52	4.24	4.68	4.92	107.16	165.04	156.24	60.24	3.08	3.896
Kantharipadarppan	3.40	140.8	161.48	172.8	3.2	3.36	4	62.12	78.72	71.08	107.31	1.875	1.369
C D	N S	12.524	14.241	16.96	0.49	0.38	.44	10.553	16.681	15.72	11.55	.380	0.638

Significant difference was also noticed in average inter nodal length between varieties and the highest was recorded for Sree Vijaya (5.88 cm) followed by Vellayani Hraswa (4.92 cm). The lowest inter nodal length was observed for Kantharipadarppan (4 cm). It was also observed that there was significant difference in number of functional leaves plant^{-1}, height of branching, number of primary branches plant^{-1} and leaf area index of all varieties. The average number of functional leaves was highest for Vellayani Hraswa (164.05) at 4 MAP followed by Sree Vijaya (94.16). The average height of branching was found to be highest for Sree Jaya (206.05 cm) followed by Kantharipadarppan (107.31cm) while average number of primary branches was highest for Vellayani Hraswa (3.08) followed by Sree Swarna (2.5). The average height of branching was lowest in Vellayani Hraswa (60.24 cm) since the branching was completed at 2 MAP for this variety. The average number of primary branches was minimum in Kantharipadarppan. Leaf area index was found to be more in Sree Jaya (3.95) followed by Vellayani Hraswa (3.90) and the lowest was noticed in Kantharipadarppan (1.37) and Sree Swarna (1.10).

4.3 CORRELATIONS BETWEEN YIELD AND BIOMETRIC CHARACTERS

4.3.1 Correlation Analysis of Sree Jaya

The correlations were worked out to identify the nature of association of biometric characters at each stages of growth with tuber yield and the result is presented in Table 32. Similarly correlation between tuber yield and yield attributes were also computed and the result is presented in Table 33.

4.3.1.1 Correlation between Tuber Yield and Biometric Characters

It is evident from the table 32 that plant height, inter nodal length, number of functional leaves plant^{-1} at all growth stages were not correlated with yield and height of branching and number of primary branches also had no correlation with yield up to third month. However, the correlation coefficient between number of branches at 4 MAP and 5 MAP with yield was significant and its values were 0.506 and 0.463 respectively. Similarly height of first branching at 4 MAP and 5 MAP had significant correlation with yield. But the correlation coefficient of LAI with yield was only 0.282 and it was not significant. Plant height was not associated with yield but height of first branching had influence on tuber yield.

Table 32.Correlation between tuber yield and biometric characters at each growth stages of Sree Jaya

	Tuber yield (2 MAP)	Tuber yield (3 MAP)	Tuber yield (4 MAP)	Tuber yield (5 MAP)
pl	0.045	-0.038	-0.053	-0.082
in	0.044	-0.157	-0.088	-0.032
fl	-0.343	-0.241	0.117	0.282
pb	0.122	-0.011	0.560**	0.463*
hb	0.122	-0.090	0.451*	0.350*
LAI				0.282

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

4.3.1.2 Correlation between Tuber Yield and Yield Attributes

The association between tuber yield and yield attributes, was examined by calculating correlation coefficient between them and the results are presented in Table 33. All the yield parameters were positively correlated with tuber yield but only one parameter, *i.e.* number of tubers plant^{-1} had significant correlation (0.683) with tuber yield at harvest stage. There was significant inter correlation between tuber length and tuber weight (0.521).

Table 33.Correlation between tuber yield and yield attributes of Sree Jaya

	Tuber yield (kg)	Number of tubers plant^{-1}	Tuber weight (g)	Tuber length (cm)	Tuber girth (cm)
Tuber yield	1				
Number of tubers	0.683**	1			
Tuber weight	0.292	-0.200	1		
Tuber length	0.358	0.147	0.522**	1	
Tuber girth	0.113	-0.250	0.292	-0.276	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

4.3.2 Correlation Analysis of Sree Vijaya

To find out the biometric character which is positively associated to tuber yield, linear correlation coefficient was computed between these variables at each growth stages of Sree Vijaya. Similarly correlation between tuber yield and yield attributes were also estimated and the results are presented as follows.

4.3.2.1 Correlation between Tuber Yield and Biometric Characters

The product moment relationship between yield and biometric characters and between yield and yield attributes are presented in Table 34 .The result shows that, in the case of Sree Vijaya there exist a significant correlation between tuber yield and number of functional leaves at 3 MAP (0.452) and 5 MAP (0.410) at 5 per cent level of significance. LAI and number of functional leaves had positive correlation with tuber yield, and it was significant at 10 per cent level of significance. All other biometric characters had non- significant effect on yield. Moreover, plant height at 2 MAP and 3 MAP had positive association with yield and correlation coefficient was significant at 10 per cent, but height of branching was not significant even at 10 per cent.

Table 34.Correlation between tuber yield and biometric characters of Sree Vijaya

	Tuber yield (2 MAP)	Tuber yield (3 MAP)	Tuber yield (4 MAP)	Tuber yield (5 MAP)
pl	0.322	0.373	0.281	0.314
in	0.218	-0.041	0.055	0.303
fl	0.363	0.452*	0.353	0.410*
Pb	0.257	-	-	-
hb	0.062	-	-	-
lai				0.351

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

4.3.2.2 Correlation between Tuber Yield and Yield Attributes

Table 35. Correlation between yield and yield attributes of Sree Vijaya

	Tuber yield (kg)	Number of tubers	Tuber weight (g)	Tuber length (cm)	Tuber girth (cm)
Tuber yield	1				
Number of tubers	0.771**	1			
Tuber weight	0.691**	0.397	1		
Tuber length	0.539**	0.174	0.642	1	
Tuber girth	-0.260	-0.260	-0.154	-0.389	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

It was found from Table 35 that yield attributes such as number of tubers plant^{-1}, tuber weight and tuber length had positive significant correlations with tuber yield. The highest association of yield was for number of tubers (0.771), tuber weight (0.691) and tuber length (0.539). Hence, these tuber characters can be effectively used for the estimation of tuber yield after the harvest of the crop. It was also noticed that there exist a strong association between tuber length and tuber weight (0.642).

4.3.3 Correlation Analysis of Sree Swarna

To find out the parameter which, contribute positively and significantly to tuber yield, linear correlation coefficients were computed between tuber yield and biometric parameters for Sree Swarna separately for each growth stages (monthly interval). Similarly correlation between tuber yield and yield attributes were also computed and the results are presented as follows.

4.3.3.1 Correlation between Tuber Yield and Biometric Characters

Table 36.Correlation between tuber yield and biometric characters of Sree Swarna

	Tuber Yield (1 MAP)	Tuber Yield (2 MAP)	Tuber Yield (3 MAP)	Tuber Yield (4 MAP)	Tuber Yield (5 MAP)
pl	0.431*.	0.303	0.362	0.277	0.210
in	.010	-0.059	0.132	0.346	0.308
fl	.410*	0.414*	0.477*	0.455*	0.510**
pb	.459*	0.351	0.398*	0.428*	0.347
hb	.487*	0.239	0.307	0.100	-0.207
lai					0.283

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

The significant product moment correlation coefficient between yield and biometric characters were identified using the critical values of ‘r’ for 23 degrees of freedom. It is evident from Table 36 that yield was positively and significantly correlated with number of functional leaves plant^{-1} at 1, 2, 3, 4 and 5 MAP, number of primary branches at 3 and 4 MAP. The results of correlation analysis indicated that number of functional leaves plant^{-1} and number of primary branches plant^{-1} were the major contributing factors to the yield. Plant height and LAI also had positive effect on yield but not significant.

4.3.3.2 Correlation between Tuber Yield and Yield Attributes

Table 37. Correlation between yield and yield attributes of Sree Swarna

	Yield	Number of tubers plant^{-1}	Tuber weight	Tuber length	Tuber girth
Yield	1				
Number of tubers	0.867**	1			
Tuber weight	0.517**	0.159	1		
Tuber length	0.672**	0.401	0.809 **	1	
Tuber girth	0.028	0.189	-0.373	-0.328	1

** Significant at 1 per cent level of significance, * significant at 5 per cent level of significance

At the harvest stage, number of tubers (0.867), tuber weight (0.517) and tuber length (0.672) had positive relationship with tuber yield and these characters mainly contribute to the tuber yield (Table 37). It was also found that high and significant correlation exists between tuber length and tuber weight (0.801).

4.3.4 Correlation Analysis of Vellayani Hraswa

Correlation analysis is a statistical procedure to understand the inter relationship between the variables. Thus, linear correlation coefficients were computed between tuber yield and biometric characters for Vellayani Hraswa and the results are presented in the coming section. Similarly correlation between tuber yield and yield attributes were also computed and the results are presented as follows.

4.3.4.1 Correlation between Tuber Yield and Biometric Characters

In case of Vellayani Hraswa, the estimated correlation coefficient of plant height at 3 MAP and number of functional leaves plant^{-1} at 2 MAP with tuber yield were 0.475 and 0.369 respectively and they were found to be significant at 5 per cent level of significance (Table 38). All other biometric characters including LAI showed a different type of association with tuber yield of this variety.

Table 38.Correlation between tuber yield and biometric characters of Vellayani Hraswa

	Tuber Yield (1 MAP)	Tuber Yield(2 MAP)	Tuber Yield (3 MAP)	TuberYield (4 MAP)	Tuber Yield (5 MAP)
pl	0.571*	0.170	0.475*	-0.230	-0.288
in	.004	0.037	0.309	0.259	0.131
fl	.308	0.369*	-0.226	-0.059	-0.252
Pb	.09	0.061	-	-	-
hb	.310	0.316	-	-	--
lai					-0.094

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

4.3.4.2 Correlation between Tuber Yield and Yield Attributes

The yield and yield attributes of Vellayani Hraswa behaved differently as compared to other varieties. All the yield attributes such as number of tubers plant^{-1} (0.807), average tuber weight (0.732), average tuber length (0.512) and average tuber girth (0.494) at harvesting stage had positive and significant correlation with yield. Moreover, tuber length (0.620) and tuber girth (0.752) were highly correlated with tuber weight. Hence, these characters can be effectively used for the estimation of yield after harvest.

Table 39.Correlation between yield and yield attributes of Vellayani Hraswa

	Tuber yield	Number of tubers plant^{-1}	Tuber weight	Tuber length	Tuber girth
Yield	1				
Number of tubers plant^{-1}	0.807**	1			
Tuber weight	0.732**	0.278	1		
Tuber length	0.512**	0.198	0.620 **	1	
Tuber girth	0.494*	0.205	0.752 **	0.075	1

** Significant at 1 per cent level of significance, * Significant at 5 per cent level of significance

4.3.5 Correlation Analysis of Kantharipadarppan

Kantharipadarppan is a locally available short duration variety of cassava in southern Kerala. Correlation coefficient was also worked to study the association between tuber yield and plant biometric characters. Similarly correlation between tuber yield and yield attributes were also computed and the results are presented as follows.

4.3.5.1 Correlation between Tuber Yield and Biometric Characters

The product moment relationship between yield and biometric characters and between yield and yield attributes are presented in Table 40. The results shows that, in the case of Kantharipadarppan there exists a significant correlation between tuber yield and inter nodal length at 2 MAP (0.400) and number of functional leaves at 5 MAP (0.412). It is interesting to note that LAI was not at all significant for this variety. However, the height of plant was not significant and contributing negatively to the tuber yield.

Table40. Correlation between tuber yield and biometric characters of Kantharipadarppan

	Tuber Yield (2 MAP)	Tuber Yield (3 MAP)	Tuber Yield (4 MAP)	Tuber Yield (5 MAP)
pl	-0.321	-0.398	-0.323	-0.315
in	0.280	0.400*	0.390	0.357
fl	-0.159	-0.052	0.190	0.412*
pb	-0.069	0.103	-	-
hb	0.073	0.010	-	-
lai				-0.0002

** significant at 1 per cent level of significance, * significant at 5 per cent level of significance

4.3.5.2 Correlation between Tuber Yield and Yield Attributes

Table 41.Correlation between yield and yield attributes of Kantharipadarppan

	Yield	Number of tubers	Tuber weight	Tuber length	Tuber girth
Yield	1				
Number of tubers	0.783**	1			
Tuber weight	0.354	-0.143	1		
Tuber length	-0.006	-0.213	0.507 **	1	
Tuber girth	0.293	0.048	0.668**	0.289	1

The yield attributes of this variety showed a different pattern of association with yield (Table 41). Only one parameter, number of tubers plant^{-1} (0.783) had positive significant correlation with yield. However, tuber weight was highly and positively associated to tuber length (0.507) and tuber girth (0.668).

4.4 PRE-HARVEST YIELD PREDICTION USING MULTIPLE LINEAR AND NON-LINEAR REGRESSION MODELS

Statistical models play a major role in pre-harvest forecasting of crop yield. An effort was made to develop the pre-harvest forecasting models of cassava yield using biometric characters at various stages of growth and one which explains maximum variation in yield was selected. Multiple linear regression technique was employed to find the linear effect of biometrical parameters on tuber yield at different stages of crop growth of cassava varieties Sree Jaya, Sree Vijaya, Sree Swarna, Vellayani Hraswa, and Kantharipadarppan. To find the non linear effect, Cobb-Douglass production function was used. Regression models were fitted for each month by using tuber yield as the dependent variable and biometric characters as the independent variables. Multiple linear regression for the third month was done by considering the biometric characters at the previous and current period. Same procedure was adopted at the fourth and fifth growth stage. At each stage character having Variance Inflation Factor (VIF) greater than 10 and the variables which are not significant at 30 per cent were excluded from the model. The estimated p values are used to identify the significant contribution. If the estimated p value of a particular variable is less than .05, then that variable is considered as significant at $\alpha = .05$ per cent.

4.4.1 Estimated Multiple Linear and Log Linear Model for Predicting Tuber Yield of Sree Jaya

Multiple linear prediction models for tuber yield using biometric characters were attempted for every growth stage. The best model was selected on the basis of R^2, adjusted R^2, and Mallow's C_p criteria and the results are presented in the Table 42. In the second month, biometric characters such as plant height, inter nodal length, number of functional leaves plant^{-1}, number of primary branches plant^{-1} and height of first branching were used in the prediction model.

Table 42. The estimated multiple linear prediction model of Sree Jaya

Month	No. of variables	Model	Adj.R^2	R^2	C_P
2	4	$Y=3.405+.006pl_2+.017in_2-.025fl_2+.010hb_2$ (1.10) (1.13) (1.05) (1.06)	0	.14	3.05
2 &3	5	$Y=4.520-.011hb_3+.671in_2-.017fl_2+.018\ hb_2-.695in_3$ (2.58) (2.92) (1.09) (2.62) (2.55)	.09	.28	4
2,3 &4	5	$Y=5.92+1.28pb_4{*}+.502in_2-.022fl_2{*}-.866in_3{*}-.009hb_4{*}$ (7.84) (2.54) (1.08) (2.58) (7.81)	.52	.62	4.02
2,3,4 &5	7	$Y=6.40-.010hb_3+.015fl_5{*}-.018fl_2+.018hb_2{*}-.008hb_4-$ (3.19) (2.12) (1.25) (3.09) (8.73) $.764in_5{*}+1.08pb_4{*}$ (2.06) (8.47)	.58	.70	6.03
	5	$Y=6.71+.145lai-.769in_5{*}+.009hb_2-.011fl_3+.545pb_4{*}$ (1.85) (1.71) (1.44) (1.45) (1.15)	.40	.53	4.02
	4	$Y= 3.81+.163pb_5+.532in_2+.482pb_4{*}-.811in_3{*}$ (1.22) (2.47) (1.25) (2.56)	.40	.50	3.01

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

The result of analysis indicated that, only 14 per cent of variation of the model was explained by these variables. The estimated p value of all the variables were more than .05 indicated that none of the variables had significant effect on tuber yield. Stepwise regression analysis performed using the observations at the second and third month showed that there was an increase in R^2 of 28 per cent but none of the variables had significant effect on yield. The estimated model at the fourth month using biometric characters at the previous months and current month explained 62 per cent variation in tuber yield. The biometric characters such as inter nodal length at third month (p =0.018), number of functional leaves at second month (p= 0.036), height of branching at fourth month (p= 0.046) and number of primary branches at fourth month (p= 0.002) had significant effect on yield with VIF of all variables less than 10. Similarly stepwise regression analysis was repeated for fifth month by considering previous months and current month observation which produced a multiple R^2 of 70 per cent with significant variables as number of functional leaves at fifth month (p= 0.008), height of branching at second month (p=0.046), inter nodal length at fifth month (p= 0.017) and number of primary branches at fourth month (p= 0.007). Stepwise regression was repeated by removing variable having high variance inflation factor and not significant at 30 per cent and thus the final model was developed. The final model consisted of 4 variables having significant effect on yield and explained 50 per cent variation in tuber yield with a Mallow's C_p of 3.01 with significant variables as inter nodal length at third month and number of primary branches at fourth month.

Non linear regression models were also performed to check whether there is an increase in the R^2 value so as to increase the reliability of prediction. To perform non linear regression natural logarithm of dependent and independent variables at different growth stages were taken. Regression analysis of second month observation using biometric characters such as plant height, inter nodal length, number of functional leaves, number of primary branches and height of first branching produced a model (Table 43) which explained 18 per cent variation of the model and found that none of the variables had significant effect on tuber yield. Stepwise regression analysis performed using the observations at the second and third month showed that there was an increase in R^2 of 31 per cent but none of the variables had significant effect on yield , since these variables has a p value greater than 0.05. The estimated model at the fourth month using biometric characters at the previous months and current month explained 64 per cent variation in tuber yield. The biometric characters such as number of functional leaves at second month and number of primary branches at fourth month had significant effect on yield with VIF of all variables was found to be less than 10. Similarly stepwise regression analysis was repeated for fifth month by considering previous months and current month observation which produced a multiple R^2 of 70 per cent with significant variables as number of functional leaves at fifth month, height of branching at second month and number of primary branches at fourth month. Stepwise regression was repeated by removing variable having high variance inflation factor and not significant at 30 per cent and thus the final model was developed. The final model consisted of 4 variables having a significant effect on yield and explained 56 per cent variation in tuber yield with significant variables as number of functional leaves at 2 MAP and number of primary branches at 4 MAP.

Table 43. The estimated non linear prediction model of Sree Jaya

Month	No. of variables	Model	Adj. R^2	R^2	C_P
2	4	$\log Y=.257+.696\log(pl_2)-.072\log(in_2)-.728\log(fl_2)+.070\log(hb_2)$ (1.18) (1.16) (1.10) (.07)	.01	.18	5.08
2 &3	5	$\log Y=1.401-.115\log(hb_3)+.849\log(in_2)-.443\log(fl_2)+.195\log(hb_2)-$ (2.34) (2.60) (1.10) (2.36) $1.01\log(in_3)$ (2.29)	.14	.31	4.2
2,3 &4	6	$\log Y=-1.16-.068\log(hb_4)+.844\log(pb_4)^*-.877\log(fl_2)^*+.427\log(fl_4)+$ (3.47) (3.25) (1.46) (2.98) $1.17\log(pl_3)-.582\log(in_3)$ (3.27) (1.02)	.52	.64	5.18
2,3,4,5	8	$\log Y=-.026-.363\log(fl_4)-.065\log(hb_4)+.037\log(hb_5)+.202\log(hb_2)^*+$ (4.22) (5.01) (1.65) (3) $.888\log(fl_5)^*+.624\log(pb_4)^*-.798\log(in_5)$ (3.91) (2.03) (3.29)	.55	.70	7.6
	4	$\log Y=1.69+.171\log(pb_5)-.479\log(in_3)-.570\log(fl_2)^*+.438\log(pb_4)^*$ (2.21) (3.6) (3.32) (3.5)	.48	.56	3.25

*Significant at 5 %, ** significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

4.4.2 Estimated Multiple Linear and Log Linear Regression on Yield Based on Biometric Characters of Sree Vijaya

Pre – harvest forecasting model for tuber yield was developed for short duration variety Sree Vijaya. Multiple linear and non linear regression models attempted using STATA software are presented in Table 44 and Table 45 respectively. It is evident from Table 44 that none of the variables had a significant effect on tuber yield at the second month with R^2 of 33 per cent. Stepwise regression analysis using second and third month observations revealed that inter nodal length at second month had significant effect on yield with R^2 of 52 per cent. Stepwise regression analysis was repeated using second, third and fourth month observations and the model explained 61 per cent of variation in tuber yield. The variables inter nodal length at second and third month, number of functional leaves at second month and plant height at fourth month had p values less than 0.05 indicated that these variables had significant effect on tuber yield. For fifth month, model was remodified by using observations of the previous months and current month. By removing variables having high VIF obtained a model has 5 variables which explained 58 per cent of variation in tuber yield. The variables which contribute significant to the tuber yield were inter nodal length at second and fifth month and number of functional leaves at second month and plant height at fifth month.

Table 44. The estimated multiple linear prediction model of Sree Vijaya

Month	Number of variables	Model	Adj. R^2	R^2	C_P
2	5	$Y= -4.13+.017pl_2+.660in_2+.038fl_2-.138pb_2+.012hb_2$ (1.50) (1.24) (1.40) (3.33) (3.85)	.16	.33	3.99
2 &3	5	$Y= -3.47+.017pl_3+1.27in_2*+.048fl_2-.867in_3+.008hb_2$ (1.60) (2.32) (1.60) (2.35) (1.31)	.39	.52	3.98
2,3 &4	7	$Y= -5.64-.029pl_2 +1.56in_2* +.070fl_2* +.011hb_2$ (3.57) (2.68) (1.56) (1.45) $+.023pl_4*-1.20in_3*+.487in_4$ (3.50) (3.52) (2.13)	.45	.61	6
2,3,4,5	7	$Y= -7.77-.033pl_2+ 1.22in_2* +.080fl_2* +.010hb_2$ (3.28) (2.66) (1.63) (1.46) $+.424in_5*- .665in_3+.0275pl_5*$ (1.34) (2.41) (3.36)	.57	.69	6.0
	5	$Y= -7.78+.763in_2*+.072fl_2*+.018pl_5*+.563in_5*-$ (1.56) (1.23) (1.40) (1.45) $.531in_4$ (1.53)	.47	.58	4

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Non linear prediction model was performed as similar to multiple linear model. To select variable having significant effect on yield, stepwise backward regression analysis were conducted using logarithmic value of all the dependent and independent variables. It is evident from Table 45 that non linear model developed using biometric observations at second month had non -significant effect on tuber yield. Stepwise regression analysis using second and third month observation produced a model with R^2 of 50 per cent and found that the variables such as inter nodal length at second month had significant effect on tuber yield. Stepwise regression analysis was repeated using second, third and fourth month observations and the model explained 50 per cent of variation in tuber yield. The variables inter nodal length at second month had p values less than 0.05 indicated that these variables had significant effect on tuber yield. At fifth month, model was developed by using observations of the previous months and current month. The final model had 5 variables which explained 59 per cent of variation in yield. The variables which contribute significant to the tuber yield were inter nodal length at 2 and 3 MAP and functional leaves plant^{-1} at 5 MAP.

Table 45. The estimated non linear prediction model of Sree Vijaya

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	5	$\log Y = -3.06 + .745\log(pl_2) + .981\log(in_2) + .756\log(fl_2) -$ (1.51) (1.36) (1.49) $.271\log(pb_2) + .114\log(hb_2)$ (3.13) (3.50)	.19	.35	4.76
2 &3	5	$\log Y = -3.05 - 1.42\log(in_3) + 1.76\log(in_2)^* + .900\log(fl_2)$ (2.40) (2.38) (1.65) $+.826\log(pl_3) + .062\log(hb_2)$ (1.64) (1.30)	.37	.50	5
2,3 &4	5	$\log Y = -3.05 - 1.42\log(in_3) + 1.76\log(in_2)^* + .900\log(fl_2)$ (2.40) (2.38) (1.65) $+.826\log(pl_3) + .062\log(hb_2)$ (1.30) (1.64)	.37	.50	5
2,3,4& 5	5	$\log Y = -3.36 + .638\log(fl_5)^* + 1.56\log(in_2)^* + 1.28\log(fl_2)$ (1.32) (2.54) (1.32) $+.534\log(in_5) - 1.50\log(in_3)^*$ (1.19) (2.31)	.48	.59	5.3
	4	$\log Y = -2.25 + .571\log(fl_5) + 1.52\log(in_2)^* + .498\log(fl_3)$ (1.93) (2.22) (1.96) $+.717\log(in_3)$ (2.04)	.43	.52	3.68

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

4.4.3 Estimated Multiple Linear and Log Linear Regression on Yield Based on Biometric Characters of Sree Swarna

Table 46. The estimated multiple linear prediction model of Sree Swarna

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	4	$Y= .742-.001pl_2-.024in_2+.035fl_2+.001hb_2$ (2.33) (1.07) (2.69) (1.46)	.01	.17	3.14
2 &3	3	$Y= .593+.353pb_3*-.833in_2*+1.09in_3*$ (1.05) (3.38) (3.43)	.24	.33	2.01
2,3 &4	3	$Y= -1.12+.030 fl_4*-.832 in_2*+1.14 in_3*$ (1.05) (3.36) (3.44)	.31	.40	2.01
2,3,4 & 5	3	$Y = -.509+1.05in_3*-.852in_2*+.031fl_5*$ (3.06) (3.04) (1.01)	.35	.43	1.95

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Table 46 presents the prediction models for tuber yield of Sree Swarna using biometric characters at every month. In Sree Swarna the model developed at 2 MAP using all biometric characters as the independent variables did not produced significant effect on tuber yield. Stepwise regression using observations at 2 MAP and 3 MAP revealed that inter nodal length at second and third month and number of primary branches plant^{-1} had significant effect on yield and explained 33 per cent of variation in tuber yield. Stepwise regression analysis was repeated using second, third and fourth month observations and the model explained 40 per cent of variation in tuber yield. The variables inter nodal length at second and third month and number of functional leaves at fourth month had significant effect on yield. At the fifth month, Stepwise regression was performed using current and previous period biometric characters that explained 43 per cent of variation in tuber yield. The biometric characters inter nodal length at 2 MAP and 3 MAP and number of functional leaves plant^{-1} at 5 MAP had significant effect on yield.

Table 47. The estimated non linear prediction model of Sree Swarna

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	4	$\log Y = -.934 + .171 \log(pl_2) - .117 \log(in_2) + .594 \log(fl_2)$ (2.79) (1.09) (3.33) $+ .005 \log(hb_2)$ (1.65)	-.02	.15	3.03
2 &3	3	$\log Y = -1.66 + 1.40 \log(in_3) - .883 \log(in_2) + .922 \log(fl_3)^*$ (2.95) (3.04) (1.05)	.23	.33	2.75
2,3 &4	3	$\log Y = -1.53 + .79 \log(fl_4)^* - 1.25 \log(in_2)^* + 1.919 \log(in_3)^*$ (1.04) (2.95) (3.01)	.33	.42	2.42
2,3,4 & 5	4	$\log Y = -1.43 + .906 \log(fl_5)^* - 1.32 \log(in_2)^* - .261 \log(lai) +$ (1.62) (3.06) (2.10) $1.56 \log(in_3)^*$ (3.07)	.37	.47	3.3

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Non linear regression models were also developed for the short duration variety Sree Swarna as similar to multiple linear regression. Stepwise backward regression analysis were conducted using logarithmic value of all the dependent and independent variables to select variable having significant effect on yield. It is evident from the Table 47 that regression model using second month observation produced a model of 4 variables on yield and each having estimated p value greater than 0.05 thus had a non significant effect on yield. Stepwise regression analysis using second and third month observation produced a model with R^2 of 33 per cent and found that the variables such as functional leaves plant^{-1} at 3 MAP had significant effect on yield. Stepwise regression analysis was repeated using second, third and fourth month observations and the model explained 42 per cent of variation in tuber yield. The variables inter nodal length at 2 and 3 MAP and number of functional leaves plant^{-1} at 4 MAP had p values less than 0.05 indicated that these variables had significant effect on tuber yield. At fifth month, model was developed by using observations of the previous months and current month and fifth month model was developed by including variables having VIF less than 10 and the final model had 4 variables which explained 47 per cent of variation in tuber yield. The variables inter nodal length at 2 and 3 MAP and number of functional leaves at 5 MAP had significant effect on yield.

4.4.4 Estimated Multiple Linear and Log Linear Regression on Yield Based on Biometric Characters of Vellayani Hraswa

Table 48. The estimated multiple linear prediction model of Vellayani Hraswa

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	5	$Y= -5.92+.027pl_2+.067in_2+.053fl_2-.651pb_2$ (1.27) (1.23) (2.55) (2.72) $+.056hb_2$ (1.26)	.09	.28	4.07
2 &3	7	$Y= -.350-.055pl_2-.669in_2+.119fl_2^*-.846pb_2$ (4.20) (2.04) (3.96) (2.75) $+.043hb_2+.075pl_3-.069fl_3^*$ (1.29) (3.99) (3.55)	.43	.60	6.1
2,3 &4	7	$Y= -.552-.061pl_2-.519in_2+.127fl_2^*+.038hb_4$ (4.20) (2.16) (3.92) (1.32) $+.08pl_3^* -1.05pb_4- .066fl_3^*$ (4.03) (2.73) (3.53)	.47	.63	6.06
2,3,4 & 5	7	$Y= -6.68-.488lai-1.29in_2+.060fl_2^*+.044hb_4$ (1.31) (3.97) (2.65) (1.35) $+.040pl_3 +1.44in_3^*-.831pb_5$ (1.29) (4.01) (2.96)	.41	.58	6.02
	2	$Y= 5.52-.049pl_4^*+.074fl_2^*$ (1.72) (1.72)	.29	.35	1.05

*Significant at 5 % , ** Significant at 1 % , values in parenthesis indicates VIF

Table 48 presents prediction models for tuber yield of Vellayani Hraswa with biometric characters for every month. In the second month all biometric characters are used as the independent variables, but results was not satisfactory. None of the variables were found to have a significant effect on tuber yield. Stepwise regression using second and third month observation revealed that number of functional leaves plant^{-1} at 2 and 3 MAP had significant effect on yield and explained 60 per cent of variation. Stepwise regression was repeated using second, third and fourth month observation and which explained 63 per cent of variation in yield and the significantly contributing variables were number of functional leaves plant^{-1} at 2 and 3 MAP, plant height at 3 MAP. At fifth month, stepwise regression analysis using current and previous periods observation explained 58 per cent of variation in yield by the variables number of functional leaves plant^{-1} at 2 MAP and inter nodal length at 3 MAP. From fifth month model, variables having high VIF were removed and obtained a model with 2 variables which explained only 35 per cent of variation in yield. Therefore the model developed with two variables was considered as the final model with significantly contributing variables as number of functional leaves plant^{-1} at 2 MAP and plant height at 4 MAP.

Table 49. The estimated non linear prediction model of Vellayani Hraswa

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	5	log Y= -7.73+2.46 log(pl_2)-.108 log(in_2)+.518 log (fl_2)- (1.30) (1.25) (2.46) .647 log (pb_2)+ 1.36 log(hb_2) (2.55) (1.27)	.05	.25	4.02
2 &3	6	log Y= -4.55-2.67 log (fl_3)*-1.55 log (in_2)*+2.35log(fl_2)*- (3.11) (2.15) (3.19) .989 log (pb_2)+.991 log(hb_2)+2.58 log (pl_3)* (2.61) (1.29) (1.23)	.42	.57	5.37
2,3 &4	6	log Y= -5.09-1.3 log (pb_4)*-1.32 log (in_2)+ 2.62log(fl_2)*+ (2.60) (2.24) (2.99) .872 log (hb_2) +2.61 log (pl_3)*-2.55 log(fl_3)* (1.20) (3.02) (1.31)	.49	.62	5.31
2,3,4 & 5	7	log Y= -4.59-1.13 log (pb_4)-1.19log (in_2)+2.70 log (fl_2)* (2.74) (2.27) (3.01) +1.05 log (hb_2)+2.37 log(pl_3)*-2.63log (fl_3)*- .862log(lai) (1.23) (3.04) (1.30) (1.36)	.53	.67	6.34
	3	log Y= 1.12-4.14 log (pl_4)*+1.64 log(fl_2)*+2.57 log (pl_3)* (2.10) (1.80) (1.23)	.32	.40	2.37

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Non linear regression models were also performed to check whether there is a chance to get high R^2 value. To perform non linear regression natural logarithm of dependent and independent variables at different growth stages were taken. Non linear regression of second month performed using biometric characters such as plant height, inter nodal length, number of functional leaves plant^{-1}, number of primary branches plant^{-1} and height of first branching produced a model which explained 25 per cent variation of the tuber yield and found that none of the variables had significant effect on tuber yield. Stepwise regression analysis was repeated using the observations at the second and third months showed that there was an increase in R^2 of 57 per cent and variables such as inter nodal length at 2 MAP, number of functional leaves $plant^{-1}$ at 2 and 3 MAP and plant height at 3 MAP had significantly influence tuber yield with p value less than 0.05. The estimated model using biometric characters at the fourth month and the previous month explained 62 per cent variation in tuber yield. The biometric characters such as number of functional leaves $plant^{-1}$ at 2 and 3 MAP, plant height at 3 MAP and number of primary branches $plant^{-1}$ at 4 MAP had significant effect on yield and VIF of all variables found to be less than 10. Similarly stepwise regression analysis was repeated for fifth month by considering previous month and current month observation which produced a multiple R^2 of 67 per cent with significant variables as number of functional leaves $plant^{-1}$ at 2 and 3 MAP and plant height at 3 MAP. Stepwise regression was repeated by removing variable having high variance inflation factor and not significant at 30 per cent and thus the final model was developed. The final model consisted of 3 variables having significant effect on yield and explained 40 per cent variation in tuber yield and significantly contributing variables as number of functional leaves $plant^{-1}$ at 2 MAP and plant height at 2 and 4 MAP.

4.4.5 Estimated Multiple Linear and Log Linear Regression on Yield Based on Biometric Characters of Kantharipadarppan

Multiple linear prediction models for tuber yield of Kantharipadarppan using biometric characters were attempted for every growth stage. The best model was selected on the basis of R^2, adjusted R^2, and Mallow's C_p criteria and the results are presented in Table 50. In the second month, biometric characters such as plant height, inter nodal length, number of functional leaves $plant^{-1}$, number of primary branches $plant^{-1}$ and height of first branching were used in the prediction model. The result of analysis indicated that, only 12 per cent of variation of the model was explained by these variables. The estimated p value of all the variables were more than .05 indicated that none of the variables had significant effect on tuber yield. Stepwise regression analysis performed using the observations at the second and third month showed that there was an increase in R^2 of 25 per cent and the variables plant height at 3 MAP and number of functional leaves plant^{-1} at 3 MAP had significant effect on yield. The estimated model at the fourth month using biometric characters at the previous month and current month explained 33 per cent variation in tuber yield. The biometric characters such number of functional leaves plant^{-1} at 4 MAP and plant height at 3 MAP had significant effect on yield with VIF of all variables less than 10. Similarly stepwise regression analysis was repeated for fifth month by considering previous month and current month observation which produced a multiple R^2 of 34 per cent with significant variables as number of functional leaves plant^{-1} at 4 MAP and plant height at 3 MAP. For this variety the explanatory power of pre- harvest yield prediction was very low.

Table 50. The estimated linear prediction model of Kantharipadarppan

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	4	$Y= 4.05-.014pl_2+.201in_2+.006fl_2+.109pb_2$ (2.19) (1.93) (1.76) (1.07)	.05	.12	3.07
2 &3	2	$Y=5.35+.029fl_3$*$-.026pl_3$* (1.95) (1.95)	.19	.25	1
2,3 &4	2	$Y= 5.60-.023pl_3$*$+.014fl_4$* (1.27) (1.27)	.27	.33	1.12
2,3,4 & 5	2	$Y= 5.60-.024pl_3$*$+.014fl_4$* (1.25) (1.25)	.25	.34	1.12

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Table 51: The estimated non linear prediction model of Kantharipadarppan

Month	Number of variables	Model	Adj.R^2	R^2	C_P
2	4	log Y=1.31-.641 log(pl_2)+.166 log (in_2)+.239 log(fl_2) (2.37) (1.79) (2) +.072 log (pb_2) (1.06)	.04	.13	3.19
2 &3	2	log Y= 1.87-1.28 log (pl_3)*+.778 log (fl_3)* (2.48) (2.48)	.23	.29	1.93
2,3 &4	2	log Y=2.21+.478 log (fl_4)*-1.18 log (pl_4)* (1.61) (1.61)	.28	.34	2
2,3,4 & 5	2	log Y= 2.21-1.23 log (pl_2)*+.454 log (fl_4)* (1.54) (1.54)	.27	.33	2.35
	2	log Y=-2.24-1.14 log (pl_4)*+.438 log (fl_5)* (1.32) (1.98)	.26	.32	1.06

*Significant at 5 %, ** Significant at 1 % level, values in parenthesis indicates Variance Inflation Factor

Non linear regression models were also performed as similar to linear regression analysis to check whether there is an increase in R^2 value. Regression analysis of the data recorded at 2 MAP on biometric characters such as plant height, inter nodal length, number of functional leaves plant^{-1}, number of primary branches plant^{-1} and height of first branching produced a model which explained 13 per cent variation of the model and found that none of the variables had significant effect on tuber yield. Stepwise regression analysis performed using the observations at the second and third month showed that there was an increase in R^2 value 29 per cent and the variable plant height at third month and number of functional leaves at third month had significant effect on yield and having p value less than 0.05. The estimated model at the fourth month using biometric characters at the previous month and current month explained 34 per cent variation in tuber yield. The biometric characters such number of functional leaves at fourth month and plant height at fourth month had significant effect on yield and VIF of all variables was found to be less than 10. Similarly, stepwise regression analysis was repeated for fifth month by considering previous month and current month observation. The final model developed consisted of 2 variables having a significant effect on yield and explained 33 per cent variation in tuber yield. The model having highest R^2 value was selected to identify the most significantly contributing variables.

4.4.6 Detection of Multicollinerity

Detection of multicollinerity among independent variables was checked for all the models of all varieties. The best model was selected if the calculated VIF of all the biometric parameters were below the specified level (VIF < 10), indicating that no severe multicollinerity exist between the biometric characters.

4.5 TRENDS IN AREA, PRODUCTION, PRODUCTIVITY AND PRICE

Cassava is a major tuber crop cultivated in Kerala, as a sole crop or as a mixed crop, mainly cultivating in homesteads and primarily used for household consumption. Even though, it is a remunerative crop, its importance has declined over the years with shrink in land under cultivation. The share of cassava area in Kerala to all India declined from 85.57 to 45.5 per cent in 2001-02. In sixties, 90 per cent of all India production was from Kerala, but it was reduced to 37.9 per cent in 2001-02. With the introduction of short duration varieties, there was an increase in productivity, but not up to the level of Tamil Nadu. In this context, it is better to have an idea about the present status in area, production and productivity of cassava in Kerala. The trend was studied by considering last twenty five years data starting from 1991-92 to 2014-15. Usually exponential model provides a better understanding in trends in these characteristics. Moreover, cassava generally grows under area that receives normal rainfall. The variable rainfall is also incorporated in the model to understand the effect of rain fall on production and productivity. The estimated equations are presented in Table 52 and 53 respectively.

4.5.1 Trend in Area

The estimated trend equation in area of cassava using semi log function was log Y = 5.16- 0.0137 t with R^2 of 95 per cent. CAGR obtained was -1.37 per cent which indicated that there was a significant decline in area at the rate of 1.37 per cent per annum.

4.5.2 Trend in Production

The estimated trend equation in production of cassava using semi log function was log Y = 6.41- 0.0002 t with R^2 of 40 per cent. CAGR obtained was -.02 per cent which indicated that there was a decline in production and it was not significant.

4.5.3 Trend in Productivity

The estimated trend equation in productivity of cassava using semi log function was log Y = 4.24 + 0.013 t with R^2 of 96 per cent. CAGR obtained was 1.3 per cent which indicated that there was a significant increase in productivity at the rate of 1.3 per cent per annum.

4.5.4 Trend in Price

The estimated trend equation in nominal price of cassava using semi log function revealed was log Y =2.18+ 0.035 t with R^2 of 92 per cent. CAGR obtained was 3.5 per cent which indicated that there was a significant increase in price at the rate of 3.5 per cent per annum.

Table 52. Estimated annual compound growth rates in area, production and productivity of cassava

Characters	$Log(y) = a + b T+e_t$	R^2	p value for t	CAGR
Area	log (area) = 5.16- 0.0137t	95	.0002	-1.37
Production	log(production) = 6.41- 0.0002t	40	.739	-.02
Productivity	log(productivity) = 4.24+ 0.013t	96	.0004	1.3
Price	log (price) = 2.18+ 0.035t	92	.0001	3.5

Table 53. Rain fall adjusted compound annual growth rates in area, production and productivity of cassava

Characters	$logy = a + b T+e_t$	R^2	p value for rf	CAGR
Area	log (area) = 5.08+0.02rf- 0.0137t	96	.15	-1.37
Production	log (production) = 6.33+0.02rf- 0.0002t	50	.15	-.02
Productivity	log(productivity)= 4.25- 0.0009rf +.013t	96	.95	1.3
Price	log (price) = 2.54- 0.109rf+0.035t	93	.05	3.5

4.6 INSTABILITY ANALYSIS

Instability analysis on area, production and productivity of cassava for a period of 25 years was carried out. Instability measures such as coefficient of variation, Cuddy-Della Valle index and Coppock index were determined and presented in Table 54.

It was found that C.V in area, production and productivity was 23.38, 4.72 and 23.56 per cent respectively (Table 54). Cuddy-Della Valle and Coppock instability indices have shown similar pattern for area, production and productivity. Cuddy-Della Valle index provided best estimates of instability and the instability and was found to be more in productivity (4.04) followed by area (3.98) and production (0.80).

Table 54. Measures of Instability in area, production and productivity of cassava

Measures of instability	Area	Production	Productivity	Price
C.V	23.38	4.72	23.56	70.38
Cuddy-Della Valle index	3.98	.80	4.01	37.04
Coppock Index	10.63	10.59	10.41	11.99

Discussion

5. DISCUSSION

5.1 SUMMARY STATISTICS

In order to have an idea about the behavior of the biometric observations and yield of the plants, summary statistics including mean, standard deviation, minimum and maximum were worked out for all the varieties at each growth stage. Summary statistics of the variety Sree Jaya revealed that plant height increased up to 4 MAP with maximum inter nodal length of 6 cm. It is also observed that the number of functional leaves plant^{-1} was maximum at 4 MAP. Branching was late and it was completed at fourth month for this variety with an average height and number of branches of 206.05 cm and 2.23 respectively. Average leaf area index obtained was 3.94. The average number of tubers plant^{-1} obtained was 8.00 with an average tuber yield of 2.90 kg plant^{-1} and average tuber weight of 330.73 g. The average tuber length and tuber girth were 21.82 cm and 15.62 cm respectively and the variety had a minimum yield of 1.25 kg plant^{-1} and a maximum of 5.6 kg plant^{-1} with a standard deviation of 1.01 kg.

Summary statistics of the variety Sree Vijaya revealed that plant height showed an increasing trend up to 4 MAP with maximum inter nodal length of 5.88 cm at 5 MAP. It is also observed that the number of functional leaves plant^{-1} was maximum at 4 MAP. Branching was completed at 2 MAP with average number of branches of 2.04 and average leaf area index of 2.23. The average number of tubers plant^{-1} obtained was 9.00 with an average tuber yield of 2.88 kg and average tuber weight of 285.73 g. The average length and girth of tubers were 20.43 cm and 13.43 cm respectively. The variety Sree Vijaya had a minimum yield of 1.27 kg and a maximum of 4.9 kg with a standard deviation of 1.0 kg indicating that there was not much variation in tuber yield.

Summary statistics of the variety Sree Swarna revealed that plant height showed an increasing trend up to 5 MAP with maximum inter nodal length of 4.76 cm at 5 MAP. It is also observed that the number of functional leaves plant^{-1}

was maximum at 3 MAP. Branching was completed at 4 MAP with average number of branches of 2.5 and average leaf area index of 1.10. Average number of tubers plant^{-1} recorded was 8 with an average tuber yield of 2.63 kg and average tuber weight of 308.78 g. Variety Sree Swarna had a minimum yield of 1.15 kg and a maximum yield of 4.75 kg and the tuber weight varied from 212 g to 467.85 g. The average length and girth of tuber were 21.31 cm and 13.21 cm respectively.

Summary statistics of the variety Vellayani Hraswa showed that plant height increased up to 5 MAP with maximum inter nodal length of 4.92 cm. It is also observed that the number of functional leaves plant^{-1} was maximum at 4 MAP. For this variety branching was earlier and completed at 2 MAP with average height and number of branches as 60.24 cm and 3.08 respectively. Average leaf area index obtained was 3.89. The average number of tubers plant^{-1} obtained was 7 which varied from 2 to 14 tubers plant^{-1}. The average tuber yield plant^{-1} was 2.80 kg with minimum yield of 0.5 kg to maximum yield of 8 kg. The average tuber weight was 358.18 g and it ranged from a minimum weight of 180 g to maximum weight of 639.28 g. The estimated tuber length and girth were 22.85 and 14.73 cm respectively. The estimated variance was high in tuber yield plant^{-1}.

Summary statistics of the local variety Kantharipadarppan concluded that plant height showed an increasing trend up to 5 MAP with maximum inter nodal length of 4 cm. It is also observed that the number of functional leaves plant^{-1} was maximum at 4 MAP. Branching was completed at 4 MAP with average number of branches plant^{-1} of 1.87 and average leaf area index of 1.36 .The average number of tubers plant^{-1} was 9 which varied from 5 to 15 tubers plant^{-1} .The average tuber yield per plant was 3.40 kg with minimum yield of 1.6 kg to maximum yield of 5.75 kg. The average tuber weight was 354.73 g and having minimum weight of 190 g to maximum weight of 646.87 g. The estimated tuber length and girth were 21.51 and 15.96 cm respectively.

5.2 CORRELATION STUDIES

Correlation analysis emphasis a way to identify the association between cassava yield and biometric characters and provide better understanding of the contribution of each biometric character to crop yield. Keeping this view, the crop yield and biometric characters were subjected to correlation studies and the results are discussed at this juncture.

An attempt on correlating the biometric characters with tuber yield of variety Sree Jaya revealed significant results in case of number of primary branches plant^{-1} and height of first branching at later stages of crop growth *viz.*, 4 MAP and 5 MAP. The results of correlation analysis between tuber yield and yield attributes showed that among the yield attributes, number of tubers plant^{-1} had significant correlation with tuber yield. These findings are in concurrence with study by Rajendran *et al.* (1985) indicating the significant effects of this yield attribute on tuber yield plant^{-1}.

In case of Sree Vijaya variety, number of functional leaves plant^{-1} was significantly correlated with tuber yield at 3 and 5 MAP and these results are in agreement with the findings of Sreekumari and Abraham (1991), who reported that number of leaves plant^{-1} had significant effect on tuber yield of cassava. The inter nodal length at third month had negative correlation with yield. This finding is in accordance with the results of Sankaran, *et al.* (2008). Correlation analysis between yield and yield attributes revealed that number of tubers plant^{-1}, tuber weight and tuber length had significant correlation with tuber yield plant^{-1}. Similar result was reported by Ntui, *et al.* (2006).

In Sree Swarna variety, plant height, number of functional leaves plant^{-1}, number of primary branches plant^{-1} and height of branching had significant correlation with tuber yield while inter nodal length had negative correlation. Correlation analysis between yield and yield attributes revealed that number of tubers plant^{-1}, average tuber weight and tuber length had significant correlation with tuber yield. These findings are in agreement with results of Padma *et al.* (2009).

In case of Vellayani Hraswa variety, plant height and number of functional leaves plant^{-1} had significant correlation with yield. All the yield attributes *viz.,* number of tubers plant^{-1} (0.807), tuber weight (0.732), tuber length (0.512) and tuber girth (0.494) at harvesting stage had positive and significant correlation with yield. Moreover, tuber length (0.620) and tuber girth (0.752) were highly correlated with tuber weight. A similar result was reported by Balashanmugham (1980).

In Kantharipadarppan variety, inter nodal length and functional leaves plant^{-1} had a positive significant correlation with yield while plant height had a negative correlation. These findings are in conformity with the reports of Rajendran *et al.* (1985). Correlation between yield and yield attributes revealed that number of tubers plant^{-1} and average tuber girth had a positive and significant correlation while average tuber weight and average tuber length had a negative correlation. This is in conformity with the findings of Magoon *et al.* (1972).

5.3 COMPARISON BETWEEN THE VARIETIES

There was no significant difference between tuber yield of all the varieties while significant difference was observed for biometric characters of all the varieties at each growth stages.

5.4 MULTIPLE REGRESSION ANALYSIS

The influence of plant growth characters on cassava yield established by correlation analysis confirmed empirically the inter relationship between yield and biometric characters. Models were built in order to predict yield with the help of minimum number of variables. Best prediction models were selected based on the significance of the model, R^2, adjusted R^2 and C_p, which explains the variation in dependent variable due to independent variables.

5.3.1 Sree Jaya

The best yield prediction models were estimated using biometric characters as independent variables and tuber yield as dependent variable and the best estimated linear and non linear model were obtained at fifth month is,

$$Y = 3.81+.163pb_5+.532in_2+.482pb_4^{*}-.811in_3^{*} \quad R^2= 50$$

$$\log y = 1.69+.171\log(pb_5)-.479\log(in_3)-.570\log(fl_2)^{*}+.438\log(pb_4)^{*} \quad R^2= 56$$

where, pb: number of primary branches, in: inter nodal length and fl: number of functional leaves.

It was observed that the partial regression coefficient using data of previous months and current month in the fifth month were significant. The percentage of variation explained in total yield by the above biometric characters in linear and non linear was 50 and 56 per cent respectively.

5.3.2 Sree Vijaya

In the case of Sree Vijaya variety, the partial regression coefficients corresponding to inter nodal length at second and fifth month, number of functional leaves at second month and plant height at fifth month were statistically significant in linear model and highly contributing to tuber yield and explained 58 per cent variation in yield. In case of non linear model, inter nodal length at second and third month and number of functional leaves at fifth month had significant effect on yield with R^2 of 59 per cent. The models developed are furnished below,

$Y= -7.78+.763in_2^*+.072fl_2^*+.018pl_5^*+.563in_5^*-.531in_4$ R^2= 58 per cent

$\log Y= -3.36+.64 \log(fl_5)^*+1.56 \log(in_2)^*+1.28 \log(fl_2)+.534 \log(in_5)-1.50 \log (in_3^*)$ R^2= 59 per cent

where, pl: plant height , in: inter nodal length and fl: number of functional leaves.

5.3.3 Sree Swarna

Results of prediction models for Sree Swarna variety indicated that, pre-harvest prediction of cassava yield is possible at fifth month with the help of inter nodal length at second and third month and number of functional leaves plant^{-1} at fifth month as explanatory variables both in linear and non linear models and the same are furnished below,

$Y = -.509+1.05in_3^*-.852in_2^*+.031fl_5^*$ R^2= 43 per cent

$\log Y= -1.43+.906 \log(fl_5)^* -1.32\log(in_2)^*-.261 \log (lai)+1.56 \log (in_3)^*$ R^2= 47 per cent;

where lai : leaf area index, in: inter nodal length and fl: number of functional leaves.

5.3.4 Vellayani Hraswa

In the case of Vellayani Hraswa variety, the partial regression coefficients corresponding to plant height at fourth month and number of functional leaves plant^{-1} at second month were statistically significantly contributing to linear model of tuber yield and explained 35 per cent variation in yield. In case of non linear model, plant height at second and third month and number of functional leaves plant^{-1} at second month had significant effect on yield with R^2 of 40 per cent. The models are furnished below

$$Y= 5.52-.049pl_4^*+.074fl_2^* \qquad R^2= 35 \text{ per cent}$$

$$\log Y= 1.12-4.14 \log(pl_4)^*+1.64 \log(fl_2)^*+2.57 \log (pl_3)^* \qquad R^2= 40 \text{ per cent}$$

where pl: plant height and fl: number of functional leaves

5.3.5 Kantharipadarppan

Results of prediction models for the local variety Kantharipadarppan revealed that, pre- harvest prediction of cassava yield is possible in fifth month with the help of plant height at third month and number of functional leaves plant^{-1} at fourth month using linear model and plant height at fourth month and number of functional leaves at fifth month on the basis of non linear model. The models developed are,

$$Y= 5.60-.024pl_3^*+.014fl_4^* \qquad R^2= 34 \text{ per cent}$$

$$\log Y=-2.24-1.14 \log(pl_4)^*+.438 \log(fl_5)^* \qquad R^2= 32 \text{ per cent}$$

where pl: plant height and fl: number of functional leaves

Results of multiple regression analysis were in agreement with the findings of (Kumar *et al.*, 2007) who reported that growth and yield characters were used separately for developing yield prediction models.

5.3 TREND ANALYSIS OF CASSAVA PRODUCTION IN KERALA

The share of area under cassava in Kerala to all India area declined from 85.57 to 45.5 per cent in 2001-02. In sixties, 90 per cent of all India production was from Kerala, but it was reduced to 37.9 per cent in 2001-02. With the introduction of short duration varieties, there was an increase in productivity, but not up to the level of Tamil Nadu and north eastern states like Meghalaya. In this context, it is better to have an idea about the present trend in area, production and productivity of cassava in Kerala for which the last twenty five years data starting from 1991-92 to 2014-15 was used. Usually exponential model provides a better understanding in trends in these characteristics. Moreover, cassava generally grows under area that receives normal rainfall. The variable, rainfall is also incorporated in the model to understand the effect of rain fall on production and productivity of cassava.

Non- Linear models were fitted to the available data sets. Results of fitted trend equations revealed that there was a significant decline in area (CAGR= -1.37 %) with R^2 of 95 per cent, a non significant decline in production (CAGR= -.02 %) with R^2 of 40 per cent, a significant increase in productivity (CAGR= 1.3 %) with R^2 of 96 per cent and a significant increase in nominal price (CAGR= 3.5 %) with R^2 of 92 per cent.

5.4 INSTABILITY ANALYSIS

Instability analysis in area, production and productivity of cassava for a period of 25 years were carried out. Instability measures such as coefficient of variation, Cuddy-Della Valle index and Coppock index were estimated.

Instability was found to be more in productivity followed by area and production and found that Cuddy-Della Valle index provides best estimates for instability.

FUTURE LINE OF WORK

- Similar multiple regression strategy may also used for different crops for pre-harvest prediction.
- Most of the work on pre-harvest forecasting of yield on biometrical characters is fitted using linear models. Since some of the biometrical characters may be related to yield in non linear form, hence it is better to explore non linear models for pre-harvest forecasting.
- For effective and essence of results in deciding the appropriate growth models, data for a long period can be made use.

Summary

6. SUMMARY

The present investigation entitled "Pre-harvest forecasting models and Instability in production of cassava (*Manihot esculenta* Crantz.)" was formulated with the following objectives.

- To develop early forecasting models for yield of five major short duration varieties of cassava.
- To carry out trend and instability analysis on area and production of cassava in Kerala.

The study was mainly based on biometric characters and yield attributes of five major short duration varieties of cassava *viz.,* Sree Jaya, Sree Vijaya, Sree Swarna, Vellayani Hraswa and a local variety Kantharipadarppan for developing forecasting models. A field experiment was conducted at College of Agriculture, Vellayani and a simple random sample of 25 plants of each variety was selected from a total of 225 plants in the field. All the varieties were planted during March 2016 and harvested during August 2016. Biometric observations were taken at monthly interval. Correlation and multiple regression techniques (Stepwise) were performed to develop the best forecasting models. Secondary data on area, production, productivity and price of cassava for last twenty- five years was collected from the Department of Economics and Statistics, Government of Kerala. Non -linear models were used to estimate trend of cassava production. Instability measures such as coefficient of variation, Cuddy-Della Valle index and Coppock index were worked out to analyze the instability in area, production and productivity of cassava.

The salient findings of the study are given below

- Growth characters such as number of functional leaves plant^{-1}, number of primary branches plant^{-1} and height of first branching had a significant correlation with yield at all stages of crop growth.

- Yield attributes such as number of tubers plant^{-1}, average tuber weight and average tuber length had positive correlation with yield in all varieties.
- In prediction models of Sree Jaya, the best linear model was obtained using inter nodal length at 3 MAP and number of primary branches plant^{-1} at 4 MAP with R^2 of 50 per cent. The best predicted variables based on non linear models were number of functional leaves plant^{-1} at 2 MAP and number of primary branches plant^{-1} at 4 MAP with R^2 of 56 per cent.
- In case of Sree Vijaya, the best linear model was obtained for the pre-harvest prediction of yield, by using inter nodal length at 2 and 5 MAP and number of functional leaves plant^{-1} at 2 MAP and plant height at 5 MAP with R^2 of 58 per cent; based on non linear equations, the best model obtained was using inter nodal length at 2 and 3 MAP and number of functional leaves plant^{-1} at 5 MAP with R^2 of 59 per cent.
- Multiple regression models for the variety Sree Swarna showed that the best linear model obtained for prediction of yield was using inter nodal length at 2 and 3 MAP and number of functional leaves plant^{-1} at 5 MAP with R^2 of 43 per cent; with non linear functions the best model obtained was using inter nodal length at 2 and 3 MAP and number of functional leaves plant^{-1} at 5 MAP with R^2 of 49 per cent.
- The best linear model obtained for prediction of yield in the variety Vellayani Hraswa was using number of functional leaves plant^{-1} at 2 MAP and plant height at 4 MAP with R^2 of 35 per cent; with non linear equations the best model obtained was using number of functional leaves plant^{-1} at 2 MAP and plant height at 2 and 4 MAP with R^2 of 40 per cent.
- The best linear model obtained for prediction of yield in the local variety Kantharipadarppan was using number of functional leaves plant^{-1} at 4 MAP and plant height at 3 MAP with R^2 of 34 per cent; with non linear equations the best model obtained was using plant height at 4 MAP and number of functional leaves plant^{-1} at 5 MAP with R^2 of 33 per cent.
- The estimated trends in area, production and productivity of cassava, using semi log function revealed that there was a significant decline in

area with a compound annual growth rate of 1.37 %, non significant decline in production by -0.02 % and a significant increase in productivity by 1.3 %.

- Climatic factor rainfall was found to be non significant for the last 25 years which means that change in area, production and productivity trend was not due to the effect of climatic factors on cassava cultivation.
- Instability analysis in area, production and productivity of cassava indicated that Cuddy-Della Valle index provides the best estimates and instability was found to be more in productivity (4.04 %) followed by area (3.98 %) and production (0.80 %) .

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Abstract

PRE- HARVEST FORECASTING MODELS AND INSTABILITY IN PRODUCTION OF CASSAVA

(*Manihot esculenta* Crantz.)

by

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ABSTRACT

The study entitled "Pre-harvest forecasting models and Instability in production of cassava (*Manihot esculenta* Crantz.)" was conducted at Instructional Farm, College of Agriculture, Vellayani during 2015-2017 with the objectives to develop early forecasting models for yield of five major short duration varieties of cassava and also to carry out trend and instability analysis on area and production of cassava in Kerala.

The study was based on both primary and secondary data. The varieties Sree Jaya, Sree Vijaya, Sree Swarna, Vellayani Hraswa and Kantharipadarppan were grown in Randomized Block Design with three replication in a spacing of 90 cm x 90 cm. Twenty five plants were randomly selected and monthly observations were recorded for all the varieties on biometric parameters. Yield and yield parameters were recorded at harvest. Secondary data on area, production and productivity over a period of twenty five years (1992-2016) were collected from published sources of Directorate of Economics and Statistics, Government of Kerala and State Department of Agriculture.

In order to give an idea about the behavior of the biometric observations and yield of the plants, summary statistics including mean, standard deviation, minimum and maximum were worked out for all variety at each growth stage.

Inter correlations were worked out between growth parameters and yield and the results showed that the number of primary branches, height of branching and number of functional leaves had positive and significant correlation with yield while correlation between yield and yield attributes revealed that number of tubers and average tuber weight were positively correlated with yield.

Multiple linear regression and non linear regression analysis were carried out for all the varieties using yield as dependent variable and biometric observations as independent variables. Stepwise regression was performed and

significantly contributing biometric characters were selected using R^2, Mallow's C_p and t-values for predicting the yield.

Among various linear regression equations the best model obtained for the prediction of yield in Sree Jaya was using inter nodal length at 2 and 3 MAP and number of primary branches at 4 and 5 MAP with R^2 of 50 per cent and based on non linear equations the best model obtained was using number of functional leaves at 2 MAP, number of primary branches at 4 and 5 MAP and inter nodal length at 3 MAP with R^2 of 56 per cent.

Best linear model obtained for the pre-harvest prediction of yield in Sree Vijaya was by using inter nodal length at 2, 4 and 5 MAP, number of functional leaves at 2 MAP and plant height at 5 MAP with R^2 of 58 per cent. Non linear model obtained was using inter nodal length at 2, 3 and 5 MAP, number of functional leaves at 3 and 5 MAP with R^2 of 59 per cent

Best linear model obtained for prediction of yield in Sree Swarna was using inter nodal length at 2 and 3 MAP and number of functional leaves at 5 MAP with R^2 of 43 per cent and with non linear functions the best model obtained was with inter nodal length at 2 and 3 MAP and number of functional leaves at 5 MAP and leaf area index with R^2 of 47 per cent.

Best linear model obtained for prediction of yield in Vellayani Hraswa was using number of functional leaves at 2 MAP and plant height at 4 MAP with R^2 of 35 per cent and with non linear function the best model obtained was with plant height at 3 and 4 MAP and number of functional leaves at 2 MAP with R^2 of 40 per cent.

Best linear model obtained for prediction of yield in Kantharipadarppan was using number of functional leaves at 4 MAP and plant height at 3 MAP with R^2 of 34 per cent and with non linear equations the best model obtained was using plant height at 2 MAP and number of functional leaves at 4 MAP with R^2 of 33 per cent

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The estimated trends in area, production and productivity of cassava using semilog function revealed that there was a significant decline in area (CAGR= -1.37 %), non significant decline in production (CAGR= -.02 %), and a significant increase in productivity (CAGR= 1.3 %).

Instability in area, production, productivity and nominal price of cassava was also worked out using various measures and the results of the analysis shown that Cuddy-Della Valle index provides best estimates and instability was found to be more in productivity (4.04) followed by area (3.98) and production (.80).

The present study concluded that non- linear model provides better yield prediction model of cassava as compared to linear prediction model on the basis of R^2 and Mallow's Cp. Moreover, the biometric characters such as number of functional leaves and inter nodal length were the significant predictor variables in most varieties.

Appendices

APPENDIX 1

Weather parameters during the cropping period, March 2016 – August 2016

PERIOD	Maximum temperature (°C)	Minimum temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Evaporation (mm)
March	33.3	24.5	81.2	28.2	4.6
April	34.3	26	80.8	0	5.4
May	33.8	24.8	85	463.3	4.1
June	31.6	24.5	87.9	442	2.7
July	31.6	24.7	85.6	126.5	3.7
August	31.8	24.8	83.8	37.4	4.3
Average/ Total	32.73	24.88	84.05	1097.4	4.13