CROP-WEATHER-NUTRIENT RELATIONS IN CASSAVA UNDER DROUGHT STRESS

By
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(2014-21-103)

THESIS

Submitted in partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRONOMY
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ACKNOWLEDGEMENT

The realization of this thesis wouldn't have been possible without the benevolence of my parents, blessings of my teachers and help of my friends.

. It gives me immense pleasure to express my profuse and deep sense of gratitude, and sincere thanks to my Major advisor and Chairman of my Advisory Committee **Dr. Meera V. Menon,** Professor and Head, Department of Agronomy, for her invaluable expert guidance, constructive suggestions and painstaking efforts for going through this manuscript and mostly the profuse inspiration and encouragement which stood me in a good stead for the entire period of my study. My glossary sinks below zero to express emotions towards her for her outlook, generosity, simplicity and friendliness in understanding my problems with patience par excellence.

I sincerely extend my profound gratitude and appreciation to the members of my Advisory Committee whose expertice went a long way in carrying out this investigation and bringing the thesis to the final form**.** The valuable suggestions, positive criticisms and wholehearted cooperation rendered to me by Advisory Committee members **Dr. G. Suja,** Principal Scientist (Central Tuber Crop Research Institute, Thiruvananthapuram), **Dr. T. Girija,** Professor and Head (Department of Plant Physiology), **Dr. B. Ajithkumar**, Assistant Professor and Head (Department of Agricultural Meteorology) and **Dr. P. Prameela**, Professor (Department of Agronomy) are immeasurable.

I deem it my privilege in expressing my affection to my teachers, **Dr. C. T. Abraham, Dr.C. George Thomas, Dr. P. S. John, Dr. P. A. Joseph, Dr. P. Sreedevi, Dr. K. E. Savithri, Late Dr. E. K. Lalitha Bhai, Dr. K. E. Usha, Dr. K.P. Prameela, Dr. T. K. Bridgit, Dr. A. Latha, Dr. P. V. Sindhu, Dr. S. Anitha** and **Dr. J. S. Bindhu**, for their excellent teaching and guidance, which enabled me to complete my course work and research.

I am deeply obliged to **Dr. S. Krishnan, Dr. T.K. Ajitha** and **Mr. Ayoob K.C** (Department of Agricultural Statistics), **Dr. P.K. Sushama** and **Dr. Jayasree Sankar** (Department of Soil Science & Agricultural Chemistry) **Dr. P.K. Suresh Kumar** (Department of Agricultural Engineering), **Dr. Sharon C.L., Dr. Diji Bastin** and **Dr. S. Biju** (Academics) for their valuable help and relevant suggestions throughout the course of my study.

I am at a loss of words to express my love and gratitude to my mentor and well-wisher **Dr. R. Vijayalakshm**i and her husband **Dr Anandraj** for always considering me as their own and forever including me in their prayers.

I am deeply thankful to **Sreela chechi** and **Syamala chechi** for their unreserved cooperation, support, love and care during my study. I wish to express my sincere gratitude to **Deepika, Sophia, Vandana, Athira, Franklin, Sijith, Midhun, Nidhin** , **Shameer** (Farm managers and field staff of Dept. of Agronomy), **Sophi**a (Research Assistant, AICRP on Weed Control), **Dr. Mayadevi and Dr. Sindhu** (Soil Science & Agricultural Chemistry), **Mrs. Sheena** and **Mrs. Ammini** (Plant Physiology) and **Dr. Seena** (CTCRI, Thiruvananthapuram) for their sincere help during the research work.

I express my warmest thanks to my beloved friends **Radhu,** who I know is always there for me and **Rajesh chettan,** who put away all his busy schedule and found time to help out always, and **Viju mash**, **Sharu**, **Jayasree chechi, Sindhu chechi**, **Meera, Aswathi, Arya, Anshi, Aswini, Saneera, Reshma** and **Anoop** for their support, love and encouragement. Thank you for being my all time favorite cheerleaders.

I would like to express my love to my seniors **Asha chechi, Indhu chechi, Savitha chechi, Syama chechi**, my dearest classmates **Anusha, Rajanad bhai**, **Jayanth, Irene, Renuja** and **Thasni** my friends **Garggi chechi, Shilpa, Shobha, Saravanan, Chijina, Vandana and Rajkumar** for their sincere help, timely suggestions and mental support. I am happy to place on record my sincere thanks to the senior and junior students of Dept. of Agronomy for their countless help and support during the course of this study.

I am extremely delightfed to acknowledge my profound sense of gratitude to **labourers** of Agronomy Farm for their sincere help and cooperation during my field experiments.

I am forever beholden to my family for their prayers and support. I can never do justice in words to the moral support and unrelenting help I was given by my father **Dr. V.K Krishnankutty** and mother **N. Lila** in addition to their love, affection and unstinted encouragement throughout my study. My sincere words of thanks to my beloved Vellichan **Dr. Ramankutty**, Vellimma **Dr. Girija**, my father-in law, **Sri. Vijayaraghavan** and mother-in-law **Smt. Radhamma (Late**), for their constant support. I express my deep sense of gratitude to my brother, **Hari,** sister-in law, **Gayathri** their beautiful daughter **Ichu** and my sisters **Soum** and **Rem** for their unmatchable encouragement and love. I am deeply thankful to **Priya chechi, Sarin chettan, Ammachi, Chechumma** and **Seehan kuttan** for their love and care.

It is impossible to express my soulful gratitude to my husband **Rakesh Vijayaraghavan**, for his selfless sacrifice and unbounding love. Amidst his busy schedule he has been there for me as a beacon light to my faltering steps in every challenging situation. Diction is not enough to express love and affection to my son **Ambadi** for the time he had sacrificed for me.

I duely acknowledge the valuable help and services rendered by the staff of **Central Tuber Crops Research Institute**, Thiruvananthapuram.

I thankfully remember the services rendered by all staff members of **Computer Club, Library, Central Library** and **College Office.**

I am thankful to **Kerala Agricultural University** for technical and financial assistance for carrying out my study and research work. The award of **UGC Rajiv Gandhi National Fellowship** during the period of my study is gratefully acknowledged.

Above all I bow my head before the "**Almighty God** "who blessed me with health and confidence to undertake the work successfully.

Any omission in this brief acknowledgement does not mean lack of gratitude.

Sreelakshmi K.

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Introduction

1. Introduction

Environmental stress is becoming a serious issue as global climate change tends to unfold with respect to temperature and soil moisture in the tropics (IPCC, 2014). In order to meet future food demand, cultivation needed to be extended to poorer soil and more parched regions. Future increase in frequency and intensity of drought due to climatic change, especially in most agriculturally productive zones around the world is anticipated.

Cassava is one of the most important staple foods in the tropics and is ranked as the third most important calorie food in human diet after rice and maize. Cassava as a crop is well-known for withstanding challenging environmental conditions with little need for active agronomic management relative to other crops. In Kerala, cassava is an important crop and the state stands second in the country with a production of 26, 62,000 tonnes (FIB, 2018). The role of cassava in the food security of the state is more prominent today with ever declining area and production under rice. Presently, cassava is also gaining popularity as a connoisseur dish in high class restaurants. It is grown mainly as a rainfed crop, but planting is done throughout the year to ensure year long availability.

Cassava is mainly cultivated by small farmers and is well-known for its ability to produce reasonable yields on poor soils, in areas with low or erratic rainfall, and without agrochemicals and other external inputs. These “hardy” traits have made cassava highly suitable for low-input, small-scale agriculture, while its inherent potential has placed it among the crops most suitable for resource-poor farming in the tropics and neotropics under the climate change scenario of 21st century. Cassava can withstand relatively prolonged periods of drought. However, the crop is sensitive to soil water deficit during the first three months after planting. In southern India, its water requirement is put at 400 to 750 mm for a 300 days production cycle. But higher yields have been obtained with much higher levels of water supply. Water stress during later stages of crop growth causes reduced yield and quality of tubers. Little is known about the effect of inadequate water at different stages in varieties of varying duration and key information would to help choose varieties suitable to specific agro-ecological location.

Water is becoming scarce and expensive nowadays and necessitates utilization in a systematic manner. In situations where supplemental irrigation is not feasible, exploring other avenues for imparting drought tolerance is the alternative. Some nutrients have been reported to play important roles in imparting drought resistance to crops.

Of the mineral nutrients, K plays a critical role in the stomatal activity and water relations of plants (Mengel and Kirkby, 2001). Potassium ions have been reported to help in increasing osmotic adjustment, and silicon to improve root endodermal silification and to improve cell water balance. Decrease in photosynthesis caused by drought stress in wheat became particularly high in plants growing under K deficiency, but are only minimal when the K supply was adequate (Nezhadahmadi *et al.,* 2013).

Studies have shown that silicon application may increase tolerance to drought in plants (Bauer *et al.,* 2011). Silicon can affect biochemical, physiological, and photosynthetic processes and, consequently, alleviate drought stress. Natural silicates have the potential to mitigate environmental stresses Guntzer *et al.* (2012). Proline concentrations increased under lower water availability and higher Si availability in the soil, which indicates that Si may be associated with plant osmotic adjustment. Water deficit and Si application decreased total sugars and soluble protein concentrations in the leaves. Gong *et al*. (2005) found that application of silicon improved the water status of stressed wheat plants. Silicon was found to increase the water use efficiency in maize, and plants treated with 2 mmol L^{-1} silicic acid (Si) had 20 % higher WUE than plants without Si application (Gao *et al.,* 2005). Silicon application reduced stalk lodging and increased mean tuber weight and, consequently, potato tuber yield (Crusciol *et al.,* 2009).

Calcium is reported to be involved in plant tolerance to heat stress by regulating antioxidant metabolism and/or water relations. Plants treated with calcium under heat stress had higher catalase, glutathione reductase and ascorbate peroxidase activities than untreated plants of some cool-season grasses (Jiang and Huang, 2001). In potato, calcium was seen to mitigate the adverse effects of heat stress. Upadhyaya *et al.* (2012) reported that foliar application of calcium chloride showed some positive response in influencing growth and anti-oxidative responses during post drought recovery process in tea. Application of calcium also improved the cell membrane thermo stability under field conditions.

These nutrients, potassium, silicon and calcium could thus help in imparting drought resistance in periods of water stress and help in maintaining the productivity and quality of tubers.

With more attention given to cassava, it is expected to prevent further massive starvation and poverty in the coming years. In view of the above, an investigation was undertaken at the Agronomy Farm, College of Horticulture, Vellanikkara during 2015-16 and 2016-17 to find out the crop-weather-nutrient relation in cassava under drought stress. In this background, this study was planned with the following objectives

- To study the crop-weather relations in cassava under drought stress
- To identify varieties of varying duration under inadequate water in different seasons
- To study the effect of foliar application of potassium, silicon and calcium on growth and productivity of cassava under moisture stressed condition

Review of Literature

2. Review of literature

Drought is an extended period of dry weather characterized by a shortage of water. About 45 per cent of the world's geographical area occupied by 38 per cent of the world's population is adversely affected by drought (Bota *et al*., 2001). This stress is primarily brought about by either shortage of rain or by large variation in the amount of rainfall. Future increase in frequency and intensity of drought due to climatic changes especially in most agriculturally productive zones around the world is anticipated (Salinger *et al.*, 2005; Mir *et al.*, 2012). Cassava is an important root crop, which is inherently drought tolerant. However, cassava growth and yield can be decreased by prolonged dry periods (Alves, 2002). Water stress during initial stages of crop growth causes reduced yield and quality of tuber. Therefore, understanding the extent of drought stress and finding out devices to mitigate it is very crucial in changing climate. In situations where supplemental irrigation is not feasible, exploring other avenues for imparting drought tolerance is the alternative. Some nutrients have been reported to play important roles in imparting drought resistance to crops. Hence, the present field experiments were conducted to find out the effect of inadequate water at different stages in varieties of varying duration and to find out the effect of various nutrients in alleviating drought stress in cassava. The review of literature pertaining to it is presented in this chapter.

2.1. Effect of drought on tuber crops

Food productivity is waning due to the negative effects of various environmental stresses and therefore minimising these losses is a major area of concern to ensure food security under the changing climatic scenario. Given the significance of root per tuber crops, there is a need for greater understanding of the resilience of root per tuber species to water stress and how differently these crops respond to drought.

a. Growth of tuber crops under drought stress

According to Deblonde and Ledent (2001), drought decreases plant growth, shortens the growth cycle and reduces the number and size of potato tubers. Mahamud *et al.* (2014) indicated that plant height of potato was greatly affected by different degrees of drought. Mean reduction in plant height was 17.75 per cent and 7.30 per cent in severe droughts and mild drought compared to well watered condition.

Stress almost invariably increases the root/shoot ratio as a consequence of drastic reduction in vegetative growth (Cowan and Farquhar, 1977). Under stress, leaves might become thicker with smaller epidermal and mesophyll cells. Leaves were found to be highly sensitive to drought conditions (Clegg *et al*., 1978).

Reduction in stem and root growth was noticed under water stress situation, although most evident consequence of water stress in plants was the growth of roots in search of water into deeper layers of soil (Kaufmann, 1981).

Other adaptations include reduction in leaf hairs, abundance of coating such as cutin, suberin and resin, leaf rolling or folding and acceleration of the process of abscission (Slatyer, 1967). Effects of water stress on root crops are more pronounced at the time of root formation or root bulking (Porto, 1983).

With regard to the adventitious root, Pardales and Esquibel (1996) reported that the number of adventitious roots in cassava decreased during early season drought and if such condition prolonged, it reduced the number of adventitious roots that would differentiate into storage roots.

Significant difference at the leaf-level response to drought was reported in sweet potato and potato. According to Ravi and Indira (1999) sweet potato leaves wilt permanently at a much lower water potential than potato leaves and late-season drought was found to promote lignification of storage roots in sweet potato which later impeded their growth.

Ravi and Saravanan (2001) reported that majority of the root system of cassava laterally spreads up to 45 cm with maximum up to 2m depth in the soil under field condition. This make the crop to extract moisture stored in the soil. Ravi and Saravan (2001) noted a drastic reduction in foliage weight of cassava under water deficit stress conditions. According to Lahlou *et al.* (2003), drought stress reduced the total stem number of cassava by 28 per cent in the field.

Genetic characters of different species also determine drought tolerance in crops. Yam is considered to have better adaptation to early-phased drought as the young plants are capable of reducing transpiration through shedding of leaves and it can tap most of its moisture needs during initial stages from the mother tuber (Lebot, 2009).

Root or tuber crops have much potential in terms of water use efficiency (WUE) and nutrient content compared to other food crops. Studies have shown that potatoes produce more dry matter and protein per hectare than major cereal crops (Birch *et al.,* 2012). They are also considered as the most energy productive crops producing 5600 kcal per cubic metre of water, compared to 3860 in maize, 2300 in wheat and 2000 in rice (Monneveux *et al.*, 2013).

Among the anatomical characteristics that allowed survival during drought was the ability of cassava plants to develop deep roots. Extended period of drought was reported to reduce leaf area (Okogbenin *et al.,* 2013). Cassava and sweet potato was found to be sensitive to drought during storage root initiation.

b. Biochemical and physiological properties of tuber crops under drought stress

Chadha and Nayar (1994) observed that tuber crops possesses high photosynthetic ability and capacity to yield under poor and marginal soils and tolerate adverse weather conditions and can serve as substitutes for cereals due to their high carbohydrate and calorie content. The stomata of cassava were found to be particularly sensitive to vapor pressure difference and that they closed even before signs of water stress develop within the plant (Onwoume and Charles, 1994). According to Volaire and Thomas (1995), drought stress altered the production and partitioning of metabolically important non-structural carbohydrates (sugar, starch and sugar alcohols) in coleus.

Decline in stomatal conductance was reported in cassava leaves under water deficit stress conditions (Cayon *et al.*, 1997; Ravi and Saravan, 2001).

In potato, a positive turgor was maintained throughout the growth period during water stress condition mainly by the accumulation of chlorine and proline. Chlorophyll content in potato leaves was found to significantly decline under water stress (Nadler and Heuer, 1995). It probably helped the plant in altering cell wall elasticity or cell size (Heuer and Nadler, 1998).

There is a strong correlation between higher chlorophyll, carotenoids content and stress tolerance in plants. Rukundo *et al.* (2014) reported that drought resistant genotypes of different tubers showed higher chlorophyll content. It was observed that drought stress had a negative effect on yields of different genotypes of crop. The genotypes that were able to maintain their chlorophyll content were also able to maintain its yield potential (Khayatnezhad and Gholamin, 2012). From studies of Nuwamanya *et al*. (2014), changes in pigment properties were observed with 65 per cent reduction in total carotenoid and 40 per cent reduction in chlorophyll a content with no notable difference in chlorophyll b content under moisture stress.

Higher temperature acting in subsequent stages of potato plant development had negative effect on tuber fornation like deformation, germination, tuber sprouting in soil before harvest and tubers physiologically younger (Rykaczewska, 2004).

Proline and glycinebetain accumulates in higher plants in response to low water content. There they act as an osmoprotectant and maintain cell membrane integrity therby making the crop drought tolerant (Quan *et al*., 2004). Plants that can maintain adequate relative water content for a longer period of time under drought exposure will have the greatest likelihood of continued metabolic functioning and survival (McCann and Huang, 2008).

Under drought situation, prolibe acts as a signal that modulates mitochondrial functions, cell proliferation and reduction of photo inhibition (Szabados and Savoure, 2009). According to Legay *et al.* (2011), several studies in potato have demonstrated that drought stress led to the accumulation of osmotically active solute-proline.

c. Yield and quality of tubers under drought stress

With the imposition of drought stress, accumulation of tuber dry matter and final tuber yield of potato have been shown to decline (Levy, 1986). Emergence and tuberization were two critical periods where water stress most affects final tuber yield (Martinez and Moreno, 1992). Under water shortage conditions, cassava and other tuber crops experienced yield reduction comparable to drought sensitive species. Heuer and Nadler (1998) observed a reduction in protein content of potato during the onset of water stress.

Ekanayake and Collins (2004) reported that reduction in root dry matter could be considered as an indicator for drought. Deguchi *et al*. (2010) noted that high leaf/stem ratio coupled with high HI with low number of branches in potato contributed to a stable yield under drought environment.

Potato plants when subjected to water stress led to greater Ca^{2+} accumulation in tubers and reversed Ca^{2+} deficiency resulted in tuber necrosis (Lefevre *et al.*, 2012). Root quality of sweet potato was affected by prolonged soil water deficit. Storage root shape was affected by drought, causing distinctive unattractive fluting along the main axis. (Lethwaite and Triggs, 2012).

2.2. Cassava and climate

Cassava (*Manihot esculenta* Crantz *subsp. esculenta*) belongs to the family Euphorbiaceas, sub-family Crotonoidea and tribe Manihotae (Alves, 2002; Jennings and Iglesias, 2002). The crop is a native to tropical Americas with Northeastern and Central Brazil as the centre of origin (Allem, 2002). The crop is considered as poor man's crop and has been cultivated mostly for its starchy roots in several regions of the world.

Cassava is considered to inherently produce reasonable yield under adverse edaphic and climatic conditions (Howeler and Cadavid, 1983; Romanoff and Lynam, 1992). However, extreme environmental fluctuations imposed significant yield loss in the crop.

Cassava can be grown in areas ranging from humid to semi-arid conditions. It is considered to be drought tolerant but, several studies have found out that the crop is unable to withstand prolonged dry spell (Alves, 2002). The response of cassava to drought depends upon the duration and severity of water stress and the stages of development of the cultivar (Burns *et al.*, 2010).

2.3. Water stress response in cassava

The principal mechanisms that are supposed to control tolerance to drought in cassava include its sensitivity and response to changes in atmospheric humidity and soil water status (El-Sharkawy and Cock, 1984). According to Embrapa (1992) cassava leaves partially close their stomata under prolonged drought stress.

Cassava conserves water extended stress by reducing light interception, achieved through a reduced leaf canopy through restricted formation of new leaves, production of leaves of a smaller size, drooping of leaves, and leaf fall (Porto, 1983; El-Sharkawy and Cock, 1987).

Reduction in leaf area was found to conserve water in cassava, and this would lead to a reduction in total biomass and yield (El-Sharkawy and Cadavid, 2002). According to El-Sharkawy (2004), even though cassava has sparse fine root systems compared with other crops, it is capable of penetrating into deeper layers into soil under water stress.

In areas with only one rainy season or year, farmers usually planted as soon as rain starts-around April-May in the northern tropics and October-November in the southern tropics. Cassava can be planted throughout the year if rainfall is evenly distributed, but not during periods of heavy rain or drought (FAO, 2012).

2.4. Varietal variations and drought

Connor and Cock (1981) observed less leaf conductance in a drought tolerant variety M Mex 59 than M Col 22, which is a drought susceptible variety.

Cassava is subjected to highly varying temperature, precipitation, photoperiods and solar radiation in the tropics (Alves, 2002).The ability of the crop to grow in low fertile soil and to tolerate sporadic and seasonally extended drought episodes have led to cassava being regarded as a ‘ drought, war and famine’ crop (Pearce, 2007; El-Sharkawy, 2004). Even though cassava is considered as a drought tolerant crop, prolonged dry periods tend to reduce its yield and quality (Alves, 2002).

Cassava can come up well in low rainfall regions and the plant can survive prolonged dry periods. Its response to moisture stress is mainly by reducing transpiration, thereby conserving the soil-plant water status. Under extreme conditions, the plants shed their leaves and remain biologically active in contrast to other crops and put new canopies when stress condition is removed.

Yield reductions depend on duration of water deficit and are determined by sensitivity of a particular growth stage to water stress (Alves, 2002).

Several reporters have suggested that the critical period for water deficit effect in cassava is from 1-5 months after planting *i.e.*, the stages of rapid leaf growth, root initiation and tuberization (Ghosh *et al.*, 1988; Pardales and Esquibel, 1996; Agili and Pardales, 1997; Alves 2002). According to El-Sharkawy *et al*. (1992a), prolonged periods of drought (more than 2 months) at these stages can cause storage root yield decrease of 32-60 per cent.

Photosynthesis of M_4, the most popular cultivar in India was reduced drastically under moisture stress (Ramanujam, 1990) compared to other high yielding varieties like H-226, H-1687 and H-2304. In the same study he reported that variety S-856 could be suggested as a drought tolerant variety compared to other varieties, which responded with a yield reduction of 27-42 per cent.

HCN content is considered to be influenced by the age of the plant. Indira *et al*. (1994) reported that in M_4 variety, the leaf HCN content was maximum during 9th month. In high cyanide clone (Ce-22), the leaf HCN content increased with the advancement of age and there was no significant decrease in tuber HCN.

During water shortage, staygreen genotypes are able to retain more green leaf area, potentially intercepting more solar radiation and increasing their productivity than their non-staygreen counterparts (Hortensteiner *et al.*, 1998).

Varieties responded differently to adverse conditions. In a study conducted by Santisopasri *et al.* (2001), KU-90 and KU-50 recovered quickest after stress condition was achieved. According to Ravi *et al*. (2008), the degree of leaf shedding under water deficit condition varied among different cultivars.

El-Sharkawy and De Tafur (2010) proposed that storage root formation and subsequent filling process required greater amount of assimilates in shorter cultivars than in the taller ones. Based on the information, it was suggested by him that shorter cultivars, such as ‘Preta do Sul’ would be more likely to present lower productivity in water stress conditions than cultivars with greater height like ‘BRS Tapioqueira’.

According to Odubanjo *et al.* (2011), higher concentration of glucose and sucrose were present in tolerant genotypes compared to susceptible ones. Suja *et al.* (2011) reported that short-duration varieties utilized the prevailing favourable agro-climatic conditions efficiently. Nedunchezhiyan *et al.* (2012) reported that higher stomatal conductance was recorded in dry periods in cassava varieties like M-4,H-226, H-27 and Sree Vishakham. Duque (2012) reported that the genotypes which were favourably known for their stress tolerance showed a smaller reduction in biomass when compared to their susceptile counterparts.

Okogbenin *et al*. (2013) reported that cassava variety TMS30572 showed 30 per cent reduction in yield under drought stress. According to Turyugyenda *et al.* (2013), physiological and morphological analyses were conducted to assess the drought response of the two genotypes and confirmed the relative tolerance of MH 96/0686 and susceptibility of Nyalanda that had been observed in the field.

Zhao *et al.* (*2*015) reported that between the varieties SC-124 and Arg-7, SC-124 plants adapted a ‘survival’ mode under mild drought stress as evidenced by early stomatal closure and a reduction in the levels of various photosynthetic proteins and photosynthetic capacity. SC-124 plants were more capable of surviving prolonged severe drought than Arg-7.

Leaf relative water content in the water stress treatment remained at values similar to control throughout the experiment in the full set of 15 genotypes. Maintainance of RWC occurred while soil water content was depleted and growth was inhibited (Damour *et al*., 2010).

Vellayani Hraswa is an early duration variety with a growing period of 5-6 months duration. Eventhough the variety is high yielding with good cooking quality, it is reported to be drought susceptible (KAU, 2011).

2.5. Variations in morphological traits under drought

Higher plants are sessile and therefore have evolved or deviced mechanisms to survive a variety of environmental stress including drought (Rao *et al.,* 2006). These mechanisms are exhibited as either drought escape or drought resistance with resistance further classified into drought avoidance and drought tolerance (Price *et al.,* 2002).

a. **Root and shoot development**

Extensive root system is necessary for all crops to support early plant growth and to extract water from shallow soil layers. A signal cascade induced by roots to the shoots via xylem causes physiological changes under drought stress situation.

Hisao (1973) reported that the internodes produced during the dry spell are short, while those produced under well-watered condition are long. Cassava root development is influenced by drought, regardless of the time of incidence during its establishment period.

Pardales and Esquibel (1996) reported that water stress during early establishment period of the plant caused marked reduction in the number and total length of adventitious roots. Continuous drought throughout the establishment period would cause reduction in the root system and the potential storage root yield. Even though cassava is widely considered as a drought tolerant crop, it showed some degree of susceptibility to drought stress during its establishment periods. Cassava can extract slowly water from deep soils, a characteristics of paramount importance in seasonally dry and semiarid environments where deeply stored water needs to be tapped (El-Sharkawy, 2004). During water stress, fine roots of cassava extend for more than 2 m into deeper, wetter soil from where cassava can extract between 20 % and 40 % of its total water uptake (El-Sharkawy *et al*., 1992b).

Pardales and Yamauchi (2003) reported that formation and elongation of cassava's adventitious and lateral roots was reduced by soil moisture. During water scarcity, sparse fine roots of cassava capable of penetrating more than 2 m into deeper and wetter soil. This enable the plants to withdraw the stored water slowly thus enduring long periods of drought, although with reduced productivity (El-sharkawy, 2004).

Cassava has the ability to grow roots into deep soil zones during its long period of growth and extract deep soil water that is not accessed by other crop (Duque, 2012).

The cassava plants grow as shrub with the stem reaching heights of up to 4 m in some varieties or only attaining height of 1m or so in some of the dwarf varieties. The distance between the nodes varies with cultivar and also with environmental conditions. Cassava plants which have been through several dry spells can be seen to have series of long internodes alternating with a series of short internodes (Tan and Cock, 1979). Connor and Cock (1981), reported that stress reduced number of nodes were noted in cassava.

Ability of cassava to maintain adventitious root elongation under drought resulting in large horizontal spreading of root system under drought was found to help the plant to recover sharpely from drought and to have a fairly good yield performance.

Odubanjo *et al.* (2011) studied the response of stem diameter to varying water availability and found that the largest average stem diameter at 75 DAP for 100 per cent available water and conrol were 1.30 and 0.90 cm respectively.

Duque (2012) reported that well watered plants increased plant height by 25 per cent whereas, water stressed plant increased only by 2 per cent from 30 to 60 DAP.

b. The leaf response

Leaf growth in cassava is highly susceptible to water stress (Yao *et al*., 1988). Drought ignites a reduction in light interception through reduction in leaf canopy which is an adaptation to conserve water by reducing transpirational surface, thereby keeping the sink and demand well balanced with plant assimilatory capacity (Palta, 2000).

Leaf area index of cassava ranges from 4 to 8 depending on the cultivar and the atmospheric and edaphic conditions during crop growth, but at the onset of dry period it was noticed that cassava crop reduced its leaf area by producing fewer and smaller leaves by shedding older leaves.

According to Yao *et al.* (1988) drought affects leaf expansion in existing leaves, rate of new leaf appearance as well as restriction in leaf area development. Osiru *et al.* (1995) reported that after a decline during the dry season and followed by a second rainy season; leaf area may increase a second time, but may not be as high as in the first season. Drastic reduction in leaf area growth was reported by Itani *et al*. (1999).

Cassava leaf growth is highly sensitive to drought (Alves and Setter, 2000). Leaves of plants under stressed condition have the capacity to regain growth soon after re-watering (Alves and Setter, 2000). Calatayud *et al.*, (2002) reported that cassava plant has the ability to retain activity for photosynthesis by closing stomata in dry air and nearly complete stomatal closure during soil water deficit. According to El-Sharkawy and Cadavid (2002), cassava ameliorates loss in root yield through rapid recovery by forming new leaves, which increases photon interception and canopy photosynthesis.

Alves and Setter (2004) reported that leaves of cassava conserved available water and maximized water use efficiency of the crop during prolonged periods of drought. Under drought stress, leaf drooping resulted in reduced transpiration rates while the leaf maintained reasonable photosynthetic rates at a higher leaf conductance (El-Sharkawy, 2004).

The newly developed leaves exhibited higher photosynthetic rates compared to non-stressed plants (El-Sharkawy, 2004). Duque and Setter (2005) reported that under severe or extended drought, leaf buds slowly and naturally developed numerous young shoots in the vicinity of abscised leaf scars.

Short term water-stress was also found to arrest cell expansion, cell proliferation and the rate of new leaf appearance response that conserves photosynthate resources (Setter and Fregene, 2007). Cassava under non stressed plots showed an average leaf area index of 4.30, whereas stressed plots hardly reached 2.52 (IITA, 2007). This type of retort was perfect for survival of cassava in environments with frequent water deficit episodes interspersed with concise or broken rainfall patterns (Setter and Fregene, 2007).

Cassava also possesses strong leaf heliotropic response that allows leaves to track solar radiation early in the morning and late afternoon when the leaf-to-air water vapour deficit (VPD) is low. El-Sharkawy and Cock, (1990) observed that at midday when solar elevation was high and VPD was greatest, cassava leaves bend downward irrespective of soil water content and leaf turgor pressure. This helped in maximizing light interception and total canopy photosynthesis, when WUE was greatest and minimized light interception when WUE was least.

c. Leaf retention

According to Rosas *et al.,* (1976), leaves dropped as a percentage increase from high water treatment to low water treatment was recorded.

Increased longevity of leaves is a means to increase the productivity and quality of cassava. Cock (1984) suggested that simple visual evaluation of leaf retention could be used as a field selection criterion.

El-Sharkawy *et al.,* (1992a) reported that high retention or staygreen traits are positively correlated with drought tolerance. Cassava under drought situation reduced the production of new leaves and permited greater accumulation of photosynthates in the roots and thus increased the harvest index (El-Sharkawy *et al.,* 1992b).

Harvest index and leaf retention were found to be strongly correlated with fresh root and root dry matter yield (Vencovsky and Barriga, 1992). De Tafur *et al.* (1997) reported that cassava grown under rainfed conditions showed reduction in leaf area index due to drought stress.

Substantiating this report, Lenis *et al.* (2006) found that the harvest index was found to be less in clones without the leaf retention trait. Increased leaf retention was found to increase the total photosynthates and thereby increased the total biomass production.

Leaf retention trait was advantageous for total biomass production under extremely long drought conditions. Other crops like sorghum and sunflower also exhibited staygreen trait, which was associated with drought tolerance (Borrell *et al*., 2000).

Ekanayake and Ginthinguri (2000) reported that optimal leafiness for varieties was required for the attainment of high yield under high and low stress conditions. According to Ravi and Saravan (2001), the degree of leaf shedding under water deficit condition varied among cultivars.

Leaf number, LAI and canopy area were found to be positively related to the amount of rainfall, but negatively correlated with evaporation and solar radiation. Storage root growth in cassava was limited by the source or leaf area index rather than by the sink strength of the roots (Lenis *et al.,* 2006).

Studies by Setter and Fregene (2007) have found that cassava genotypes with greater leaf retention have better yield performance under varying degrees of stress.

Stay green score (SCG) is considered to have a relation with water table depth and weather variables. The lower the SCG the better the stay green ability of the crop. In a study conducted at Alabata, the SGS was negatively correlated with water table depth (Gregerse *et al.,* 2013).

2.6. Physiological and biochemical response in cassava under drought

The interaction and adaptation of plants to environmental signals and stresses is a complex network model (Shwani *et al.,* 2010). Cassava is considered to have inherent ability to tolerate drought by means of various mechanisms.

a. Stomatal conductance and photosynthesis

Ramanujam (1990) studied the effect of moisture stress on interception of radiation, net photosynthetic rate (Pn), dry matter production and tuber yield of eight cassava cultivars for two seasons and observed reductions in LAI (18-40 %), light interception (42-70 %), Pn (24-56 %), total dry biomass (25-36 %), and tuber yield (28-42 %) due to moisture stress depending upon the cultivar.

Sensitivity of cassava to abiotic stress resulted in stomatal closure in response to reduction in atmospheric humidty and increase in transpiration demand in the afternoon (Clark *et al*., 1991).

Cadavid *et al.* (1998) found that leaf water potentials at 06:00 h across all varieties were -0.39 and -0.40 MPa for the control and stressed plants, respectively. This was partly achieved by reducing total leaf area, thereby reducing total canopy transpiration and by slow withdrawal of water from the deeper layers of the soil profile. Thirty one per cent reductions in leaf incidence under water stress were reported by De Tafur *et al.* (1997).

When under water stress, cassava stomata are exceptionally sensitive to leaf to air vapour deficit. This helps to maximize water use efficiency during prolonged periods of drought. Leaf photosynthetic rates of various cassava varieties subjected to water stress in the field were significantly and positively correlated with the activity of the C_4 enzyme PEPC in extracts of the same measured leaves (El-Sharkawy *et al.*, 1993).

An important physiological mechanism of cassava leaves is their ability to partly close their stomata in response to water stress. An average of 43 % reduction in leaf conductance to water vapour in stressed plots and consistent reduction over the stress period, compared to the control was observed. The partial closure of stomata enabled cassava leaves to maintain, to some extent, the midday leaf water potential at levels comparable with those of cassava leaves in the control plot (El-Sharkawy, 2004).

According to Duque and Setter (2005), under drought stress cassava exhibited to significantly decline leaf water potential by rapidly decreasing stomatal conductance thereby protecting photosynthetic apparatus.

An important mechanism that enables cassava to withstand severe water stress is its ability to maintain a pre-dawn leaf water potential comparable with that of unstressed cassava. Most notable among these characteristics are the high photosynthetic capacity of cassava leaves in favourable environments and the maintenance of reasonable rates throughout prolonged water deficits, a crucial characteristic for high and sustainable productivity. Cassava possesses a tight stomatal control over leaf gas exchange that reduces water losses when plants are subjected to soil water deficits as well as to high atmospheric evaporative demands, thus protecting leaves from severe dehydration (El-Sharkawy, 2004).

According to Setter and Fengene (2007), described cassava as isohydric, since it maintaince a relatively high water potential coupled by a relative water content under stress

Samarah *et al*. (2006) reported that decrease in photosynthetic activity under drought stress may be due to stomatal or non-stomatal mechanisms.

Drought tolerant cultivar showed high stomatal diffusive resistance, low transpiration rate, higher relative water content and retained minimum number of leaves to support tuber growth during moisture stress (Bansal and Nagarajan, 1987).

According to Zhang *et al.* (2010), a reduction in photosynthesis and transpiration rate was noticed under water deficit condition. Damour *et al.* (2010) suggested that acute sensitivity of stomata to minor decrease in leaf water potential during periods of water stress as has been observed in other species.

Turyuagyenda *et al.* (2013) reported that reduced water loss through partial stomatal closure made a major contribution to drought tolerance of a drought tolerant cultivar.

b. Phytohormone and osmotic adjustment

Sundaresan and Sudhakaran (1995) reported 25 fold increase in proline in a drought susceptible cassava variety (M_4), while the increase was about 9 fold in drought tolerant variety (S-1315). ABA is found to manipulate the plant morphological features to cope up with extreme drought episodes (Okogbenin *et al.,* 1997).

Drought stress results in an increase in free proline synthesis. Several studies reported that sensitivity of plants to water deficit is correlated with changes in ABA concentrations (Borrell *et al*., 2000).

Under drought condition, changes in ABA concentration within plant organs and tissues play an important role in sensing changes in soil water and atmospheric humidity (Schachtman and Goodger, 2008).

According to Alves and Setter (2000), ABA was also involved in certain biological functions such as expression of dehydrins and other proteins that are thought to stabilize macromolecular structures. Alves (2002) reported that accumulation of ABA at an early phase of water deficit was followed by rapid cessation of leaf expansion, growth and transpiration. Plants accumulated different types of organic and inorganic solutes in cystosol to lower osmotic potential thereby maintaining cell turgor (Rhodes and Samaras, 1994).

The maintenance of leaf turgor during drought may also be achieved by the way of osmotic adjustment in response to the accumulation of proline, sucrose, soluble carbohydrates, glycinbetaine and other solutes in cytoplasm improving water uptake from drying soil. Out of this, proline is the most common indicator for drought tolerance. Similar study was reported by Levy *et al*. (2013), where there was 8-27 fold increase in proline content in fully wilted potato leaves. Proline concentration has been found to be higher in stress tolerant crops than in stress sensitive plants.

During water stress, several alterations were found in the metabolism of proline in cassava and the extent of alteration varied between drought susceptible and tolerant cultivars (Sundaresan and Sudhakaan, 2006).

According to Szabados and Savoure (2009) proline acts as a signalling molecule, which influences cellular functions of the plant and triggers specific gene expression, which can be essential for plant recovery from stress. Enhanced accumulation of proline under drought during flower initiation stage was reported in canola by Din *et al.* (2011).

Antioxidant enzymes act as a defensive system in plants. It can be considered as a internal protective enzyme-catalyzed clean up system (Horvath *et al.,* 2007). The enzymatic and non-enzymatic antioxidant enzymes were evolved by plants to minimize oxidative stress. According to Yang *et al*. (2009), increased activities of antioxidants were exhibited in 25 per cent field capacity compared to 100 per cent field capacity in *Populus cathayana* and *Populus kangdingensis.* The capability of antioxidant enzymes to scavenge ROS and reduce the damaging effects may correlate with the drought resistance of plant.

According to Odubanjo *et al.* (2011), ABA content increased substantially early in the stress episode (15 DAP) in fibrous roots and stem. ABA response to drought in cassava is genotype dependent (Okogbenin *et al.*, 2013). Zhao *et al.* (2015) identified drought responsive proteins like aquaporin, myo-inositol, 1-phosphatesynthase and a number of proteins that are involved in antioxidant system and secondary metabolism. Linamarin was also found to play a role in nitrogen reallocation in cassava under drought episodes.

Bardzik *et al.* (1971) reported that in situation of water deprivation, maximum foliar extractable nitrate reductase (NR) activity has been found to decrease in various plants. According to Heuer and Nadler (1998), drought stress induced proline biosynthesis and increased proline content to 86.70 per cent in comparison to control.

Azedo-Silva *et al.* (2004) observed that nitrate reductase activity in sunflower decreased under drought stress. According to Gupta *et al.* (2011), nitrate reductase could be involved in synthesis of nitric oxide as nitrate reductase is known to be a major enzyme in nitric oxide synthesis in plants.

Zhao *et al.* (2015) reported that nitrate reductase and sucrose synthase were among the most strongly correlated protein in the stressed leaves, although the plants were expected to have reduced levels of nitrate uptake and glucose formation from photosynthesis.

Reduced root cyanogen levels were associated with elevated root nitrate reductase activity, presumably to compensate for the loss of reduced nitrogen from cyanogen (Zidenga *et al.*, 2017).

2.7. Cassava yield under drought

Moisture stress during 3-5.5 month of crop growth reduced tuber yield by 32 per cent (Connor *et al.*, 1981), whereas moisture stress during any time of the initial 6 months period of crop growth reduced tuber yield by 60 per cent (Olivera *et al.*, 1982).

When there is prolonged moisture deficit during tuber bulking phase, leaf area index declines and potential productivity could not be attained for want of optimum canopy as suggested by Ramanujam and Birader (1987).

Aresta and Fukai (1984) reported that the cassava storage root development was sensitive to drought and photosynthesis and short term stress severely affected storage root yield.

Accrding to Ramanujam (1990), the stage of the crop most sensitive to moisture stress was tuberization. Kawano *et al.* (1978) suggested that high yield could be achieved by an optimum harvest index.

In cassava, bulk of the roots, 86 per cent and 96 per cent were confined to the upper 10 cm and 30 cm soil respectively. Majority of the root system laterally spread up to 45 cm with maximum up to 2 m depth in soil under field conditions, therefore prolonged water-deficit conditions resulted in poor establishment of the crop and leaf shedding (Ravi and Saravanan, 2001). But, El-Sharkawy and Cadavid (2002) reported that under drought conditions there will be delay in cassava development, but the final yield was little affected when compared to well watered plant.

Lenis *et al.* (2006) reported that clones with leaf retention trait produced more total fresh biomass and yielded 33 per cent more dry matter than plants without the trait. Under stressed environment, cassava genotypes with greater leaf retention had better yield performance (Setter and Fregene, 2007). Aina *et al.* (2007) reported that reduction in storage yield depends on the duration of water deficit and was determined by the sensitivity of a particular growth stage to water stress.

The average number of tubers per plant was influenced by the percentage of water applied. According to Odubanjo *et al.* (2011), average cassava tuber yield under water stressed condition was found to be 4.56 t/ha compared to 28.15 t/ha obtained with hundred per cent available water.

According to Gregerse *et al.* (2013), cultivars with good maintenance of canopy parameters during mid-season drought and late season excess moisture could increase tuber yield.

2.8. Cassava starch-sugar quality under drought

Water availability early or late during plant development is critical for starch yield and quality. Good starch quality can be recovered if the plant growth was extended long enough to ensure complete maturity of the plant (Defloor *et al.,* 1998). According to Komor (2000), the export of sucrose from source to sink organs depended upon the current photosynthetic rate and concentration of sucrose in the leaf. Kim *et al.* (2000) opined that leaves under stress were subjected to limited photosynthesis and sucrose accumulation and this hampered the export of sucrose to the sink organs and ultimately affected the reproductive development of the plant.

Drought induced carbohydrate deprivation enhanced endogenous abscisic acid concentration and impaired the ability to utilize the incoming sucrose (Setter, 1990).

Santisopasri *et al*. (2001) reported that plants grown under initial water stress exhibited low starch content (1.2-3.5 % for 6 months) compared to those grown without initial water stress (20.4-25.9 % for 6 months). The influence of water stress on starch production seems to be dependent on the growth stages of the plant. The pasting temperature of cassava starch was found to be higher in crop with initial water stress compared to those without initial water stress.

Starch granules from the crop with initial water stress were smaller relative to those from the crop without initial water stress. Duque and Setter (2005) indicated that cassava relied heavily on its stored CHO reserves within its stem as well as petioles and were remobilized during drought stress episode providing a source of CHO for continued metabolic activity.

According to Pardales and Esquibel (1996), changing the growth condition such that the plants receive sufficient water would lead to impressive gain in root starch content. Duque (2012) found that reserves in leaf blades were limited and these reserves depleted rapidly during stress.

2.9. Cyanogenic glucosides in cassava under drought

Cyanogenic glucosides are phytotoxins that occur in about 200 plant species of which cassava and sorghum are of importance (Bruijin, 1971). According to Conn (1980), bitter taste and high levels of cyanogens can be related to environmental stress conditions, especially drought. Water stress was found to influence the amount of HCN content in cassava. O' Brien *et al.* (1991) reported that roots harvested during drought contained a higher concentration of cyanogenic compound compared to those harvested after the rain. In a study of ten cassava cultivars grown in different locations with varying rainfall found that the cyanogenic content was maximum at the driest place, Bokanga *et al.* (1994).

It is believed that cyanogens confer protection against the attack by some herbivores (Bellotti and Riis, 2003).

Santisopasri *et al.* (2001) reported that cyanide content was 96.60-253.80 and 70.30-119.10 µg/g respectively for peeled roots harvested after the initial drought at 6 months and after rain at 8 months of the crop with initial water stress.

Ernesto *et al.*, (2002) reported that the flour from cassava grown in years with average rainfall in Northern Mozambique contained an average of 40 ppm total cyanide compared with about 120 ppm in drought year. According to Bograd *et al.* (2011), cassava's cyanogenic potential exacerbated during drought.

2.10. Protein content under drought

Cassava leaves are a substantial source of protein. Leaf protein content of cassava ranges from 14 per cent to 40 per cent of drymatter in different varieties (Eggum, 1970). Cassava leaves contain more proteins, minerals and vitamins than tubers (Westby, 2002).

Parida *et al.* (2007) observed lower protein content in sensitive genotypes was recorded in cassava under drought compared to tolerant genotype. According to Zewdie *et al.* (2008), lower protein content in cassava may be the result of one or more effects of nitrogen mobility, uptake and assimilation.

2.11. Critical period of drought tolerance in cassava

There exists a positive correlation between total biomass and storage root biomass for cassava grown in a wide range of environment. However, during growth, there is distinct developmental phase.

There was a yield reduction of 32 per cent in cassava over control, when rainfall was with held for 10 weeks commencing 12 weeks after planting (Connor *et al.,* 1981).

According to Oliveira *et al.* (1982), critical period of cassava root yield extended from the first to the fifth MAP, which is the stage for root initiation and tuber bulking. Ghosh *et al.* (1988) reported that during the first 3 months, cassava accumulates dry matter more in the leaves than the stems and tuberous roots. After the third month, more was accumulated to the roots than the rest of the plants.

Porto (1983) reported that the more severe effect corresponds to stress during the period of rapid leaf growth and bulking rather than the later period of bulking.

2.12. Effect of mineral nutrition under drought stress

As cassava is known to grow in nutrient poor soils, it is often believed that cassava is a scavenger crop that is highly efficient in nutrient absorption from a low-fertile soil. Newly developed leaves were found to exhibit higher photosynthetic rate under proper fertilization (Cayon *et al.,* 1997).

Water stress is one of the major limitations to the agricultural productivity worldwide, particularly in warm, arid and semi arid parts of the world (Boyer, 1982). Increasing evidences suggest that mineral nutrient status of plants play an important role in drought stress (Marschner, 1995). A decline in soil productivity and fertility is globally noted and proper soil management has become the need of the hour (Gruhn *et al.,* 2000). Optimal nutrition and most favourable soil tillage greatly affect water circulation in plants thereby increasing uptake of mineral nutrients.

a. Nitrogen, phosphorous and potassium effects

Cassava as an exhaustive crop removes substantial amounts of nutrients with the harvested root (Howeler and Cadavid, 1983).

Cock *et al.* (1985) explained that the reasonable carbon uptake rates in the absence of NPK application was due to the lower leaf area per plant as well as lower LAI. Restricted new leaf formation with smaller size and lower specific leaf area (leaf area/unit leaf weight) allowed concentrated and sustainable leaf NPK contents.

According to Kathju *et al.* (1990), higher nitrogen application was found to increase nitrate reductase activity.

Several experiments and long term NPK trial substantiate the fact that cassava yields responded markedly to K, moderately to P and slightly to N application (CIAT, 1993).

In absence of NPK fertilization, production of reproductive organs (flowers, fruits and seeds) was enhanced and HI increased indicating phenology changes in cassava growing on infertile soils as previously observed (Pellet and El-Sharkawy, 1993).

Drought induced N deficiency leads to growth inhibition of plants. Lower rates of photosynthesis under limited N supply affects chlorophyll content and rubisco activity reduces the leaf production, individual and total leaf area (Toth *et al.*, 2002). Lawlor (2002) reported that plant metabolic processes, based on proteins, leading to increased vegetative, reproductive growth and yield are totally dependent upon the adequate supply of N.

Azedo–Silva *et al.* (2004) reported that stressed leaves of sunflower exhibited a reduction in nitrate reductase (NR), which is the first enzyme involved in the pathway of nitrogen assimilation and it increased with N supply. Water stress at seedling stage may lead to higher dry root weight, longer roots, coleoptiles and higher root/shoot ratio. Dhanda *et al.* (2004) suggested that the above mentioned parameters could be considered as a criterion for stress tolerance in crop plants.

Waraich *et al.* (2011) opined that the possible means of minimising the detrimental effect of drought was by improving water use efficiency with N supply.

Zhou and Oosterhuis (2012) reported that high concentration of N (32 mM, approximately 672 mg N/L water) at 22, 29 and 36 DAT was found to increased the super oxide dismutase (SOD) activity of cotton seedlings under water stress.

Phosphorous is important in plant bioenergetics. A component of ATP, P is required for photosynthesis. It is useful to apply a high P content fertilizer such as bone meal to help with successful root formation. Turner (1985) pointed out that P deficiency appeared to be one of the earliest effects of mild to moderate drought stress in soil-grown plants and it could be improved by external application of P (Molina and El-Sharkawy, 1995). Nybe and Nair (1986) reported that the root growth of black pepper has restricted under P stress. So application of P is advantageous for root formation which under drought situation helped to extract enough water for its growth and development.

Garg *et al.* (2004) emphasized the positive effect of P in improving growth under drought stress.Seed priming using P in barley improved germination rate (Ajouri *et al.*, 2004). Phosphorus improved root growth and maintained high leaf water potential (Palta, 2000).

Khanna-Chopra *et al.* (1980) emphasized the role of K nutrition under water stress resulting in an increase in nitrate reductase activity and other physiological parameters. Adequate quantity of K supply was essential for enhancing the drought resistance of the plants by improving their root permanence. K fertilization increased tolerance to stress in plants (Edwards, 1982).

Application of KCl spray at one per cent was found to increase the proline content and yield in brinjal (Hernandez *et al.*, 1993). Foliar spray of one per cent KCl increased plant height, leaf area index and dry matter production in green gram (Govindan and Thirumurugan, (2000).

Of the mineral nutrients, K plays a critical role in stomatal activity and water relations of plants (Mengel and Kirkby, 2001). Decrease in photosynthesis caused by drought stress in wheat became particularly high in plants growing under K deficiency, but were only minimal when the K supply was adequate.The root survival rate was strongly reduced in *Hibiscus rosasinensis*, at the lowest K supply and when water availability was limited (Egilla *et al*., 2001).

The beneficial effects of an adequate K supply was ascribed to the role of K in re-translocation of photo-assimilates in roots, which contributed to better root growth under drought stress. Trehan and Sharma (1998) reported that tuber yields of potato were significantly increased by soil and foliar application of potassium.

El-Ashry *et al.* (2005) suggested that potassium spray in wheat was found to reduce the negative effect of drought on growth and yield through its role in photosynthesis, protein synthesis, plant stomatal regulation and water use. Egilla *et al.* (2001) suggested that increasing the chloroplastic K^+ content with external supply of K, prevented photosynthetic inhibition under drought stress.

Under water stressed condition, yield of potato was found to be increased by application of K. High levels of K under 80 per cent available water gave significant values of dry matter content (El–Latif *et al*., 2011). Patil *et al.* (2010) also opined that foliar spray of 3 per cent KCl as stress reducing chemical, improved nitrate reductase activity in sugarcane.

Cakmak and Engels (1999) reported that plants suffering from environmental stresses like drought had a larger internal requirement for K. Alleviation of detrimental effects of drought stress, especially on photosynthesis was affected by sufficient K.

According to Indira *et al*. (1994), basal application of K alone or combination of N and P increased the tuber HCN, but combination of N, P and K significantly reduced the tuber HCN. Cakmak (2005) reported that under severe drought intensity K deficiency was observed to reduce the net photosynthesis of wheat seedlings.

Raza *et al*. (2012) conducted an experiment to study the response of wheat to foliar application of 1 per cent K at different growth stages (tillering, flower initiation and milking) under water limited environment.

b. Silicon

Silicon is the second most abundant element in soil after oxygen. It occurs in two major forms: silica and oxides of silicon, and both types exists in crystalline and amorphous forms such as quartz, flint, sandstone, opal and diatomaceous earths silicates. Silicon is found to improve plant growth and tolerance to abiotic and biotic stresses.

Liang *et al.* (2003) strongly suggested the involvement of Si in metabolic or physiological and structural activity in higher plants exposed to abiotic and biotic stresses. Ma (2004) studied the effect of silicon on water use efficiency and found the element to be beneficial.

Gong *et al.* (2005) found that application of silicon improved the water status of stressed wheat plants. Silicon increased the water use efficiency in maize and plants treated with 2 mmol/L silicic acid (Si) had 20 per cent high water use efficiency than plants without Si application (Gao *et al.,* 2005). Silicon application reduced stalk lodging and increased mean tuber weight and consequently potato tuber yield (Crusciol *et al.*, 2009).

Proline concentration increased under lower water availability and higher Si availability in the soil, which indicates that Si may be associated with plant osmotic adjustment. Water deficit and Si application decreased total sugars and soluble protein concentration in leaves.

Studies have shown that silicon application may increase tolerance to drought in plants (Bauer *et al.*, 2011). According to Guntzer *et al.* (2012) silicon fertilization by natural silicates has the potential to mitigate environmental stresses and soil nutrient depletion and can be used as an alternative to NPK fertilizers for maintaining sustainable agriculture. Silicon when applied under drought was found to reduce the photo-oxidative damage and maintain the integrity of chloroplast membrane (Waraich *et al.,* 2011).

Zaimenko *et al.* (2014) reported enhancement in drought resistance in wheat under different moisture regime by nanoparticles of natural mineral analcite. Analcite $[AlSi_2O_6]$-H_2O is a natural mineral of volcanic tuffs.

c. Calcium

Calcium is a major controller of plant metabolism and development (Poovaiah and Reddy, 2000). Calcium has a prominent role in maintaining cell structure. Calcium is reported to be involved in plant tolerance to heat stress by regulating anti oxidant metabolism and water relations.

Plants treated with calcium under heat stress had higher catalase glutathione reductase and ascorbate peroxidise activities than untreated plats of some cool- season grasses (Jiang and Huang, 2001).

Sadiqov *et al.* (2002) found that Ca^{2+} participated in signalling mechanisms of drought induced proline accumulation for osmotic adjustment.

Rawal *et al.* (2007) reported that Ca application improved the cell membrane thermo stability under field conditions and thus Ca mediated potato cultivation can withstand heat stress to improve productivity. Foliar application of calcium chloride showed some positive response in tea. Calcium also plays a role as calmodulin which controls the plant metabolic activities and enhances the plant growth under drought conditions.According to Jaleel *et al*. (2007) calcium chloride was found to increase the glycine betain content in *Cathranthus roseus* under moisture stress.

d. Organic manures

The beneficial effect of FYM in improving the tuber yield was due to the effect on soil productivity by raising the residual organic carbon (C) content, building up soil N, and hence increasing the CEC, decreasing the bulk density and resulting in a greater availability of water to plants, as reported by Prakash *et al*. (2002). Moreover, conjoint use of fertilizers and FYM can sustain the nutrient supply until the end of the crop growth period. According to Singh *et al*. (1995), the favourable effect of FYM may be partly due to an apparent N recovery of about 20 %. Organic farming systems were found to profit from the higher soil aggregates in dry years (Raupp and

Oltmanns, 2006). A higher crude protein content in cassava was reported when cassava was intercropped with legume (Cooke, 1978).

2.13. Agronomic practices on drought alleviation

Studies indicate that during periods of drought, yield increases with increasing amount of surface irrigation water applied (El-Sharkawy, 1993).

Paradales and Esquibel (1996) reported that when planted towards the end of rainy season, cassava benefited from supplemental irrigation during rainless period. Deng *et al.* (2000) reported that under semi-arid condition, building of level terraces enhanced water infiltration, raised the rainfall utilization rate and created high-yielding farmland, while also conserving soil and water. Maximum fresh root size was obtained when cassava was intercropped with maize and melon at a spacing of 1m x 1m (Eke-Okoro *et al.*, 1999).

According to Ujuanbi (2002), under drought condition, cassava emergence and growth were higher in ridge than zero tillage.Under dry condition; drip irrigation in cassava was found to be finest and more effective.

Odjugo *et al.* (2008) reported that soil moisture was higher in zero tillage followed by mound tillage. The yield in the ridge was higher than the mound by 22 % and in zero tillage by 46 %. Eke-Okoro *et al.* (1999) suggested that difference in weather conditions influenced the yield of cassava in sole and in intercrops.

Friedrich and Kassam (2009) opined that mulch cover in cassava plantation served as an insulating layer that reduced diurnal temperature variations and water evaporation under prolonged drought condition.

Good quality cassava stakes is of primary importance for high stem and root yields. High germination percentage of cassava is one of the most important factors for cassava production and depends upon the quality of the stakes as well as the growth conditions. Poor quality planting material is often linked with marginal growth and productivity of cassava. Therefore selection of stake is necessary for getting better root yield of cassava (Esa and Tan, 2012).

Drip irrigation makes more efficient use of water by providing small, frequent applications, which saves water while maintaining soil moisture at a level that is highly favourable to crop growth.

According to Odubanjo (2011) in moderate water scarcity area, drip irrigation with 50 % of available water could be used for achieving higher yields of cassava, whereas in areas where water is very scarce, drip irrigation with 25 % available water can be recommended to obtain yields higher than under T_0 with zero irrigation.

High yielding varieties with tolerance to biotic and abiotic stresses need to be planted. Stakes should be planted at a shallow depth of 5-10 cm, in heavy and wet soils, but slightly deeper in light textured and dry soils to avoid surface heat and lack of moisture (FAO, 2014).

This review may be considered as an effort to highlight the effect of drought in cassava and its mitigation strategy through mineral nutrition.

Materials and Methods

3. Materials and methods

The present study entitled “Crop-weather nutrient relation in cassava under drought stress” was carried out at the Agronomy Farm, College of Horticulture, Vellanikkara during May 2015 to April 2017.The main objective of the study were to understand the relation of crop to changing weather and to evaluate the effect of nutrients on extenuating drought stress. The studies were carried out in two experiments:

Experiment I: Crop- weather relations in cassava

Experiment II: Effect of foliar application of potassium, silicon, and calcium on growth and productivity of cassava in moisture stressed condition

The details of the materials used and the methods adopted for the study are presented in this chapter.

3.1. Details of the study area

a. Location

The experiments were conducted at the Agronomy Research Farm, College of Horticulture, Kerala Agricultural University. Geographically, the area is situated at 10 ^{o}31’ N latitude and 76 ^{o} 13’ E longitude and at an altitude of 40.3 m above the sea level.

b. Climate and weather

The site enjoys a typical humid tropical climate. Data on weather conditions that prevailed during the experimental periods are presented in Appendix I and II and illustrated in Fig**.** 1 and 2. During the period of the first experiment, a total of 5694.20 mm of rainfall was obtained; of which 2191.20 mm was received during the period of the first crop, 1809.60 mm during the second crop and 1693.40 mm during the third crop. The second experiment was conducted for 2 years, during which 514.10 mm was received in the first year, and 136.30 mm in the second year.

c. Soil

The soil of the experimental site is sandy clay loam in texture (Order: Ultisol). Physical and chemical properties of the soil are given in Table 1.

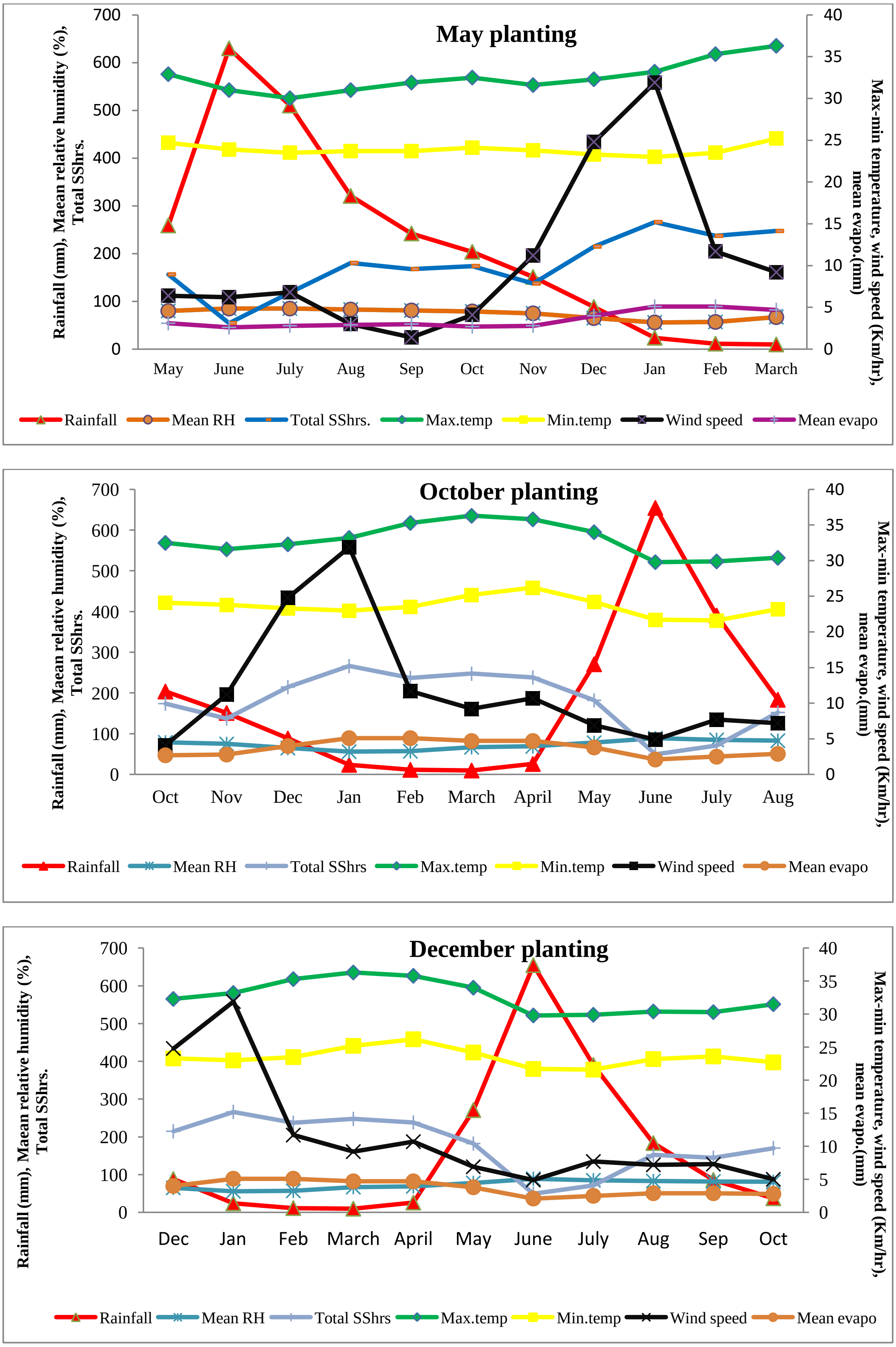


Fig. 1. Weather conditions during three plantings in 2015-16 seasons

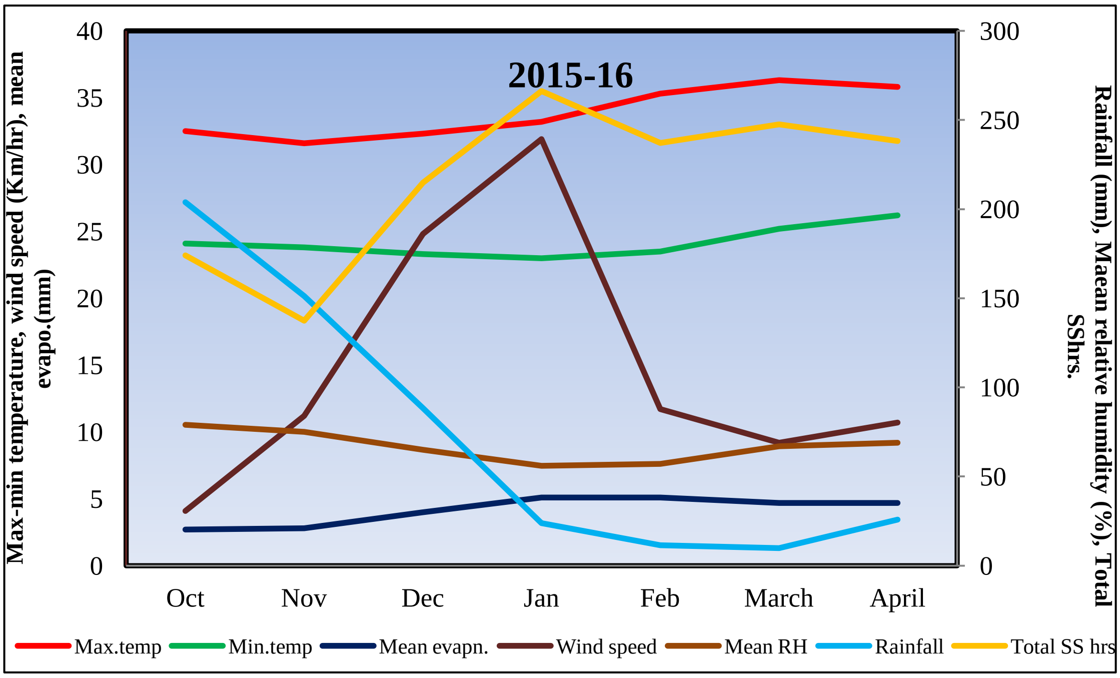


Fig. 2a. Weather conditions during 2015-16 cropping period (experiment II)

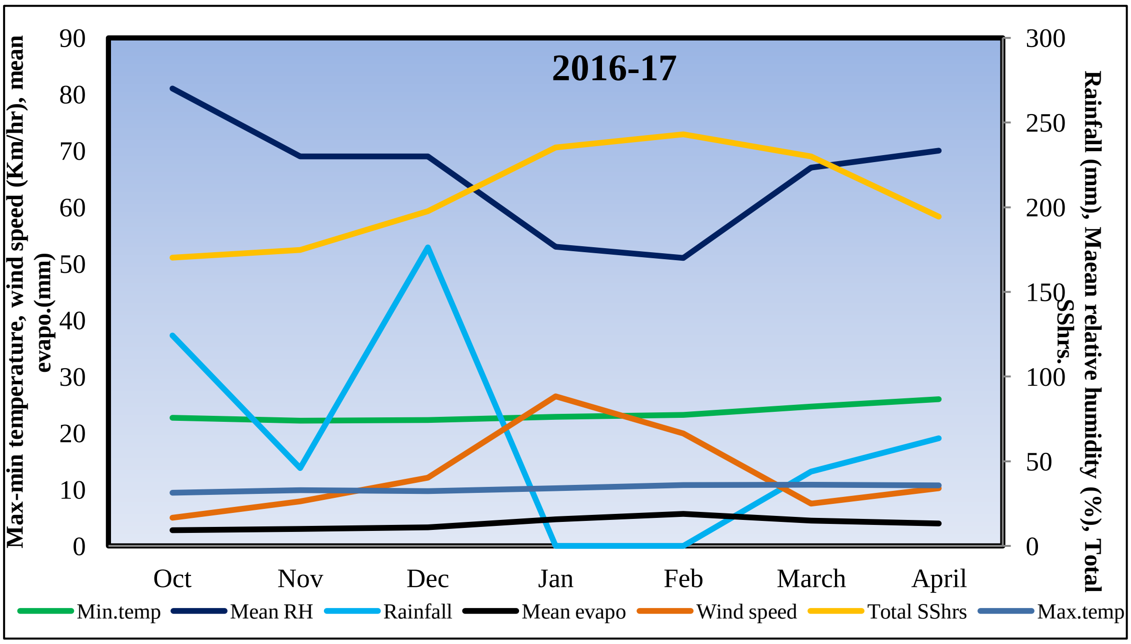


Fig. 2b . Weather conditions during 2016-17 cropping period (experiment II)

Table 1. Physico-chemical properties of soil

Particulars	Value					Method used
Particle size composition						
Sand (%)	56.40					Robinson international pipette method (Piper, 1966)
Silt (%)	18.45					
Clay (%)	22.91					
Field capacity (%)	12.30					Field method (Michael, 2009)
Permanent wilting point (%)	5.00					Sunflower Method (Michael, 2009)
Bulk density (Mg/m)	1.58					Core sampler method (Michael, 2009)
Chemical composition	**Experiment I**			**Experiment II**		**Method used**
	May planting	**Oct planting**	**Dec Planting**	**2015-16**	**2016-17**	
pH	4.70	4.80	4.20	4.50	5.50	1:2.5 soil water ratio Beckman glass electrode (Jackson,1958)
Organic carbon (%)	1.11	1.27	1.04	1.74	1.40	Walkley and Black method (Jackson,1958)
Available N (kg/ha)	244.00	246.20	190.70	157.20	173.10	Alkaline potassium permanganate method (Subbiah and Asija,1956)
Available P_2O_5 (kg/ha)	22.00	24.10	24.80	27.70	24.90	Bray-1 extractant Ascorbic acid reductant method (Watnabe and Olsen,1965)
Available K_2O (kg/ha)	236.10	234.80	310.00	312.40	315.20	Neutral Normal Ammonium Acetate extractant flame photometry (Jackson, 1958)
Exchangable Ca (meq/100g)	0.61	1.05	1.08	1.07	1.09	Atomic Absorption Spectrophotometry (Jackson,1958)
Exchangable Mg (meq/100g)	1.02	1.06	1.08	1.09	1.15	
Available S (mg/kg)	2.98	3.19	3.11	3.22	3.34	$CaCl_2$ extract-turbidimetry method (Chesnin and Yein, 1951)

3.2. Materials

a. Varieties

Two short-duration and two normal-duration varieties were grown in Experiment I. The details of the varieties are as follows:

1. **Vellayani Hraswa**: A high yielding, early variety, with 5-6 months duration, this variety cannot tolerate drought. The plants are dwarf with good branching characteristics. The tubers are reddish brown in colour with good cooking quality.
2. **Sree Vijaya:** This is a short-duration, high yielding variety released from Central Tuber Crops Research Institute, Sreekaryam. It is a selection from the germplasm of cassava. The variety recorded a yield of 25-28 t/ha and starch content of 25-30%. The tuber flesh colour turns light yellow after cooking.
3. **M_4:** This is an erect type with excellent cooking quality having 10 months duration. The starch content is 29 per cent.
4. **Sree Athulya:** This is a high yielding (39 t/ha) variety with high starch content (34.80 %).The tubers are normal and cylindrical, with brown skin and white flesh. Sree Athulya is ideal for cassava based industries due to higher tuber yield and higher extractable starch content.

All these four varieties were planted in three seasons (May, October and December of 2015) for experiment I. In experiment II, the short duration variety “Vellayani Hraswa” was selected and planted during October in 2015 and 2016.

b. Sources of planting material

The sources from which the planting materials were collected are given in Table 2.

Table 2. Source of planting material

Varieties	**Source**
T_1-Vellayani Hraswa	COA, Vellayani, Thiruvanathapuram
T_2-Sree Vijaya	ICAR-Central Tuber Crop Research Institute, Sreekariyam, Thiruvananthapuram
T_3-Sree Athulya	
T_4-M_4	Farmer, Vellanikkara

3.3. Experimental details

Two experiments were conducted during the course of study. The details of the experiments are given below:

a. Experiment I: **Crop-weather relations in cassava**

This experiment was conducted in the year 2015-16. Two cassava varieties each belonging to short (5 to 6 months) and normal (9 to 10 months) duration were planted in three seasons to study the effect of weather on growth and yield. The experiment was laid out in Randomized Block Design (RBD) with four varieties (Vellayani Hraswa, Sree Vijaya, M_4 and Sree Athulya) and four replications. The package of practices recommendations of the Kerala Agricultural University (KAU, 2011) was followed for raising the crops. The crops in the first two plantings were entirely rainfed. In December planting, irrigation was provided for two weeks to facilitate sprouting and to avoid prolonged dry spell.

Plate 1. Varieties used in experiment I at 3 MAP

N

a. May planting

R1T1	**R2T2**	**R3T3**	**R4T4**
R1T4	**R2T1**	**R3T4**	**R4T1**
R1T2	**R2T3**	**R3T2**	**R4T3**
R1T3	**R2T4**	**R3T1**	**R4T2**

b. October planting

R1T2	**R2T1**	**R3T3**	**R4T1**
R1T3	**R2T4**	**R3T1**	**R4T2**
R1T4	**R2T3**	**R3T2**	**R4T4**
R1T2	**R2T3**	**R3T4**	**R4T3**

c. December planting

R1T1	**R2T3**	**R3T4**	**R4T2**
R1T3	**R2T2**	**R3T2**	**R4T3**
R1T2	**R2T4**	**R3T1**	**R4T4**
R1T4	**R2T1**	**R3T3**	**R4T1**

5.4 m

Fig.3. Layout of Experiment I

5.4 m

Plate 2. General field view of experiment I

b. Experiment II: Effect of foliar application of potassium, silicon, and calcium on growth and productivity of cassava in moisture stressed condition

This experiment was conducted in 2015-16 and 2016-17. Cassava was planted in October and foliar application of potassium, silicon, and calcium was done to assess the drought mitigating effect. The experiment was laid out in Randomized Block Design (RBD) with 10 treatments, replicated thrice. The treatment details are given in Table 3.

Table 3. Treatment details of experiment II

Treatment No.	**Treatments**
T_1	POP*-12.5 t FYM + N,P,K @ 50:50:50 kg/ha
T_2	POP + 1 % KCl, 2 foliar sprays 3 and 4 MAP**
T_3	POP + 2 ppm silicic acid , 2 foliar sprays 3 and 4 MAP
T_4	POP + 0.1 % $CaCl_2$, 2 foliar sprays 3 and 4 MAP
T_5	POP + 1 % KCl + 2 ppm silicic acid, 2 foliar sprays 3 and 4 MAP
T_6	POP + 1 % KCl + 0.1 % $CaCl_2$, 2 foliar sprays 3 and 4 MAP
T_7	POP + 2 ppm silicic acid + 0.1 % $CaCl_2$, 2 foliar sprays 3 and 4 MAP
T_8	POP + 1 % KCl + 2 ppm silicic acid+ 0.1 % $CaCl_2$, 2 foliar sprays 3 and 4 MAP
T_9	POP + water spray, 2 foliar sprays 3 and 4 MAP
T_{10}	Water spray alone

*POP-Package of practices recommendations, **MAP-Months after planting

N

R1T1	R2T10	R3T5
R1T3	R2T7	R3T1
R1T5	R2T5	R3T2
R1T7	R2T9	R3T8
R1T9	R2T3	R3T6
R1T2	R2T1	R3T4
R1T4	R2T6	R310
R1T6	R2T4	R3T3
R1T8	R2T2	T3T1
R1T10	R2T8	R3T7

5.4 m

Fig.4. Layout of Experiment II (2015-16)

5.4 m

N

R1T2	R2T5	R3T7
R1T3	R2T7	R3T5
R1T1	R2T10	R3T8
R1T4	R2T9	R3T3
R1T6	R2T4	R3T1
R1T5	R2T8	R3T10
R1T7	R2T6	R3T6
R1T9	R2T2	R3T4
R1T8	R2T1	R3T2
R1T10	R2T3	R3T9

5.4 m

Fig.5. Layout of Experiment II (2016-17)

5.4 m

Plate 3a. General field view of first crop of experiment II (2 MAP)

Plate 3b. General field view of second crop of experiment II (3 MAP)

3.4. Field operations

The various field operations adopted from land preparation to harvest are detailed below.

a. Land preparation, manure and fertilizer application, and planting

The selected areas for the experiments were ploughed thoroughly with disc plough and worked with cultivator to produce fine tilth. The gross plot size was 5.4 x 5.4 m accommodating 36 plants and 16 net plants (Fig.3, 4 and 5). Manures and fertilizers were applied as per the package of practices recommendations (KAU, 2011). FYM @ 12.5 t/ha was applied uniformly during land preparation. Fertilizers were applied @ 50:50:50 N, P_2O_5 and K_2O kg/ha respectively in the form of urea, factomphos and muriate of potash in three split doses. Stem cuttings from mature healthy stems were collected from different sources (Table 2). Setts of 15-20 cm length and 5-6 nodes were planted in the centre of the mounds formed at a height of 0.5 m and spacing of 90 cm x 90 cm.

b. Irrigation

In experiment I, crops in the first two plantings were entirely rainfed. Irrigation was provided till sprouting of setts in the December planted crop, as well in experiment II in both years of experimentation.

c. Application of nutrient sources

In the second experiment, foliar applications of potassium, silicon and calcium @ 1%, 2 ppm and 0.1 % respectively, were done at 3 and 4 months after planting. Spray volume of 1200 l /ha was used.

d. After cultivation

Gap filling was done 2-3 weeks after planting. Two shoots were retained on each plant in opposite directions and excess shoots were removed about one month after planting.

e. Plant protection

Termite attack was a problem in the May planted crop. Chlorpyriphos @ 700 ml/ha was sprayed on the soil near the base of the crop at 30 days after planting. Cassava mosaic disease was noticed during the study period but its occurrence had hardly any effect on the yield of the crop.

f. Harvesting

Tubers were harvested at 6 months after planting (MAP) for short-duration varieties and 10 MAP for normal-duration varieties, when the lower leaves started to turn yellow. Harvesting was done manually by uprooting the plant and then removing tubers from the base. The upper parts of stems with leaves were cut and removed before harvest.

3.5. Observations

3.5.1. Growth parameters

From each net plot, four plants were selected at random and marked for recording the biometric observations like plant height, number of branches, stem girth and number of leaves at bimonthly intervals (2, 4, 6, 8 and 10 MAP). Destructive sampling was also done for recording total dry matter produced, root length and diameter, shoot and root fresh weight at periodic intervals of 2, 4, 6, 8 and 10 MAP. Yield and yield attributes were recorded at harvest for both the experiments.

a. Plant height

Plant height was measured from the baseline at ground level to the growing tip of the plant and the mean was expressed in cm.

b. No. of branches

Total number of branches was counted and the mean was recorded.

c. Stem girth

Stem girth was measured at 10 cm from the base and the mean was expressed in cm.

d. No. of leaves (leaf retention)

Number of leaves was counted on a per plant basis and the mean was recorded.

f. No. of leaf scars (fallen leaves)

The number of abscised leaves was estimated by counting the large scars left by the leaves on the stem and branches.

g. Dry matter production

At bimonthly intervals, two plants from each plot was uprooted and separated into leaves, stem and tubers. Fresh weight of each plant was recorded and the samples were cut into small pieces and later air dried in an oven set at 80-100 ^{o}C for a period of 48 hours till constant weight was achieved. Dry weight of each plant part was recorded and expressed as kg/ha.

h. Root length and diameter

Length from the base of the plant to the tip of the longest root was measured and expressed in cm. Diameter was taken by measuring the circumference at the broadest part of root.

i. Shoot weight and root fresh weight

Shoot and roots were separated from uprooted plants and fresh weight was measured. Mean was expressed in g/plant.

3.5.2. Growth indices

a. Leaf area index

Total leaf area of selected plants was measured using the equation, A= 0.9441*L $^{1.8985}$, where L is the length of the largest lobe (Alves and Setter, 2004). Leaf area index was expressed as the ratio of leaf area to unit land area (Hunt, 1982)

$$\text{Lea area index (LAI)} = \frac{\text{Leaf area}}{\text{Land area}} \times 100$$

b. Crop growth rate

It indicates the dry weight gained by a unit area of crop in a unit time and is expressed as g/m^2/day (Watson, 1956). It was calculated as

$$\text{Crop growth rate (CGR)} = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry weights of plants at times t_1 and t_2, respectively

c. Relative growth rate

Relative growth rate (RGR) is expressed as gram of dry matter produced by a gram of existing dry matter in a day *i.e.*, g/g/day (Williams, 1946). It is given as

$$\text{Relative growth rate (RGR)} = \frac{\text{Log}_e W_2 - \text{Log}_e W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry matter at times t_1 and t_2 respectively and Log_e is natural log.

d. Net assimilation rate

It is the increase in dry weight of plant per unit leaf area per unit time and expressed as $g/m^2/day$ (Williams, 1946).

$$\text{Net assimilation rate (NAR)} = \frac{W_2 - W_1 \, (\log_e L_2 - \log_e L_1)}{(t_2 - t_1)\,(L_2 - L_1)}$$

Where W_1 and W_2 are dry weights of whole plant and L_1 and L_2 are leaf area at t_1 and t_2 respectively.

3.5.3. Yield and yield attributes

a. Fresh tuber yield

After carefully pulling out the plants from the soils, the tubers were separated, cleaned and the fresh weights recorded. Average tuber yield per plant was then calculated based on yield from net plot and expressed as t/ha.

b. Tuber length

Length of medium sized tubers was measured and the average was computed and expressed in cm.

c. Tuber girth

Girth was taken by measuring the circumference at the broadest part of tuber and expressed in cm.

d. No. of tubers per plant

The tubers from the observational plants were separated, counted and the average number per plant was calculated.

e. Fresh tuber yield per plant

Average of fresh tuber yield/plant was calculated based on the weights of tubers of sample plants and expressed in kg/plant.

3.5.4. Physiological parameters

a. Photosynthetic rate

The photosynthetic rate was measured from each plot using Infra Red Gas Analyzer (IRGA). Observations at three stages were taken for normal-duration varieties and at two stages for short-duration crops at two months interval and expressed as μ mol $CO_2/m^2/sec$.

b. Stomatal conductance

Observations on stomatal conductance were recorded similar to those on photosynthetic rate using IRGA and expressed as mol $H_2O/m^2/sec$.

c. Nitrate reductase activity

Nitrate reductase activity in the leaves was determined colorimetrically as per the method suggested by Nicholas *et al.* (1976) at 2, 4, 6, 8 and 10 MAP.

d. Chlorophyll content

Chlorophyll content of leaves was calculated using the formula suggested by Yoshida *et al.* (1972). Fresh leaf samples were collected from each plot. Then a known weight from each sample was taken and the chlorophyll was extracted using dimethyl sulphoxide (DMSO). The intensity of colour was read using Spectronic 20 spectrophotometer at 663 nm and 645 nm.

e. Proline content

Free proline content in the leaves was determined colorimetrically as per the method suggested by Bates *et al.* (1973).

f. Leaf sugar content

Reducing sugar in the leaves was measured using 3,5-dinitrosalicylic acid (DNS) as described by Zhaofan (1985) and the absorbance was measured in a spectrophotometer at 520 nm wavelength.

g. Relative leaf water content

Relative leaf water content was measured using the fresh, physiologically active leaves collected from each plot. The leaves were then punched to form 50 uniform leaf discs and fresh weights (Fw) were recorded. Turgid weight (Tw) was recorded immediately after floating the leaf discs in water for one hour. Later the leaf disc was transferred to butter paper cover and then dried in a hot air oven at 30^{o} C for 48 hours and dry weight (Dw) was recorded. **(**Barr and Weatherley, 1962).

$$\text{Relative leaf water content} = \frac{Fw-Dw}{Tw-Dw}$$

3.5.5. Quality parameters

The rind was removed and the flesh alone was taken for analysing the quality parameters.

a. Tuber dry matter content

The tuberous root samples were dried at a higher temperature (100^{o}C) for 24-36 hrs and dry weights recorded.

b. Starch and sugar content

Starch and sugars were estimated using potassium ferricyanade method (Aminoff *et al.*, 1970).

c. Crude protein content

The nitrogen content of the oven dried samples from each plot was estimated by using modified micro-Kjeldahl method (Jackson, 1958). Nitrogen values were multiplied by the factor 3.24 (Yeoh and Truong, 1996) for obtaining the crude protein content.

d. Cyanogenic glucoside content

Cyanogenic glucoside content was estimated by colorimetric method using the enzyme linamerase and expressed as ppm (Nambisan and Shanavas, 2013).

e. Organoleptic qualities

Different attributes (appearance, colour, flavour, texture, taste and overall acceptability) of the tuber was assessed by a taste panel comprising of 15 members. A random sample of fresh tubers collected from each plot was de-rinded and cut into pieces of 3-5 cm length, washed clean and cooked for 30 minutes till the flesh was soft. The test was assessed on a discrete scale with 9 points for the above 6 attributes (Table 4). The best was allotted with a score of 9 (like extremely). The other scores in decreasing order of taste were: like very much (8), like moderately (7), like slightly (6), neither like nor dislike (5), dislike slightly (4), dislike moderately (3), dislike very much (2) and dislike extremely (1).

Table 4. Score card for organoleptic evaluation

Like extremely	9
Like very much	8
Like moderately	7
Like slightly	6
Neither like nor dislike	5
Dislike slightly	4
Dislike moderately	3
Dislike very much	2
Dislike extremely	1

3.5.6. Soil moisture studies

Soil moisture content was determined at biweekly intervals. Soil samples were collected from a depth of 0-30 cm using an auger in airtight steel containers. The containers with soil samples were weighed and oven dried at 105^{o} C for 24 hours until all moisture was driven off. Then the containers were taken out and cooled at room temperature and weighed again. The difference in weight gave the weight of soil moisture in the samples and was expressed as percentage.

$$Pw = \frac{Wm - Wd}{Wd} \times 100$$

Where, Pw-percentage of soil moisture by weight; Wm-Weight of moist sample and Wd- weight of oven dry sample.

3.5.7. Soil analysis

Soil samples were collected during land preparation (before the application of manures and fertilizers) in both the experiments. Soil samples after the complete harvest of the crop was determined in the case of experiment II. The samples were air dried, sieved to pass through a 2mm sieve and analyzed for pH, organic carbon, available N, available P, available K, Ca, Mg and S. These were determined using standard procedures as shown in Table 1.

3.5.7. Plant analysis

Plant samples of experiment II were analysed for N, P, K, Ca, Mg and S using standard procedures. The macronutrient content of leaves, stem and tuber were analyzed by standard procedures (Jackson, 1958).

Total N content of the plant sample was determined by Microkjeldal digestion and distillation method. Diacid mixture was used to digest the plant samples. P content was determined by Vanadomolydophosphoric yellow colour method. Intensity of colour was read using Spectronic 20 spectrophotometer at 420 nm. Potassium content in the diacid digest was estimated using Flame photometer. Ca and Mg contents were estimated using Atomic Absorption Spectrophotometer (AAS). Sulphur was determined by turbidimetric method using Spectronic 20 spectrophotometer.

3.5.8. Weather parameters

Weather parameters *viz.*, maximum and minimum temperature, relative humidity, rainfall, no. of rainy days and sunshine hours were recorded at fortnightly intervals.

3.5.9. Statistical analysis

The data collected were analysed and treatment effects were detected using the statistical package WASP 2.O (Web Based Agricultural Statistics Software Package). In case of experiment I, for getting precision in the crop-weather effect for experiment

I, variety and month of planting were taken as main and sub factor respectively and calculated using split plot analysis. For experiment II, pooled analysis of two years were carried out using R software after determining the homogeneity of the treatments using Barlette test.

Results

4. Results

Two field experiments were conducted during the years 2015 and 2016 to study the effect of crop-weather-nutrient relations in four varieties of cassava, at Agronomy Farm, College of Horticulture, Kerala Agricultural University. Variations in varieties with different duration were evaluated for three seasons of planting (May, October and December) during the first year. The second experiment was carried out in 2015 and repeated in 2016 with a short-duration cassava variety being planted in October. The second experiment dealt with the effect of foliar application of nutrients in mitigating water stress in cassava. The results of the experiments are presented below.

Experiment I. Crop-weather relations in cassava

An experiment was conducted to assess the effect of crop and weather on four different varieties with varying durations, when planted in three different seasons (May, October and December). Comparison of varieties was done using split plot analysis to understand the precision of the effect of months of planting on the performance of varieties.

Results of the experiment in terms of effects on biometric parameters, physiological parameters, growth indices, tuber quality parameters, yield and yield attributes, sensory qualities, soil moisture and economics of crop production are presented below.

I.1. Biometric parameters

Crop-weather relation of four cassava varieties of varying duration on different growth characters for three plantings *viz.*, May, October and December were studied. The general growth of the crop was normal during the entire growth period for May planting. A reduction in rainfall by about 4 per cent as compared to the period of the May planted crop was noticed for October planting. December planted crop received a rainfall of only 1781.70 mm, which was about 6.60 and 2.30 per cent less as compared to October and May planted crops respectively.

I.1. Plant height

a. Short-duration varieties

Plant height is the first and foremost feature affected by water stress. There was a progressive increase in height for the two short duration varieties up to 6 months after planting (Table 5).

At 2 MAP, variety Sree Vijaya had significantly greater plant height (67.11cm) as compared to Vellayani Hraswa (57.72 cm), and this was seen up to 6 MAP.

Among months of planting, October recorded significantly higher plant height (86.75 cm), followed by May planting (77.35 cm) at 2 MAP. Lowest plant height was recorded for December planting (23.16cm). At 4 MAP, May planting was noted to have significantly greater plant height (213.82 cm), followed by October planting (106.16 cm). Lowest height was recorded for December planting (44.24 cm). This trend was maintained at 6 MAP.

Interaction effect of variety with month of planting at 2 MAP revealed that significantly greater plant height was recorded for Sree Vijaya when planted during October (90.55 cm). This was followed by Sree Vijaya planted during May (82.95 cm). Although lowest plant height was observed for Sree Vijaya planted during December (24.30 cm) at this stage. At 4 MAP, plant height was significantly greater for May planted Sree Vijaya variety (251.65 cm), followed by Vellayani Hraswa planted during May (176.00 cm). Lowest plant height was recorded for Vellayani Hraswa (43.77 cm) and Sree Vijaya (44.71 cm) planted during December respectively. Similar interaction effects were noticed at 6 MAP.

b. Normal-duration varieties

Non-significant relations on plant height were recorded by both normal-duration varieties M_4 and Sree Athulya at 2, 4 and 6 MAP. Observations at 8 and 10 MAP recorded significantly taller plant for Sree Athulya variety followed by M_4 (375.52 cm and 457.80 cm respectively).

Table 5. Plant height of short-duration cassava varieties as influenced by variety and month of planting

. Plant height (cm)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	57.72	107.53	129.26
Sree Vijaya	67.11	135.28	156.59
SEd	1.80	4.23	8.07
CD (5 %)	5.74	13.46	25.67
Month of planting (M)			
May	77.35	213.82	244.92
October	86.75	106.16	118.17
December	23.16	44.24	65.68
SEd	3.38	7.37	9.49
CD (5 %)	7.34	16.00	20.66
Interaction (VXM)			
Vellayani Hraswa x May	68.20	176.00	195.80
Vellayani Hraswa x Oct.	82.95	102.82	124.25
Vellayani Hraswa x Dec.	22.03	43.77	67.73
Sree Vijaya x May	86.50	251.65	294.05
Sree Vijaya x Oct.	90.55	109.50	112.10
Sree Vijaya x Dec.	24.30	44.71	63.63
SEd	4.78	10.42	13.46
CD (5 %)	10.38	22.63	29.21

Considering the direct effect of month of planting on plant height, at 2 MAP significantly taller plant was recorded for October planting (123.58 cm), followed by May planting (83.47 cm). December planting recorded the lowest plant height of 30.82 cm. At 4 MAP, May planted cassava varieties were recorded to have significantly higher plant height (333.50 cm), followed by October planting (152.44 cm). Lowest plant height was for December planting (57.64 cm). At 8 MAP and 10 MAP, significantly greater plant height was recorded for May (463.38 cm and 576.18 cm respectively). This was followed by October planting (337.02 cm and 424.69 cm respectively), and the lowest was noted for December planting (174.84 and 242.49 cm, respectively).

Regarding the interaction effect at 2 MAP, significantly taller plant was recorded for M_4 when planted during October (130.77 cm), followed by October planted Sree Athulya (116.40 cm). Lowest plant height was noted for M_4 planted during May (30.23 cm). Interaction effect at 4 MAP revealed that significantly greater plant height was recorded for M_4 planted during May (339.00 cm), which was comparable with Sree Athulya planted during same season (328.01 cm). Lowest plant height was recorded for both normal- duration varieties when planted during December. Similar trend was followed at 6 MAP. Data at 8 MAP showed a significantly greater plant height for May planted Sree Athulya variety (530.26 cm). This was followed by M_4 planted during May (396.50 cm), which was on par with Sree Athulya planted during October (386.69 cm). Plant height was observed to be lowest for M_4 planted during December (140.06 cm). Similar trend as that of 8 MAP was followed at 10 MAP (Table 6).

I.2 Number of leaves (leaves retained) per plant

Leaf number determines the photosynthetic capacity of the plant. The data pertaining to the number of leaves retained in the plant are given in Table 7 and Table 8.

Table 6. Plant height of normal-duration cassava varieties as influenced by variety and month of planting

Plant height (cm)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	83.95	185.54	222.57	274.64	371.10
Sree Athulya	74.63	176.84	224.33	375.52	457.80
SEd	-	-	-	10.49	11.75
CD (5 %)	NS	NS	NS	33.37	37.35
Month of planting (M)					
May	83.47	333.50	391.48	463.38	576.18
October	123.58	152.44	174.49	337.02	424.69
December	30.82	57.64	104.37	174.84	242.49
SEd	4.79	11.64	14.61	15.94	20.37
CD (5 %)	10.39	25.25	31.70	34.58	44.21
Interaction (VXM)					
M_4 x May	90.87	339.00	383.35	396.50	516.12
M_4 x Oct.	130.77	164.00	182.95	287.36	388.62
M_4 x Dec.	30.23	53.64	101.41	140.06	208.56
Sree Athulya x May	76.08	328.01	399.62	530.26	636.25
Sree Athulya x Oct.	116.40	140.88	166.03	386.69	460.75
Sree Athulya x Dec.	31.43	61.65	107.33	209.62	276.40
SEd	6.77	16.46	20.66	22.54	28.82
CD (5 %)	14.701	35.72	44..83	48.91	62.53

a. Short-duration varieties

The number of leaves retained per plant reduced with decreasing trend in rainfall. Considering the direct effect of varieties on number of leaves at 2 MAP, the effect was non-significant. At 4 MAP, significantly more number of leaves was observed for Sree Vijaya (152.41) as compared to Vellayani Hraswa (117.55). Six months after planting revealed a significantly higher number of leaves for variety Sree Vijaya (67.02) than for Vellayani Hraswa (58.41).

With respect to the effect of month of planting, October planting recorded significantly more number of leaves (66.86) but was comparable with May planting (61.49) at 2 MAP and the number of leaves retained was significantly less for December planting (24.01). May planting recorded significantly higher number of leaves (289.69) at 4 MAP. This was followed by October (97.50). Lowest number was recorded for December (17.75). At 6 MAP October planted varieties showed a significantly higher number of leaves (75.63) and was followed by May planting (67.28). Lowest number of leaves per plant was recorded for December planted crop (45.23).

Interaction effect of varieties and months of planting at 2 MAP revealed a significantly higher number of leaves for Sree Vijaya planted during October (68.77). This was comparable with Vellayani Hraswa planted during October (64.96) and May (63.16). Number of leaves retained were lowest for Vellayani Hraswa planted during December (27.26), followed by Sree Vijaya planted during December (20.76). At 4 MAP, Sree Vijaya planted during May recorded significantly higher number of leaves (336.73). This was followed by Vellayani Hraswa planted during May (242.66). Lowest number of leaves were recorded for Vellayani Hraswa planted during December (14.00), which was on par with December planted Sree Vijaya (21.50). At 6 MAP, Sree Vijaya planted during October recorded significantly higher number of leaves (105.00). This was followed by Vellayani Hraswa planted during May (90.23). Number of leaves was lowest for Vellayani Hraswa planted during December (38.73).

Table 7. Number of leaves per plant of short-duration cassava varieties as influenced by variety and month of planting

No. of leaves/plant			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	51.79	117.55	58.41
Sree Vijaya	49.78	152.41	67.02
SEd	-	5.90	1.15
CD (5 %)	NS	18.75	3.66
Month of planting (M)			
May	61.49	289.69	67.28
October	66.86	97.50	75.63
December	24.01	17.75	45.23
SEd	2.70	8.64	2.64
CD (5 %)	5.86	18.75	5.73
Interaction (VXM)			
Vellayani Hraswa x May	63.16	242.66	90.23
Vellayani Hraswa x Oct.	64.96	96.00	46.26
Vellayani Hraswa x Dec.	27.26	14.00	38.73
Sree Vijaya x May	59.83	336.73	44.33
Sree Vijaya x Oct.	68.77	99.00	105.00
Sree Vijaya x Dec.	20.76	21.50	51.73
SEd	3.82	13.96	3.73
CD (5 %)	8.29	30.30	8.10

a. Normal–duration varieties

Data on direct effect of variety on number of leaves at 2 MAP revealed a significantly higher number of leaves for M_4 (42.99) compared to Sree Athulya (37.35). Similar effect of variety on number of leaves was observed at 4, 6 and 10 MAP, whereas no significant difference with regard to number of leaves was recorded at 8 MAP.

At 2 MAP, regarding direct effect of month of planting, significantly higher number of leaves was observed for October planting (59.63). This was followed by May planting (41.37). Lowest number of leaves was recorded for December planting (19.50). At 4 MAP, May planting had significantly higher number of leaves (188.24). This was followed by October planting (95.25) and lowest number was recorded for December planting. Similar trend of effect of month of planting was observed at 6, 8 and 10 MAP.

Interaction effect of variety x number of leaves at 2 MAP revealed a significantly higher number of leaves for Sree Athulya planted during October (60.63), which was comparable with M_4 planted during October (58.63). This was followed by M_4 planted during May (46.33). Lowest number of leaves was recorded for Sree Athulya planted during December (15.00).However, at 4 MAP M_4 planted during May recorded more number of leaves per plant (250.60), followed by Sree Athulya planted during May (125.87). Number of leaves per plant was lowest for M_4 planted during October (26.00), which was comparable with Sree Athulya planted during December (33.50). Similar trend was followed at 6 MAP. Again at 8 MAP, M_4 planted during May recorded significantly higher number of leaves (340.06). This was followed by Sree Athulya planted during May (267.62). Number of leaves was lowest for M_4 planted during October and was comparable with Sree Athulya planted during December. Similar was the trend observed at 10 MAP, except that Sree Athulya planted in December recorded lowest number of leaves (23.44).

Table 8. Number of leaves per plant of normal-duration cassava varieties as influenced by variety and month of planting

No. of leaves/plant					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	42.99	120.95	176.43	177.16	173.79
Sree Athulya	37.35	87.87	162.07	191.04	154.82
SEd	0.78	2.46	3.98	-	4.98
CD (5 %)	2.48	7.81	12.65	NS	15.84
Month of planting (M)					
May	41.37	188.24	285.50	303.84	321.26
October	59.63	95.25	164.12	146.16	130.21
December	19.50	29.75	58.13	102.31	41.44
SEd	2.19	6.81	10.13	9.85	10.69
CD (5 %)	4.75	14.77	21.98	21.38	23.19
Interaction (VXM)					
M_4 x May	46.33	250.60	323.76	340.06	351.90
M_4 x Oct.	58.63	86.25	153.26	123.75	110.02
M_4 x Dec.	24.00	26.00	52.26	67.68	59.43
Sree Athulya x May	36.41	125.87	247.23	267.62	290.60
Sree Athulya x Oct.	60.63	104.25	174.97	168.56	150.40
Sree Athulya x Dec.	15.00	33.50	64.00	136.93	23.44
SEd	3.10	9.63	14.33	13.94	15.11
CD (5 %)	6.72	20.90	31.09	30.24	32.79

I.3. Number of leaf scars (leaves fallen) per plant

Number of leaf scars per plant is a record of the extent of leaf fall in each variety. Phasic trend in number of leaf scars or leaf fall was recorded and is represented in Table 9 and Table 10.

a. Short-duration varieties

Direct effect of varieties recorded the same trend for all the growing periods. Short- duration variety Sree Vijaya recorded significantly less number of leaf scars (0.26, 29.39 and 9.33) at 2, 4 and 6 MAP.

With regard to the effect of month of planting, significantly lower number of leaves fallen were observed for May planting (0.25) at 2 MAP. This was followed by October (0.51) and the lowest was recorded for December planting (0.63). At 4 MAP, number of leaf scars was significantly lower for December planting (21.00) and was followed by October planting (29.50). Significantly higher number of leaf scars was for May planting (53.43). Number of leaf scars was lower for December planting (32.83) at 6 MAP. Significantly higher leaf scars were recorded for October planting (121.50) and May planting (116.50), which were on par.

Data on interaction effect of variety with months of planting showed that Vellayani Hraswa planted during December recorded significantly higher number of leaf scars (1.00) at 2 MAP (Table 9). Significantly lower number of leaf scars was recorded for Vellayani Hraswa planted during May (0.23). At 4 MAP, significantly higher leaf scars was recorded for Vellayani Hraswa during May (61.00).This was followed by Sree Vijaya planted during May (45.85). Number of leaf scars was lowest for Sree Vijaya planted during December (25.66) and was on par with Vellayani Hraswa planted during December (40.00) at 6 MAP.

Table 9. Number of leaf scars per plant of short-duration cassava varieties as influenced by variety and month of planting

No. of leaf scars/plant			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	0.67	39.89	101.22
Sree Vijaya	0.26	29.39	79.33
SEd	0.003	0.45	1.34
CD (5 %)	0.01	1.44	4.26
Month of planting (M)			
May	0.25	53.43	116.50
October	0.51	29.50	121.50
December	0.63	21.00	32.83
SEd	0.02	1.97	5.42
CD (5 %)	0.05	4.28	11.77
Interaction (VXM)			
Vellayani Hraswa x May	0.23	61.00	134.67
Vellayani Hraswa x Oct.	0.76	34.00	129.00
Vellayani Hraswa x Dec.	1.00	24.66	40.00
Sree Vijaya x May	0.26	45.85	98.33
Sree Vijaya x Oct.	0.26	25.00	114.00
Sree Vijaya x Dec.	0.26	17.33	25.66
SEd	0.04	2.79	7.67
CD (5 %)	0.08	6.06	16.65

b. Normal-duration varieties

There was no significant difference in number of leaf scars per plant in varieties at 2 and 6 MAP. However, at 4, 8 and 10 MAP, significantly higher number of leaf scars per plant was observed for variety M_4 as compared to Sree Athulya.

Regarding the effect of month of planting, no significant difference in number of leaf scars was observed at 2MAP. Number of leaf scars per plant was significantly higher for cassava varieties planted during May (33.21) at 4 MAP and followed a similar trend at 10 MAP (337.05). Significantly higher number of leaf scars was noted for October (87.50) and May planting (85.36) at 6 MAP, which were on par. At 8 MAP, significantly higher number of leaf scars was noted for May planting (300.23), and was followed by October planting (121.43). Lowest value was recorded for December planting (88.37).

Data on interaction effect showed that at 2 MAP, there was no significant relation of cassava varieties x month of planting for number of leaf scars. At 4 MAP, significantly higher number of leaf scars was recorded for M_4 planted during May (43.00). This was followed by Sree Athulya planted during December (28.66) and M_4 planted during May (25.22). At 6 MAP, significantly higher number of leaf scars was recorded for M_4 planted during October (96.00) which were on par with May planting (95.72). Number of leaf scars was significantly higher for M_4 planted during May (358.43) at 8 MAP followed by Sree Athulya planted during May (242.02). Lowest number was observed for Sree Athulya (80.00) and M_4 (96.73) planted during December, which were on par. Similar trend was followed at 10 MAP; except that variety Sree Athulya planted during October was recorded have lowest number of leaf scars (94.17).

Table 10. Number of leaf scars per plant of normal-duration cassava varieties as influenced by variety and month of planting

No. of leaf scars/plant					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M4	0.30	30.07	78.35	197.51	241.28
Sree Athulya	0.24	23.69	63.55	142.51	183.90
SEd	-	0.25	-	3.49	3.70
CD (5 %)	NS	0.79	NS	11.10	11.77
Month of planting (M)					
May	0.25	33.21	85.36	300.23	337.05
October	0.24	20.50	87.50	121.43	120.74
December	0.33	26.94	40.00	88.37	179.98
SEd	-	1.27	3.91	10.43	11.42
CD (5 %)	NS	2.76	8.48	22.64	24.78
Interaction (VXM)					
M_4 x May	0.26	43.00	95.72	358.43	386.69
M_4 x Oct.	0.23	22.00	96.00	137.36	147.30
M_4 x Dec.	0.41	25.22	43.33	96.73	189.82
Sree Athulya x May	0.23	23.41	75.00	242.02	287.39
Sree Athulya x Oct.	0.23	19.00	79.00	105.50	94.17
Sree Athulya x Dec.	0.23	28.66	36.66	80.00	170.13
SEd	-	1.27	3.91	10.43	11.42
CD (5 %)	NS	2.76	8.48	22.64	24.78

I.4. Number of branches per plant

a. Short-duration varieties

Data on direct effect of varieties on number of branches per plant showed that the variety Sree Vijaya had significantly higher number of branches at 2, 4 and 6 MAP as compared to Vellayani Hraswa (Table 11)

No significant effect was recorded for number of branches as affected by month of planting for all the three plantings.

Considering interaction effect, at 2 MAP significantly higher number of branches was for Sree Vijaya planted during May (2.00), and Vellayani Hraswa during October and December which were on par. This was followed by Vellayani Hraswa planted during May (1.90), Sree Vijaya planted during October (1.75) and Sree Vijaya planted during December (1.70). Similar trend was observed at 4 and 6 MAP.

b. Normal-duration varieties

Considering the effect of variety on number of branches per plant, significantly higher number of branches was recorded for Sree Athulya at 2, 4, 6, 8 and 10 MAP.

Regarding the effect of month of planting, number of branches was non-significant for all the plantings at 2, 4 and 6 MAP. However, number of branches per plant was significantly higher for December planting (2.17). Lowest number of branches was for May planting (1.47) at 8 and 10 MAP (Table 12).

Data on interaction effect of variety with month of planting showed significantly higher number of branches for Sree Athulya planted during December and October (2.00) which were comparable at 2, 4 and 6 MAP. This was followed by Sree Athulya planted during May. At 8 and 10 MAP, Sree Athulya planted during December (2.08) was observed to have significantly more number of branches. This was followed by M_4 planted during December (2.04). Lowest value was noted for M_4 planted during May (1.14) and October (1.23).

Table 11. Number of branches per plant of short-duration cassava varieties as influenced by variety and month of planting

No. of branches/plant			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	1.97	1.97	1.97
Sree Vijaya	1.83	1.83	1.83
SEd	0.03	0.03	0.03
CD (5 %)	0.09	0.09	0.09
Month of planting (M)			
May	1.95	1.95	1.95
October	1.88	1.88	1.88
December	1.88	1.88	1.88
SEd	-	-	-
CD (5 %)	NS	NS	NS
Interaction (VXM)			
Vellayani Hraswa x May	1.90	1.90	1.90
Vellayani Hraswa x Oct.	2.00	2.00	2.00
Vellayani Hraswa x Dec.	2.00	2.00	2.00
Sree Vijaya x May	2.00	2.00	2.00
Sree Vijaya x Oct.	1.75	1.75	1.75
Sree Vijaya x Dec.	1.75	1.75	1.75
SEd	0.08	0.08	0.08
CD (5 %)	0.18	0.18	0.18

Table 12. Number of branches per plant of normal-duration cassava varieties as influenced by variety and month of planting

No. of branches/plant					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	1.13	1.13	1.13	1.47	1.47
Sree Athulya	1.86	1.86	1.86	1.97	1.97
SEd	0.04	0.04	0.04	0.03	0.03
CD (5 %)	0.14	0.14	0.14	0.11	0.11
Month of planting (M)					
May	1.49	1.49	1.49	1.47	1.47
October	1.50	1.50	1.50	1.52	1.52
December	1.50	1.50	1.50	2.17	2.17
SEd	-	-	-	0.06	0.06
CD (5 %)	NS	NS	NS	0.13	0.13
Interaction (VXM)					
M_4 x May	1.40	1.40	1.40	1.14	1.14
M_4 x Oct.	1.00	1.00	1.00	1.23	1.23
M_4 x Dec.	1.00	1.00	1.00	2.04	2.04
Sree Athulya x May	1.57	1.57	1.57	1.80	1.80
Sree Athulya x Oct.	2.00	2.00	2.00	1.80	1.80
Sree Athulya x Dec.	2.00	2.00	2.00	2.30	2.30
SEd	0.06	0.06	0.06	0.09	0.09
CD (5 %)	0.14	0.14	0.14	0.19	0.19

Considering the effect of month of planting, significantly higher stem girth was observed for October planted varieties (2.58 cm). This was followed by the May planted crop (1.93 cm). Lowest stem girth was recorded for December planting (1.63 cm). At 4 MAP, significantly higher stem girth was recorded for May planting (8.14 cm) and was comparable with October planting (7.59 cm). Lowest stem girth was recorded for December planting (4.42 cm) and a similar trend was observed for 6 MAP.

I.5. Stem girth

a. Short-duration varieties

Stem girth was non-significant for the short duration varieties at 2 and 6 MAP. But significantly higher stem girth was recorded for Sree Vijaya (7.12 cm) at 4 MAP. Vellayani Hraswa recorded about 6.32 cm in width at this stage (Table 13).

Considering the effect of month of planting, significantly higher stem girth was observed for October planted varieties (2.58 cm). This was followed by the May planted crop (1.93 cm). Lowest stem girth was recorded for December planting (1.63 cm). At 4 MAP, significantly higher stem girth was recorded for May planting (8.14 cm) and was comparable with October planting (7.59 cm). Lowest stem girth was recorded for December planting (4.42 cm) and a similar trend was observed for 6 MAP.

Data on interaction effect showed that significantly higher stem growth was recorded for Vellayani Hraswa planted during October (2.96 cm) at 2 MAP. At 4 MAP, significantly higher stem girth was recorded for Sree Vijaya planted during May (8.99 cm) which was on par with Sree Vijaya planted during October (8.16 cm). This was followed by Vellayani Hraswa planted during May (7.30 cm). Lowest stem girth was recorded for Sree Vijaya and Vellayani Hraswa planted during December (4.20 and 4.64 cm respectively). At 6 MAP, stem girth was on par for all the treatments, however the lowest value was observed for Sree Vijaya and Vellayani Hraswa planted during December.

Table 13. Stem girth of short-duration cassava varieties as influenced by variety and month of planting

Stem girth (cm)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	2.09	6.32	8.53
Sree Vijaya	2.00	7.12	9.13
SEd	-	0.16	-
CD (5 %)	NS	0.52	NS
Month of planting (M)			
May	1.93	8.14	9.78
October	2.58	7.59	10.06
December	1.63	4.42	6.64
SEd	0.10	0.31	-
CD (5 %)	0.22	0.67	NS
Interaction (VXM)			
Vellayani Hraswa x May	1.73	7.30	9.23
Vellayani Hraswa x Oct.	2.96	7.03	10.00
Vellayani Hraswa x Dec.	1.60	4.64	6.36
Sree Vijaya x May	2.13	8.99	10.33
Sree Vijaya x Oct.	2.20	8.16	10.13
Sree Vijaya x Dec.	1.67	4.20	6.93
SEd	0.14	0.44	0.57
CD (5 %)	0.31	0.95	1.23

b. Normal-duration varieties

Significantly higher stem girth was observed for Sree Athulya variety at all the stages except at 10 MAP, which was non-significant (Table 14).Considering the effect of month of planting, significantly higher stem girth was observed for October planting at 2 MAP (3.22 cm). This was followed by May (2.50 cm). Lowest stem girth during this stage was observed for December planting (1.76 cm). Significantly higher stem girth was recorded for October planting (9.05 cm) which was comparable with May planting (8.95 cm) at 4 MAP. Similar trend was seen at 6 and 8 MAP. However stem girth was non-significant for all the three months of planting at 10 MAP.

With respect to interaction effect, Sree Athulya planted during October (3.50 cm) recorded significantly higher stem girth at 2 MAP. This was comparable with Sree Athulya planted during May (3.05 cm) and M_4 planted during October (2.95 cm).

Lowest stem girth was recorded for Sree Athulya and for M_4 planted during December. At 4 MAP, significantly higher stem girth was observed for Sree Athulya planted during October (9.47 cm) which was on par with Sree Athulya planted during May (9.41 cm). Similar trend was noticed at 6 MAP. Observation on 8 MAP, revealed that May planted Sree Athulya variety had significantly higher stem girth (12.83 cm). This was on par with Sree Athulya planted during October (11.86 cm) and M_4 planted during May (11.46 cm), and was followed by M_4 planted during October (8.46 cm). Lowest stem girth was observed for M_4 planted during December (11.12 cm) and Sree Athulya planted during December (9.36 cm), which were on par. Similar trend was observed at 10 MAP.

I.6. Root length

a. Short-duration varieties

Considering the varieties, Sree Vijaya was found to have greater root length than Vellayani Hraswa at 2 MAP and 4 MAP. Root length of the two varieties was found to be non-significant at 6 MAP (Table 15)

Table 14. Stem girth of normal-duration cassava varieties as influenced by variety and month of planting

	Stem girth (cm)				
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	2.20	7.51	9.44	10.35	11.27
Sree Athulya	2.79	8.19	10.12	11.35	12.40
SEd	0.07	0.17	0.20	0.24	-
CD (5 %)	0.23	0.55	0.65	0.75	NS
Month of planting (M)					
May	2.50	8.95	11.03	12.14	13.04
October	3.22	9.05	10.79	11.49	12.48
December	1.76	5.55	7.52	8.91	13.04
SEd	0.11	0.36	0.44	0.47	-
CD (5 %)	0.23	0.78	0.95	1.03	NS
Interaction (VXM)					
M_4 x May	1.96	8.50	10.90	11.46	12.43
M_4 x Oct.	2.95	8.63	10.23	11.12	11.99
M_4 x Dec.	1.69	5.40	7.19	8.46	9.40
Sree Athulya x May	3.05	9.41	11.17	12.83	13.66
Sree Athulya x Oct.	3.50	9.47	11.35	11.86	12.97
Sree Athulya x Dec.	1.83	5.70	7.86	9.36	10.57
SEd	0.15	0.51	0.62	0.67	0.71
CD (5 %)	0.33	1.11	1.34	1.46	1.55

Table 15. Root length of short-duration cassava varieties as influenced by variety and month of planting

Root length (cm)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	11.95	16.01	35.24
Sree Vijaya	13.65	19.36	34.31
SEd	0.37	0.51	-
CD (5 %)	1.17	1.62	NS
Month of planting (M)			
May	20.92	27.25	46.16
October	9.56	12.70	26.34
December	7.92	13.12	31.82
SEd	0.68	0.86	1.62
CD (5 %)	1.47	1.87	3.52
Interaction (VXM)			
Vellayani Hraswa x May	18.90	25.05	43.43
Vellayani Hraswa x Oct.	8.56	11.10	28.30
Vellayani Hraswa x Dec.	8.39	11.90	34.00
Sree Vijaya x May	22.95	29.45	48.90
Sree Vijaya x Oct.	10.56	14.30	24.39
Sree Vijaya x Dec.	7.45	14.35	29.65
SEd	0.96	1.22	2.29
CD (5 %)	2.08	2.64	4.98

Results on the effect of month of planting showed that at 2 MAP significantly higher root length was for May planting (20.92 cm). This was followed by October planting (9.56 cm), and lowest root fresh weight was recorded for December planting (7.92 cm). At 4 MAP, significantly higher root length was noted for May planted crop (27.25 cm). This was followed by December planting (13.12 cm) and October planting (12.70 cm), which were comparable. Considering the observation at 6 MAP, May planting recorded significantly higher root length (46.16 cm). This was followed by December planting (31.82 cm), and the shortest root length was for October planting (26.34 cm).

Interaction effect of variety on month of planting of short duration varieties resulted in a significantly higher root length for Sree Vijaya planted during May (22.95 cm) at 2 MAP. This was followed by Vellayani Hraswa planted during May (18.90 cm). At 4 MAP, significantly higher root length was recorded for Sree Vijaya planted during May (29.45 cm) and Vellayani Hraswa planted during May (25.05 cm). Similar trend was noted at 6 MAP.

b. Normal-duration varieties

Normal-duration variety Sree Athulya had significantly higher root length (17.67 cm), compared to M_4 (15.32 cm) at 2 MAP. Similar results were obtained at 4 and 10 MAP. However, variety had no significant effect on root length at 6 MAP. But at 8 MAP, M_4variety showed significantly higher root length (77.39 cm) as compared to Sree Athulya (69.87 cm).

Regarding the effect of month of planting, significantly higher root length was for May planting and was followed by December and October plantings which were comparable at 2, 4 and 6 MAP. At 8 and 10 MAP, significantly higher root length was recorded for October planting, followed by May planting. Lowest length was observed for December planting (Table 16)

Interaction effect showed that significantly higher root length was for Sree Athulya planted during May (29.90 cm) at 2 MAP, followed by M_4 planted during May (26.65 cm). At 4 MAP, significantly higher root length was for Sree Athulya

Table 16. Root length of normal-duration cassava varieties as influenced by variety and month of planting

	Root length (cm)				
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	15.32	22.16	40.58	77.39	84.83
Sree Athulya	17.67	24.28	39.09	69.87	105.62
SEd	0.51	0.59	-	2.31	3.19
CD (5 %)	1.63	1.87	NS	7.35	10.13
Month of planting (M)					
May	28.27	35.27	63.78	69.78	82.30
October	10.23	16.76	27.88	121.43	170.74
December	11.00	17.62	27.86	29.69	32.64
SEd	0.89	1.13	2.19	4.50	5.08
CD (5 %)	1.93	2.46	4.75	9.76	11.03
Interaction (VXM)					
M_4 x May	26.65	34.55	61.66	67.23	75.78
M_4 x Oct.	9.43	15.23	33.40	137.37	147.30
M_4 x Dec.	9.90	16.70	26.70	27.59	31.42
Sree Athulya x May	29.90	36.00	65.90	72.33	88.82
Sree Athulya x Oct.	11.03	18.30	22.36	105.50	194.18
Sree Athulya x Dec.	12.10	18.55	29.03	31.80	33.87
SEd	1.26	1.60	3.10	6.36	7.19
CD (5 %)	2.73	3.47	6.73	13.81	15.60

planted during May (36.00 cm), which was comparable with M_4 planted during May (34.55cm). Similar trend was followed at 6 MAP. However at 8 MAP significantly higher root length was recorded for M_4 planted during October (137.37 cm), followed by Sree Athulya in October planting (105.50 cm). Lowest length was recorded for Sree Athulya planted during December (31.80 cm) and M_4 planted during December (27.59 cm). At 10 MAP, root length was significantly higher for October planted Sree Athulya variety (194.18 cm). This was followed by M_4 planted during October (147.30 cm). Shortest root length was observed for Sree Athulya (33.87 cm) and M_4 (31.42 cm) planted during December respectively.

I.7. Root diameter

a. Short-duration varieties

During early stages of planting, significantly higher root diameter was observed for Sree Vijaya (1.27 cm) compared to Vellayani Hraswa (1.15 cm). However, no significant effect of varieties was noted on root diameter at 4 and 6 MAP (Table 17).

October planted cassava variety recorded significantly higher root diameter (1.48 cm) at 2 MAP. This was followed by December planting (1.29 cm), and the lowest diameter was noted for May planting (0.87 cm). On the other hand, significantly higher root diameter was recorded for May planting followed by October planting at 4 and 6 MAP. Lowest root diameter was observed for December planting at both the growth stages.

Regarding the interaction effect, significantly higher root diameter was observed for October planted Sree Vijaya (1.50 cm) and Vellayani Hraswa (1.46 cm), which was on par at 2 MAP. This was followed by December planted Sree Vijaya (1.33 cm) and Vellayani Hraswa (1.26 cm). Lowest diameter was observed for Sree Vijaya planted during May (1.00 cm). At 4 MAP, significantly higher root diameter was recorded for Vellayani Hraswa planted during May (6.50 cm). This was followed by Sree Vijaya planted during October (6.00 cm) and Sree Vijaya

Table 17. Root diameter of short-duration cassava varieties as influenced by variety and month of planting

Root diameter (cm)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	1.15	5.37	7.97
Sree Vijaya	1.27	5.71	8.14
SEd	0.01	-	-
CD (5 %)	0.02	NS	NS
Month of planting (M)			
May	0.87	6.12	10.00
October	1.48	5.66	8.35
December	1.29	4.84	5.83
SEd	0.03	0.12	0.10
CD (5 %)	0.07	0.27	0.21
Interaction (VXM)			
Vellayani Hraswa x May	0.75	6.50	10.30
Vellayani Hraswa x Oct.	1.46	5.33	8.23
Vellayani Hraswa x Dec.	1.26	4.29	5.40
Sree Vijaya x May	1.00	5.75	9.70
Sree Vijaya x Oct.	1.50	6.00	8.46
Sree Vijaya x Dec.	1.33	5.40	6.26
SEd	0.04	0.18	0.14
CD (5 %)	0.09	0.38	0.30

planted during May (5.75 cm). Significantly higher root diameter was recorded for Vellayani Hraswa planted during May (10.30 cm) at 6 MAP, followed by Sree Vijaya (9.70 cm). Lowest root diameter was for Vellayani Hraswa planted during December (5.40 cm).

b. Normal-duration varieties

At 2 MAP, 8 MAP and 10 MAP no significant difference among varieties with regard to root diameter was observed. However at 4 and 6 MAP, Sree Athulya recorded significantly recorded higher root diameter than M_4 (Table 18).

Considering the direct effect of month of planting, root diameter varied at all stages of planting except that no significant difference in root diameter was observed at 6 MAP. At 2 MAP, October planting had significantly higher root diameter (1.53 cm), followed by December planting (1.37 cm) and May planting (1.12 cm). At 4 MAP, December planting recorded significantly higher root diameter (5.81 cm). This was followed by October planting (5.28 cm) and May planting (5.27 cm), which were on par. At 8 MAP, significantly higher root diameter was observed for May planting (12.57 cm) which was on par with October (11.55 cm). However, at 10 MAP, significantly higher root diameter was observed for May planting (13.58 cm) followed by October planting (11.99 cm) and December planting (11.15 cm) which were comparable

At 2 MAP, significantly higher root diameter was observed for Sree Athulya planted during October (1.56 cm), and the lowest diameter was noted for the same variety planted during May (1.14 cm). At 4 MAP, root diameter was significantly higher for Sree Athulya at October (6.36 cm) and December planting (6.20 cm), which were on par. At 6 MAP, no significant difference was observed in root diameter. At 8 MAP, significantly higher root diameter was observed for Sree Athulya planted during May (13.01 cm) and M_4 planted during May (12.13 cm). Lowest root diameter was recorded for M_4 planted during December (8.26 cm). At 10 MAP, significantly higher root diameter was seen in Sree Athulya planted during May (14.03 cm) and M_4 planted during May (13.13 cm), followed

Table 18. Root diameter of normal-duration cassava varieties as influenced by variety and month of planting

Root diameter (cm)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	1.32	4.94	7.45	10.53	11.73
Sree Athulya	1.36	5.97	9.09	11.45	12.75
SEd	-	0.03	0.23	-	-
CD (5 %)	NS	0.11	0.72	NS	NS
Month of planting (M)					
May	1.12	5.27	8.84	12.57	13.58
October	1.53	5.28	8.43	11.55	11.99
December	1.37	5.81	7.55	8.85	11.15
SEd	0.01	0.05	-	0.53	0.44
CD (5 %)	0.03	0.11	NS	1.14	0.95
Interaction (VXM)					
M_4 x May	1.14	5.20	7.46	12.13	13.13
M_4 x Oct.	1.50	4.20	7.40	11.20	11.80
M_4 x Dec.	1.33	5.43	7.50	8.26	10.28
Sree Athulya x May	1.10	5.35	10.22	13.01	14.03
Sree Athulya x Oct.	1.56	6.36	9.46	11.90	12.19
Sree Athulya x Dec.	1.42	6.20	7.60	9.45	12.03
SEd	0.02	0.07	-	0.74	0.62
CD (5 %)	0.04	0.16	NS	1.61	1.35

by Sree Athulya planted during October (12.19 cm). Lowest root diameter was observed for December planted M_4 variety (10.28 cm).

I.8. Total dry matter production

a. Short-duration varieties

Among short duration varieties, Vellayani Hraswa and Sree Vijaya, significantly higher dry matter production was recorded for Sree Vijaya (71.66 g/plant) and (2129.35 g/plant) at 2 and 6 MAP respectively. There was no significant difference in dry matter production between varieties at 4 MAP (Table 19).

Among months of planting, October planting recorded significantly higher dry matter production (74.91 g/plant) at 2 MAP. This was followed by May planting (67.99 g/plant) and December (42.13 g/plant). At 4 MAP, significantly higher dry matter production was recorded for May (1720.02 g/plant). This was followed by December (1072.00 g/plant), and October planting (868.25 g/plant). Considering the dry matter production at 6 MAP, significantly higher dry matter production was recorded for May planting (2305.02 g/plant) and lowest for December planting (1576.50 g/plant).

Interaction effect showed that significantly higher dry matter production was recorded for Sree Vijaya planted during October (94.83 g/plant), followed by May planting (72.00 g/plant). At 4 MAP, significantly higher dry matter production was recorded for Vellayani Hraswa planted during May (2033.00 g/plant), followed by May planted Sree Vijaya (1407.03 g/plant). Lowest dry matter production was recorded for Vellayani Hraswa planted during October (687.50 g/plant) respectively which are comparable. At 6 MAP, significantly higher dry matter production was observed for Vellayani Hraswa planted during May (2543.00 g/plant), and this was comparable with Sree Vijaya planted during October (2425.00 g/plant). Lowest dry matter production was observed for Vellayani Hraswa planted during December (1257.00 g/plant).

Table 19. Total dry matter production of short-duration cassava varieties as influenced by variety and month of planting

Total dry matter production (g/plant)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	51.70	1213.83	1857.00
Sree Vijaya	71.66	1226.34	2129.35
SEd	1.72	-	42.56
CD (5 %)	5.49	NS	135.36
Month of planting (M)			
May	67.99	1720.01	2305.02
October	74.91	868.25	2098.00
December	42.13	1072.00	1576.50
SEd	2.49	51.81	85.29
CD (5 %)	5.41	112.44	185.10
Interaction (VXM)			
Vellayani Hraswa x May	63.97	2033.00	2543.00
Vellayani Hraswa x Oct.	54.97	687.50	1771.00
Vellayani Hraswa x Dec.	36.13	921.00	1257.00
Sree Vijaya x May	72.00	1407.03	2067.04
Sree Vijaya x Oct.	94.83	1049.00	2425.00
Sree Vijaya x Dec.	48.13	1223.00	1896.00
SEd	3.52	75.24	120.63
CD (5 %)	7.65	163.29	261.77

a. Normal-duration varieties

No significant effect of variety on dry matter production on varieties was noted at 2 MAP. At 4 MAP, Sree Athulya showed significantly higher dry matter production (1543.34 g/plant) compared to M_4 (848.16 g/plant). The variety Sree Athulya recorded significantly higher dry matter production than M_4 at all other growth stages too (Table 20).

With regard to the effect of month of planting, significantly higher dry matter production was recorded for October planting (89.20 g/plant). This was followed by May planting (59.99 g/plant) which was on par with December planting (57.38 g/plant) at 2 MAP. At 4 MAP, significantly higher dry matter production was recorded for May planting (1352.51 g/plant) and December planting (1346.00 g/plant). Lowest value was observed for October planting (888.73 g/plant). Considering the DMP, at 6 MAP, significantly higher DMP was recorded for May (2705.54 g/plant) followed by October planting (2197.50 g/plant) and December planting (2184.50 g/plant), which were on par. At 8 MAP, significantly higher DMP was recorded for October planting (4209.63 g/plant). Lowest value was observed for December planting (2905.50 g/plant). Similar trend was followed at 10 MAP.

Considering the interaction effect, significantly higher DMP at 2 MAP was recorded for Sree Athulya planted during October (89.23 g/plant), which was comparable with M_4 planted during October (89.16 g/plant). At 4 MAP, significantly higher DMP was recorded for Sree Athulya planted during May (1968.02 g/plant), which was on par with Sree Athulya planted during December (1590.00 g/plant). Lowest value was observed for M_4 (705.00 g/plant) planted during October and M_4 planted during May (737.00 g/plant), which were comparable. At 6 MAP, significantly higher DMP was observed for Sree Athulya planted during May (3542.08 g/plant). However, at 8 MAP, October planted Sree Athulya registered significantly higher DMP (5079.73 g/plant). Lowest DMP was observed for M_4 planted during December (2264.00 g/plant). Moving on to the last stage, significant higher DMP was recorded for Sree Athulya planted during May (8575.10 g/plant). Sree Athulya planted during October (8574.90 g/plant) and M_4

Table 20. Total dry matter production of normal-duration cassava varieties as influenced by variety and month of planting

Total dry matter production (g/plant)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	67.77	848.15	1872.67	3054.65	6282.72
Sree Athulya	69.94	1543.34	2852.36	4373.09	7234.00
SEd	-	46.32	79.13	109.79	173.93
CD (5 %)	NS	147.21	251.64	349.12	553.11
Month of planting (M)					
May	59.99	1352.51	2705.54	4026.49	8029.84
October	89.20	888.73	2197.50	4209.63	8211.75
December	57.38	1346.00	2184.50	2905.50	4033.50
SEd	3.09	5.47	95.54	145.50	327.05
CD (5 %)	6.70	113.88	207.32	315.73	709.69
Interaction (VXM)					
M_4 x May	55.97	737.00	1869.00	3560.42	7484.57
M_4 x Oct.	89.16	705.00	2069.00	3339.53	7848.59
M_4 x Dec.	58.16	1102.00	1680.00	2264.00	3515.00
Sree Athulya x May	64.00	1968.02	3542.08	4492.55	8575.10
Sree Athulya x Oct.	89.23	1072.00	2326.00	5079.73	8574.90
Sree Athulya x Dec.	56.59	1590.00	2689.00	3547.00	4552.00
SEd	4.36	74.21	135.12	205.76	462.52
CD (5 %)	9.47	161.05	293.20	446.51	1003.66

planted during October (7848.59 g/plant). Lowest DMP was recorded for M_4planted during December (3515.00 g/plant).

I.9. Shoot fresh weight

Shoot fresh weight was recorded through destructive sampling in all the plantings at regular intervals and data are shown in Table 21 and Table 22.

a. Short-duration varieties

With regard to the varieties, significantly higher shoot fresh weight was recorded for variety Sree Vijaya at 2, 4 and 6 MAP.

Data on effect of month of planting showed that May planted varieties had significantly higher shoot fresh weight at 2, 4 and 6 MAP.

Interaction effect of variety × month of planting revealed that at 2 MAP, that significantly higher shoot fresh weight was for Sree Vijaya planted during May (790.00 g/plant), followed by Vellayani Hraswa planted during May (672.03 g/plant). At 4 MAP, significantly higher shoot fresh weight was recorded for Sree Vijaya planted during May (1104.42 g/plant). This was followed by Vellayani Hraswa planted during May (921.30 g/plant). Lowest shoot fresh weight was recorded for Vellayani Hraswa planted during December (67.86 g/plant). At 6 MAP, significantly higher shoot fresh weight was observed for Sree Vijaya planted during May (2314.05 g/plant). This was followed by Vellayani Hraswa planted during May (1247.01 g/plant) and Sree Vijaya planted during October (1144.46 g/plant). Lowest shoot fresh weight was recorded for Vellayani Hraswa (721.72 g/plant) and Sree Vijaya (822.50 g/plant) planted during December.

b. Normal-duration varieties

Shoot fresh weight of varieties were found to be non-significant at 6 and 8 MAP. However, a higher shoot weight was observed for variety Sree Athulya at 2, 4 and 10 MAP (408.02, 817.83 and 2475.43 g/plant) compared to M_4 (342.35, 509.38 and 1619.77 g/plant). Moving on to the month of planting, significantly

Table 21.Shoot fresh weight of short-duration cassava varieties as influenced by variety and month of planting

Shoot fresh weight (g/plant)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	282.42	394.81	997.43
Sree Vijaya	385.02	538.39	1427.00
SEd	15.90	21.97	42.25
CD (5 %)	50.56	69.85	134.36
Month of planting (M)			
May	731.02	1012.86	1780.53
October	204.00	275.06	1084.01
December	66.15	111.88	772.11
SEd	23.12	32.03	61.63
CD (5 %)	50.18	69.50	133.73
Interaction (VXM)			
Vellayani Hraswa x May	672.03	921.30	1247.010
Vellayani Hraswa x Oct.	137.13	195.26	1023.56
Vellayani Hraswa x Dec.	38.10	67.86	721.72
Sree Vijaya x May	790.00	1104.42	2314.05
Sree Vijaya x Oct.	270.86	354.85	1144.46
Sree Vijaya x Dec.	94.19	155.90	822.50
SEd	32.70	45.29	87.16
CD (5 %)	70.96	98.29	189.13

Table 22. Shoot fresh weight of normal-duration cassava varieties as influenced by variety and month of planting

Shoot fresh weight (g/plant)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	342.35	509.38	1278.53	1451.14	1619.77
Sree Athulya	408.72	817.83	1220.11	1470.08	2475.43
SEd	15.96	31.29	-	-	79.08
CD (5 %)	50.51	99.50	NS	NS	251.46
Month of planting (M)					
May	797.69	1317.15	1936.15	2071.32	3199.75
October	245.34	488.99	968.88	1406.22	1783.81
December	83.58	184.68	842.93	904.30	1159.25
SEd	25.44	44.27	64.43	72.63	110.54
CD (5 %)	55.20	96.06	139.81	157.60	239.87
Interaction (VXM)					
M_4 x May	781.53	989.10	2127.10	2198.40	2152.80
M_4 x Oct.	188.71	448.41	909.56	1264.22	1688.01
M_4 x Dec.	56.80	90.63	798.92	890.80	1018.49
Sree Athulya x May	813.85	1645.19	1745.19	1944.24	4246.69
Sree Athulya x Oct.	301.96	529.56	1028.20	1548.21	1879.60
Sree Athulya x Dec.	110.35	278.73	886.93	917.80	1300.00
SEd	35.97	62.60	91.12	102.71	156.33
CD (5 %)	78.06	135.85	197.72	222.89	339.24

higher shoot fresh weight was observed for May planting (797.68 g/plant) followed by October planting (245.34 g/plant). Lowest value was recorded for December planting (83.58 g/plant) at 2 MAP. Same trend was observed at 4, 8 and 10 MAP. At 6 MAP, significantly higher shoot fresh weight was observed for May planting (1936.15 g/plant). This was followed by October planting (968.88 g/plant) and December planting (842.93 g/plant), which were comparable.

Considering the interaction effect, at 2 MAP, significantly higher shoot fresh weight was observed for Sree Athulya (813.85 g/plant) and M_4(781.53 g/plant) planted during May. At 4 MAP, May planted Sree Athulya variety recorded significantly higher shoot fresh weight (1645.19 g/plant), which was on par with M_4planted during May (989.10 g/plant). Similar trend was followed at 6 MAP. At 8 MAP, shoot fresh weight was higher for May planted M_4 variety (2198.40 g/plant) and this was followed by Sree Athulya planted during May (1944.24 g/plant). Lowest shoot fresh weight was observed for M_4 and Sree Athulya planted during December.

I.10. Root fresh weight

a. Short-duration varieties

No significant difference in root fresh weight was observed for varieties at 2 and 4 MAP. Significantly higher root fresh weight was recorded for Sree Vijaya at 6 MAP (1254.88 g/plant).

May planting showed significantly higher root fresh weight at all the stages. This was followed by October planting and December planting (Table 23).

Interaction effect of treatments showed that a significantly higher root fresh weight was recorded for Vellayani Hraswa planted during May (459.20 g/plant). This was followed by May planted Sree Vijaya (386.93 g/plant) at 2 MAP. At 4 MAP, significantly higher root fresh weight was recorded for Sree Vijaya planted during May (1323.40 g/plant) and the lowest weight was recorded for Sree Vijaya and Vellayani Hraswa planted during December. At 6 MAP, Sree Vijaya planted during May recorded significantly higher root fresh weight (1750.03 g/plant) and

Table 23. Root fresh weight of short-duration cassava varieties as influenced by variety and month of planting

Root fresh weight (g/plant)			
	2 MAP	4 MAP	6 MAP
Variety (V)			
Vellayani Hraswa	198.83	566.41	1090.88
Sree Vijaya	205.36	721.33	1254.88
SEd	-	-	133.76
CD (5 %)	NS	NS	425.36
Month of planting (M)			
May	423.07	1270.77	1585.17
October	130.25	496.70	1292.50
December	52.98	164.15	746.07
SEd	58.44	34.14	25.56
CD (5 %)	126.82	74.09	55.47
Interaction (VXM)			
Vellayani Hraswa x May	459.20	1218.13	1420.30
Vellayani Hraswa x Oct.	82.03	298.10	1201.00
Vellayani Hraswa x Dec.	55.26	183.00	651.33
Sree Vijaya x May	386.93	1323.40	1750.03
Sree Vijaya x Oct.	178.46	695.30	1384.00
Sree Vijaya x Dec.	50.70	145.30	840.80
SEd	16.04	48.29	36.15
CD (5 %)	34.81	104.79	78.45

was comparable with May planted Vellayani Hraswa (1420.30 g/plant) and October planted Sree Vijaya variety (1384.00 g/plant). Lowest root fresh weight was recorded for Vellayani Hraswa planted during December (651.33 g/plant).

b. Normal-duration varieties

Variety Sree Athulya recorded significantly higher root fresh weight at 2, 4 and 6 MAP. But a non-significant effect of variety on root fresh weight was recorded at 8 and 10 MAP (Table 24).

Considering the month of planting, at 2 MAP, May planting showed significantly higher root fresh weight (661.12 g/plant). This was followed by December planting (119.72 g/plant) and October planting (84.65 g/plant), which were on par. Similar trend was observed at 4 and 10 MAP. At 6 and 8 MAP, significantly higher root fresh weight was observed for May planting and was followed by October and December planting, which were on par.

Interaction effect revealed that at all the growth stages significantly higher root fresh weight was observed for Sree Athulya planted during May at 10 MAP. This was followed by M_4 planted during May. At 10 MAP lowest root fresh weight was observed for M_4 planted during December (1000.00 g/plant).

I.2. Physiological parameters

Physiological parameters like chlorophyll content, relative leaf water content, leaf sugar content, proline, nitrate reductase activity, photosynthetic activity and stomatal conductance were recorded.

I.2.1.Chlorophyll a content

Photosynthetic pigment content is an important indicator for plants under drought stress.

a. Short-duration varieties

No significant difference in chlorophyll a content was recorded between varieties at all growth stages (Table 25).

Table 24. Root fresh weight of normal-duration cassava varieties as influenced by variety and month of planting

Root fresh weight (g/plant)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	245.58	742.30	1279.17	1511.86	1667.74
Sree Athulya	331.41	987.21	1394.81	1702.24	1919.82
SEd	9.41	17.19	29.51	-	-
CD (5 %)	29.92	54.65	93.84	NS	NS
Month of planting (M)					
May	661.12	1870.16	2575.05	2884.14	3055.28
October	84.65	395.77	993.44	1100.52	1201.05
December	119.72	328.33	442.48	836.51	1125.00
SEd	18.29	60.67	60.14	65.54	64.60
CD (5 %)	39.68	131.64	130.50	142.23	140.17
Interaction (VXM)					
M_4 x May	534.20	1468.80	2350.10	2780.06	2900.11
M_4 x Oct.	87.83	422.40	989.46	1017.42	1103.10
M_4 x Dec.	114.70	335.70	497.96	738.11	1000.00
Sree Athulya x May	788.03	2271.51	2799.99	2988.21	3210.45
Sree Athulya x Oct.	81.46	369.138	997.42	1183.62	1299.00
Sree Athulya x Dec.	124.73	320.96	387.00	934.90	1250.00
SEd	25.86	85.80	85.05	92.69	91.35
CD (5 %)	56.11	186.18	184.56	201.14	198.24

Table 25. Chlorophyll a content of short-duration cassava varieties as influenced by variety and month of planting

Chlorophyll a (mg/g)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	0.74	1.14	1.08
Sree Vijaya	0.94	1.27	1.15
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	0.35	1.30	0.87
October	1.84	1.00	1.26
December	0.35	1.25	1.23
SEd	0.05	0.01	0.01
CD (5 %)	0.11	0.02	0.03
Interaction (VXM)			
Vellayani Hraswa x May	0.27	1.46	0.93
Vellayani Hraswa x Oct.	1.69	0.83	1.23
Vellayani Hraswa x Dec.	0.27	1.11	1.08
Sree Vijaya x May	0.42	1.14	0.80
Sree Vijaya x Oct.	1.98	1.29	1.28
Sree Vijaya x Dec.	0.42	1.38	1.37
SEd	0.07	0.01	0.02
CD (5 %)	0.15	0.03	0.04

Direct effect of month of planting showed that significantly higher chlorophyll a content was recorded for October planting (1.84 mg/g), followed by May and December planting (0.35 mg/g) at 2 MAP. At 4 MAP, significantly higher chlorophyll a content was observed for May planting (1.30 mg/g). This was followed by December planting (1.25 mg/g). Lowest chlorophyll a content was recorded for October planting (1.00 mg/g). At 6 MAP, significantly higher chlorophyll a content was observed for October planting (1.26 mg/g) and was on par with December (1.23 mg/g) planting. Lowest was recorded for May planting (0.87 mg/g).

Interaction of varieties with months of planting revealed that Sree Vijaya planted in October had significantly higher chlorophyll a content (1.98 mg/g). But at 4 MAP, chlorophyll a content was found to be significantly high for Vellayani Hraswa planted during May (1.46 mg/g). Lowest chlorophyll a content at 4 MAP was for Vellayani Hraswa planted during October (0.83 mg/g). At 6 MAP, significantly higher chlorophyll a content was for Sree Vijaya planted during December (1.37 mg/g) and was followed by Sree Vijaya planted during October (1.28 mg/g). Lowest value was noted for May planted Sree Vijaya (0.80 mg/g).

b. Normal-duration varieties

Effect of variety on chlorophyll a content was non-significant at 2, 4, 8 and 10 MAP, and the data are given in Table 26. At 6 MAP, Sree Athulya had significantly higher chlorophyll content (1.56 mg/g) than M_4 (1.40 mg/g).

Considering the effect of month of planting, at 2 MAP significantly higher chlorophyll a content was observed for October planting (1.50 mg/g). This was followed by May and December planting (0.42 mg/g), which were comparable. At 4 MAP, significantly higher chlorophyll a content was observed for May planting (2.14 mg/g), and followed by October planting (1.24 mg/g), which was on par with December planting (1.21 mg/g). However at 6 MAP, significantly higher chlorophyll a content was recorded for October planting (1.58 mg/g), which was comparable with December planting (1.53 mg/g). Lowest value was recorded for May planting (1.34 mg/g). At 8 and 10 MAP, significantly higher chlorophyll a content was noted for October planting, which was on par with May planting.

Table 26. Chlorophyll a content of normal-duration cassava varieties as influenced by variety and month of planting

Chlorophyll a (mg/g)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	0.79	1.54	1.40	1.03	0.84
Sree Athulya	0.76	1.51	1.56	1.13	0.95
SEd	-	-	0.03	-	-
CD (5 %)	NS	NS	0.10	NS	NS
Month of planting (M)					
May	0.42	2.14	1.34	1.12	0.95
October	1.50	1.24	1.58	1.16	1.01
December	0.42	1.21	1.53	0.96	0.73
SEd	0.03	0.02	0.01	0.06	0.03
CD (5 %)	0.06	0.06	0.01	0.14	0.07
Interaction (VXM)					
M_4 x May	0.37	2.11	1.23	1.01	0.89
M_4 x Oct.	1.64	1.35	1.40	1.14	0.94
M_4 x Dec.	0.37	1.17	1.57	0.94	0.70
Sree Athulya x May	0.46	2.17	1.44	1.22	1.01
Sree Athulya x Oct.	1.35	1.12	1.76	1.18	1.08
Sree Athulya x Dec.	0.46	1.24	1.48	0.98	0.76
SEd	0.04	0.04	0.01	0.09	0.05
CD (5 %)	0.09	0.08	0.02	0.20	0.11

Considering the interaction effect, significantly higher chlorophyll a content was recorded for M_4 planted during October (1.64 mg/g) at 2 MAP. This was followed by Sree Athulya planted during October (1.35 mg/g). At 4 MAP, significantly higher chlorophyll a content was for Sree Athulya and M_4 planted during May (2.17 and 2.11 mg/g respectively), which were on par and the lowest recorded was for October planted Sree Athulya (1.12 mg/g). At 6 MAP, highest chlorophyll a content was registered for Sree Athulya planted during October (1.76 mg/g), followed by Sree Athulya planted during May (1.44 mg/g) and M_4 planted during October (1.40 mg/g). Lowest value was recorded for M_4 planted during May (1.23 mg/g). At 8 MAP, significantly higher chlorophyll a content was observed for Sree Athulya planted during May (1.22 mg/g), Sree Athulya planted during October (1.18 mg/g) and M_4 planted during October (1.14 mg/g), which were all on par. Lowest content was recorded for M_4 planted in December (0.94 mg/g) followed by Sree Athulya planted in December (0.98 mg/g). At 10 MAP, significantly higher chlorophyll a content was for Sree Athulya planted in October (1.08 mg/g) and Sree Athulya planted in May (1.01mg/g), which were comparable. This was followed by M_4 planted during October (0.94 mg/g). Lowest chlorophyll a content was observed for M_4 planted in December (0.70 mg/g), which was on par with Sree Athulya planted during December (0.76 mg/g).

I.2.2. Chlorophyll b content

a. Short-duration varieties

No significant difference in chlorophyll b content was recorded between varieties at all growth stages (Table 27).

October planting was observed to have significantly higher chlorophyll b content (1.21 mg/g) at 2 MAP. This was followed by May planting (0.59 mg/g). However at 4 MAP, May planting had significantly high chlorophyll b content (0.98 mg/g) and was followed by October planting with a value of 0.86mg/g. Similar trend was noticed at 6 MAP. For all the growth stages, significantly lower chlorophyll b content was observed for December planting.

With regard to interaction effect, at 2 MAP, significantly higher chlorophyll b content was observed for Sree Vijaya planted in October (1.30 mg/g). This was followed by Vellayani Hraswa of October planting (1.11mg/g) and the lowest value recorded was for Sree Vijaya and Vellayani Hraswa planted during December (0.32 mg/g). At 4 MAP, chlorophyll b content was significantly higher for Vellayani Hraswa planted during May (1.05mg/g). This was followed by Sree Vijaya planted during October (0.98 mg/g). Lowest value was noticed for December planted Sree Vijaya (0.38 mg/g). Significantly higher chlorophyll b content at 6 MAP was noticed for Vellayani Hraswa planted during May (1.45 mg/g), followed by Sree Vijaya planted during May (1.18 mg/g). Chlorophyll b content was significantly lower for Vellayani Hraswa planted during December (0.27 mg/g) and Sree Vijaya planted during October (0.29 mg/g).

b. Normal-duration varieties

No significant difference in chlorophyll b content was observed between varieties at 2 and 10 MAP. At 4 MAP, significantly higher chlorophyll b content was for M_4 (1.07 mg/g) than for Sree Athulya (0.89 mg/g). At 6 MAP, chlorophyll b content was significantly higher for Sree Athulya (1.01 mg/g), than for M_4 (0.93 mg/g). Same trend was followed at 6 MAP (Table 28).

Result on effect of month of planting revealed that significantly higher chlorophyll b content was noted for October planting (0.75 mg/g) which was comparable with May planting (0.74 mg/g) at 2 MAP. Lowest chlorophyll b was noted for December planting (0.28mg/g). At 4 MAP, significantly higher chlorophyll b content was recorded for May planting (1.67 mg/g). This was followed by October planting (0.94 mg/g) and December planting (0.34mg/g). Trend was similar for 8 and 10 MAP.

Interaction effect of varieties with months of planting showed that at 2 MAP, significantly higher chlorophyll b content was noted for Sree Athulya planted during October (0.79 mg/g). This was comparable with M_4 planted during May (0.76 mg/g). At 4 MAP, significantly higher chlorophyll b content was obtained for Sree Athulya (1.68 mg/g) and M_4 (1.65 mg/g) when planted in the month of May. This was followed by M_4 planted during October (1.20 mg/g). Lowest chlorophyll b content

Table 27.Chlorophyll b content of short-duration cassava varieties as influenced by variety and month of planting

Chlorophyll b (mg/g)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	0.66	0.79	0.79
Sree Vijaya	0.75	0.75	0.63
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	0.59	0.98	1.32
October	1.21	0.86	0.46
December	0.32	0.48	0.35
SEd	0.02	0.01	0.03
CD (5 %)	0.06	0.03	0.06
Interaction (VXM)			
Vellayani Hraswa x May	0.55	1.05	1.45
Vellayani Hraswa x Oct.	1.11	0.74	0.64
Vellayani Hraswa x Dec.	0.32	0.57	0.27
Sree Vijaya x May	0.62	0.90	1.18
Sree Vijaya x Oct.	1.30	0.98	0.29
Sree Vijaya x Dec.	0.32	0.38	0.42
SEd	0.03	0.02	0.04
CD (5 %)	0.08	0.05	0.09

Table 28. Chlorophyll b content of normal-duration cassava varieties as influenced by variety and month of planting

Chlorophyll b (mg/g)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	0.59	1.07	0.93	0.76	0.50
Sree Athulya	0.58	0.89	1.01	0.80	0.54
SEd	-	0.01	0.02	0.08	-
CD (5 %)	NS	0.02	0.06	0.27	NS
Month of planting (M)					
May	0.74	1.67	2.07	1.77	1.08
October	0.75	0.94	0.43	0.35	0.32
December	0.28	0.34	0.42	0.23	0.18
SEd	0.01	0.03	0.04	0.05	0.029
CD (5 %)	0.03	0.07	0.10	0.10	0.06
Interaction (VXM)					
M_4 x May	0.76	1.65	2.00	1.76	1.05
M_4 x Oct.	0.71	1.20	0.42	0.33	0.30
M_4 x Dec.	0.31	0.36	0.37	0.20	0.16
Sree Athulya x May	0.72	1.68	2.13	1.78	1.10
Sree Athulya x Oct.	0.79	0.68	0.43	0.37	0.34
Sree Athulya x Dec.	0.24	0.31	0.46	0.25	0.19
SEd	0.02	0.05	0.07	0.07	0.04
CD (5 %)	0.04	0.10	0.15	0.15	0.08

was for December planted Sree Athulya (0.31 mg/g) which was comparable with M_4 (0.36 mg/g) planted in the same month. At 6 MAP, significantly higher chlorophyll b content was recorded for Sree Athulya planted during May (2.13mg/g) and M_4 planted during May (1.76 mg/g) which were comparable. Similar trend was noticed at 8 and 10 MAP.

I.2.3. Relative leaf water content

Relative leaf water content was recorded at 2, 4, and 6 MAP for short-duration varieties and 2, 4, 6, 8 and 10 MAP for normal-duration varieties and values are given in Table 29 and Table 30 respectively.

a. **Short- duration varieties**

No significant difference in relative water content of leaf due to effect of variety was noticed at all growth stages.

Considering the effect of month of planting, significantly higher leaf water content was observed for May (93.66 %) at 2 MAP. This was followed by October planting (75.85 %) and the lowest was noticed for December planting (39.58 %). Similar trend was recorded for observations at 6 MAP. However, at 4 MAP, significantly higher relative leaf water content was observed for October planting (69.14 %) and was followed by May planting (54.45 %). Lowest relative leaf water content was recorded for December planting (51.30 %).

Data on interactions revealed that at 2 MAP, significantly higher relative leaf water content was noticed for Sree Vijaya planted during May (94.47 %) which was on par with Vellayani Hraswa planted during May (92.85 %) and this was followed by Sree Vijaya planted during October (79.77 %). Lowest relative leaf water content was noticed for both varieties planted in December, which were on par. At 4 MAP, May planted short-duration variety Sree Vijaya recorded significantly higher relative leaf water content (75.45 %). This was followed by Vellayani Hraswa planted in October (62.83 %). Relative leaf water content was lowest for Vellayani Hraswa planted in December (44.36 %). Data on relative leaf water content at 6 MAP, showed that May planted Sree Vijaya variety had significantly higher relative leaf water content (74.49

%). This was followed by October planted Sree Vijaya (68.44 %) and May planted Vellayani Hraswa (69.92 %). Lowest value was noted for Vellayani Hraswa planted during December (42.58 %).

b. Normal- duration varieties

Comparing the effect of normal- duration varieties, no significant difference in relative leaf water content was recorded for normal-duration varieties at 2, 4, 6, 8 and 10 MAP.

At 2 MAP, May planting (84.75 %) resulted in significantly higher relative leaf water content and was followed by October planting (74.18 %) and the lowest noted was for December planting (55.90 %). Similar trend was maintained at 4 and 6 MAP. At 8 MAP, significantly higher relative leaf water content noticed for December planting (83.35 %) and was comparable with October planting (82.81 %). This was followed by May planting (69.55 %). At 10 MAP, significantly higher relative leaf water content was noticed for October planting (75.75 %). This was followed by December planting (72.10 %). Lowest value was noticed for May planting (61.15 %).

Moving on to the interaction of variety x month of planting, significantly higher relative leaf water content at 2 MAP was noted for Sree Athulya planted during May (89.56%). This was followed Sree Athulya planted in October (81.19 %) and M_4 planted during May (79.93 %), which were comparable. At 4 MAP, significantly higher relative leaf water content was observed for M_4 planted during May (85.58 %) and was followed by Sree Athulya planted during October (80.59 %). At 6 MAP, significantly higher relative leaf water content was recorded for M_4 planted during May (90.71 %) followed by Sree Athulya planted during October (86.24 %) and May (86.45 %). Lowest value was noticed for M_4 planted during December at 2, 4 and 6 MAP. At 8 MAP, significantly higher relative leaf water content was noticed for Sree Athulya planted during December (85.80 %) which was on par with Sree Athulya planted during October (84.70 %). This was followed by M_4 planted during October (80.91%) and December (80.90 %). Lowest value was for M_4 planted during May

Table 29. Relative leaf water content of short-duration cassava varieties as influenced by variety and month of planting

Relative leaf water content (%)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	67.33	52.96	56.66
Sree Vijaya	72.06	63.63	62.94
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	93.66	54.45	72.21
October	75.85	69.14	62.97
December	39.58	51.30	44.24
SEd	1.61	0.58	0.85
CD (5 %)	3.50	1.26	1.85
Interaction (VXM)			
Vellayani Hraswa x May	92.85	51.69	69.92
Vellayani Hraswa x Oct.	71.93	62.83	57.49
Vellayani Hraswa x Dec.	37.22	44.36	42.58
Sree Vijaya x May	94.47	57.21	74.49
Sree Vijaya x Oct.	79.77	75.45	68.44
Sree Vijaya x Dec.	41.94	58.24	45.89
SEd	2.281	0.82	1.20
CD (5 %)	4.95	1.78	2.62

Table 30. Relative leaf water content of normal-duration cassava varieties as influenced by variety and month of planting

Relative leaf water content (%)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	64.87	74.33	80.11	76.84	68.23
Sree Athulya	78.35	78.50	83.52	80.30	71.10
SEd	-	-	-	-	-
CD (5 %)	NS	NS	NS	NS	NS
Month of planting (M)					
May	84.75	81.65	88.58	69.55	61.15
October	74.18	77.94	81.39	82.81	75.75
December	55.90	69.66	75.48	83.35	72.10
SEd	0.73	0.36	0.34	0.47	0.44
CD (5 %)	1.58	0.78	0.75	1.02	0.97
Interaction (VXM)					
M_4 x May	79.93	85.58	90.71	68.70	59.80
M_4 x Oct.	67.17	75.28	76.54	80.91	74.00
M_4 x Dec.	47.51	62.12	73.08	80.90	70.90
Sree Athulya x May	89.56	77.72	86.45	70.40	62.50
Sree Athulya x Oct.	81.19	80.59	86.24	84.70	77.50
Sree Athulya x Dec.	64.29	77.19	77.87	85.80	73.30
SEd	1.03	0.50	0.48	0.66	0.63
CD (5 %)	2.24	1.10	1.06	1.44	1.37

(68.70 %). At 10 MAP, significantly higher relative leaf water content was noticed for Sree Athulya planted during October (77.50 %). This was followed by M_4 planted during October (74.00 %) and Sree Athulya planted during December (73.30 %). Lowest relative leaf water content was noticed for May planted M_4 variety (59.80 %).

I.2.4. Leaf sugar content

a. Short- duration varieties

Leaf sugar content was recorded during the crop growing season. Leaf sugar content was not significantly affected due to variety at all growth stages (Table 31)

May planting had significantly higher leaf sugar content at 2 MAP (2.93 %). This was followed by October planting (2.71 %) and lowest was recorded for December planting (2.41 %). Similar trend was recorded at 4 and 6 MAP.

Taking into account the interaction effect, Sree Vijaya planted during May exhibited significantly higher leaf sugar content (2.96 %) at 2 MAP. This was followed by Sree Vijaya planted during October (2.81 %). Lowest leaf sugar content was noted for Sree Vijaya planted during December (2.32 %). At 4 MAP, significantly higher leaf sugar content was observed for Sree Vijaya planted during May (11.76 %) and Sree Vijaya planted during October (11.01 %), which were on par. Lowest value was recorded for Vellayani Hraswa (8.06 %) and Sree Vijaya (8.22 %) planted during December. At 6 MAP, significantly higher leaf sugar content was recorded for Sree Vijaya planted during May (9.00 %). This was followed by October planted Sree Vijaya (8.54 %). Lowest value was recorded for Sree Vijaya planted during December (7.25 %).

b. Normal-duration varieties

Leaf sugar content was significantly high for Sree Athulya (2.93 %) than M_4 (2.73 %), at 2 MAP. No significant difference in leaf sugar content due to varietal effect was recorded at 4, 6, 8 and 10 MAP (Table 32)

Table 31. Leaf sugar content of short-duration cassava varieties as influenced by variety and month of planting

Leaf sugar content (%)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	2.67	9.54	7.76
Sree Vijaya	2.70	10.33	8.26
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	2.93	11.06	8.60
October	2.71	10.61	8.29
December	2.41	8.14	7.14
SEd	0.03	0.09	0.04
CD (5 %)	0.07	0.21	0.10
Interaction (VXM)			
Vellayani Hraswa x May	2.96	10.36	8.20
Vellayani Hraswa x Oct.	2.60	10.21	8.04
Vellayani Hraswa x Dec.	2.49	8.060	7.03
Sree Vijaya x May	2.96	11.76	9.00
Sree Vijaya x Oct.	2.81	11.01	8.54
Sree Vijaya x Dec.	2.32	8.22	7.25
SEd	0.04	0.13	0.06
CD (5 %)	0.10	0.30	0.147

Table 32. Leaf sugar content of normal-duration cassava varieties as influenced by variety and month of planting

Leaf sugar content (%)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	2.73	10.70	8.73	9.27	6.91
Sree Athulya	2.93	11.40	9.09	10.00	7.37
SEd	0.04	-	-	-	-
CD (5 %)	0.14	NS	NS	NS	NS
Month of planting (M)					
May	3.05	13.53	9.92	10.78	7.45
October	2.84	10.99	8.98	9.69	7.11
December	2.61	8.64	7.84	8.44	6.86
SEd	0.06	0.12	0.05	0.06	0.01
CD (5 %)	0.14	0.28	0.12	0.15	0.04
Interaction (VXM)					
M_4 x May	3.00	12.86	9.52	10.22	7.02
M_4 x Oct.	2.76	10.75	8.95	9.27	6.98
M_4 x Dec.	2.42	8.50	7.72	8.33	6.74
Sree Athulya x May	3.10	14.20	10.32	11.34	7.88
Sree Athulya x Oct.	2.91	11.23	9.00	10.11	7.24
Sree Athulya x Dec.	2.78	8.78	7.95	8.54	6.98
SEd	0.08	0.18	0.07	0.10	0.02
CD (5 %)	0.19	0.40	0.17	0.22	0.06

Leaf sugar content was significantly higher for May planting (3.05 %), followed by October (2.84 %) and lowest value recorded was 2.61 % for December planting. Similar trend was maintained for all the growth stages.

Interaction effect of variety with month of planting at 2 MAP showed that significantly higher leaf sugar content was exhibited by Sree Athulya planted during May (3.10 %), followed by M_4planted during May (3.00 %) and Sree Athulya planted during October (2.91 %), which were all on par. Lowest leaf sugar content was recorded for M_4 planted during December (2.42 %). At 4 MAP, significantly higher leaf sugar content was recorded for Sree Athulya planted during May (14.20 %), and was followed by M_4 planted during May (12.86 %). Leaf sugar content was lowest for M_4 planted during December (8.50 %) and was comparable with Sree Athulya planted during December (8.78 %). Similar trend was observed at 6, 8 and 10 MAP, with lowest leaf sugar content recorded for M_4 planted during December.

I.2.5. Proline content

Proline content plays a vital role in determining tolerance of a crop to drought stress.

a. Short- duration varieties

From table 33, it was noted that proline content was significantly higher for Vellayani Hraswa at 2 MAP (73.73 mg/g) followed by Sree Athulya (69.87 mg/g). Variety had no significant effect on proline content at 4 and 6 MAP.

With regard to month of planting, December planting recorded significantly higher proline content (90.24 mg/g) at 2 MAP. This was followed by October planting (65.39 mg/g). The same trend was maintained at both 4 and 6 MAP.

Considering the interaction effect at 2 MAP, significantly higher proline content was for Sree Vijaya planted during December (92.11 mg/g) and was followed by Vellayani Hraswa planted during December (88.36 mg/g). Lowest proline content was for Sree Vijaya planted during May (57.73 mg/g), and October (59.77 mg/g). At 4 MAP, significantly higher proline content was exhibited by Vellayani Hraswa planted during October (85.16 mg/g). At 6 MAP, significantly higher value was for Vellayani

Table 33. Proline content of short-duration cassava varieties as influenced by variety and month of planting

Proline content (mg/g)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	73.73	70.49	82.51
Sree Vijaya	69.87	57.96	68.03
SEd	7.81	-	-
CD (5 %)	24.84	NS	NS
Month of planting (M)			
May	59.78	48.95	43.30
October	65.39	69.22	75.32
December	90.24	74.52	107.20
SEd	1.01	0.94	1.85
CD (5 %)	2.20	2.06	4.03
Interaction (VXM)			
Vellayani Hraswa x May	61.82	53.45	50.15
Vellayani Hraswa x Oct.	71.00	85.16	79.46
Vellayani Hraswa x Dec.	88.36	72.87	117.93
Sree Vijaya x May	57.73	44.45	36.44
Sree Vijaya x Oct.	59.77	53.27	71.17
Sree Vijaya x Dec.	92.11	76.16	96.47
SEd	1.43	1.34	2.62
CD (5 %)	3.12	2.92	5.70

Hraswa planted during December (117.93 mg/g) followed by Sree Athulya planted during December (96.47 mg/g). Lowest proline content was recorded for Sree Vijaya planted during May (36.44 mg/g).

b. Normal- duration varieties

Considering the varietal effect, at 2 MAP, significantly higher proline content was recorded for M_4 (87.12 mg/g) as compared to Sree Athulya (56.48 mg/g). Similar trend was followed at 6 MAP. At 4 MAP, significantly higher proline content was recorded for Sree Athulya (49.98 mg/g) than for M_4 (43.68 mg/g). But there were no significant difference in the proline content at 8 and 10 MAP (Table 34)

Direct effect of month of planting showed a significantly higher proline content for October planting (77.06 mg/g) at 2 MAP. This was followed by December planting (69.93 mg/g) and the lowest was noted for May planting (68.42 mg/g). Similar trend was followed at 4 MAP. At 6 MAP, significantly higher proline content was exhibited for December planting (86.50 mg/g), and this was followed by October planting (68.77 mg/g). Lowest proline content was recorded for May planting (28.87 mg/g). Similar trend was followed at 8 and 10 MAP except that the lowest proline content was recorded for October planting (34.95 mg/g) at 10 MAP.

With regard to the interaction effect, at 2 MAP, significantly higher proline content was for M_4 planted during October (104.04 mg/g) followed by May planted M_4 (79.64 mg/g). Lowest proline content was for Sree Athulya planted during October (50.07 mg/g). At 4 MAP, significantly higher proline content was recorded for Sree Athulya planted during October (58.88 mg/g). This was followed by Sree Athulya planted during December (56.30 mg/g). Lowest proline content was exhibited for M_4 planted during May (30.20 mg/g). At 6 MAP, significantly higher proline content was for M_4 planted during December (89.97 mg/g). This was followed by Sree Athulya planted during December (83.02 mg/g). Lowest protein content was for M_4 planted during May (28.24 mg/g) followed by Sree Athulya planted during May (29.49 mg/g). At 8 MAP, significantly higher proline content was observed for M_4 planted during December (85.30 mg/g) and was followed by Sree Athulya planted during December (79.80 mg/g). Lowest value was recorded for Sree Athulya planted during May (39.80 mg/g). At 10 MAP, higher proline content was exhibited by M_4 planted during

Table 34.Proline content of normal-duration cassava varieties as influenced by variety and month of planting

Proline content (mg/g)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	87.12	43.68	63.25	60.27	58.23
Sree Athulya	56.48	49.98	59.51	55.00	55.63
SEd	0.45	1.14	0.90	-	-
CD (5 %)	1.46	3.64	2.89	NS	NS
Month of planting (M)					
May	68.42	32.48	28.87	42.75	60.25
October	77.06	54.88	68.77	47.60	34.95
December	69.93	53.14	86.50	82.55	75.60
SEd	0.50	0.65	1.48	1.27	1.22
CD (5 %)	1.10	1.42	3.23	2.76	2.65
Interaction (VXM)					
M_4 x May	79.64	30.20	28.24	45.70	57.80
M_4 x Oct.	104.04	50.87	71.53	49.80	37.90
M_4 x Dec.	77.68	49.98	89.97	85.30	79.00
Sree Athulya x May	57.19	34.75	29.49	39.80	62.70
Sree Athulya x Oct.	50.07	58.88	66.01	45.40	32.00
Sree Athulya x Dec.	62.18	56.30	83.02	79.80	72.20
SEd	0.71	0.931	2.10	1.80	1.72
CD (5 %)	1.56	2.02	4.57	3.91	3.75

December (79.00 mg/g). This was followed by December planted Sree Athulya variety (72.20 mg/g). Lowest proline content was noted for Sree Athulya planted at October (32.00 mg/g).

I.2.6. Nitrate reductase activity

Drought affected plants show changes in foliar nitrate reductase activity.

a. Short-duration varieties

Nitrate reductase activity was observed to be higher for Sree Vijaya compared to Vellayani Hraswa at 2, 4 and 6 MAP (Table 35).

Data on effect of month of planting showed significantly higher nitrate reductase activity for October planting at 2 MAP (49.86 µg NO_2/g/fresh leaf/h). This was followed by May planting (20.08 µg NO_2/g/fresh leaf/h) which was on par with December planting (19.37 µg NO_2/g/fresh leaf/h). Similar trend was noticed at 6 MAP. At 4 MAP, significantly higher nitrate reductase activity was observed for October planting (35.19 µg NO_2/g/fresh leaf/h) which was followed by December planting (25.22 µg NO_2/g/fresh leaf/h).The lowest value was exhibited by May planting (23.65 µg NO_2/g/fresh leaf/h).

At 2 MAP, Sree Vijaya planted during October recorded significantly higher nitrate reductase activity (65.81 µgNO_2/g/fresh leaf/h). This was followed by Vellayani Hraswa planted during October (33.90 µg NO_2/g/fresh leaf/h).

At 4 MAP, significantly higher nitrate reductase activity was exhibited by Sree Vijaya planted during October (48.72 µgNO_2/g/fresh leaf/h). This was followed by Sree Vijaya planted during May (31.05 µgNO_2/g/fresh leaf/h). Lowest nitrate reductase activity was for May planted Vellayani Hraswa (16.24 µgNO_2/g/fresh leaf/h). Similar trend was observed at 6 MAP, however, the second best interaction came out to be Vellayani Hraswa planted during October (18.50 µgNO_2/g/fresh leaf/h), followed by Sree Vijaya planted during May (17.66 µgNO_2/g/fresh leaf/h) and Sree Vijaya planted during December (16.80 µgNO_2/g/fresh leaf/h), which were comparable.

Table 35. Nitrate reductase activity of short-duration cassava varieties as influenced by variety and month of planting

Nitrate reductase activity (µg NO_2/g/fresh leaf/h)			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	24.9	19.75	13.67
Sree Vijaya	34.5	36.28	26.30
SEd	2.62	3.20	2.28
CD (5 %)	8.34	10.17	7.26
Month of planting (M)			
May	20.08	23.65	14.39
October	49.86	35.19	31.47
December	19.37	25.22	14.10
SEd	1.84	0.51	0.73
CD (5 %)	4.00	1.11	1.60
Interaction (VXM)			
Vellayani Hraswa x May	21.65	16.24	11.11
Vellayani Hraswa x Oct.	33.90	21.65	18.50
Vellayani Hraswa x Dec.	19.37	21.37	11.39
Sree Vijaya x May	18.51	31.05	17.66
Sree Vijaya x Oct.	65.81	48.72	44.43
Sree Vijaya x Dec.	19.37	29.06	16.80
SEd	2.60	0.72	1.04
CD (5 %)	5.65	1.57	2.26

b. Normal-duration varieties

Observations at 2, 4 and 6 MAP revealed a similar trend in the effect of variety on the activity of nitrate reductase. Sree Athulya had significantly higher nitrate reductase compared to M_4. However, no significant difference in nitrate reductase activity was recorded at 8 and 10 MAP (Table 36).

Regarding effect of month of planting, significantly higher nitrate reductase activity was observed for October planting (65.95 µg NO_2/g/fresh leaf/h) at 2 MAP. This was followed by December planting (27.21 µg NO_2/g/fresh leaf/h) and was lowest for May planting (16.09 µg NO_2/g/fresh leaf/h). At 10 MAP, a similar trend was seen. At 4 MAP, significantly higher nitrate reductase activity was for October planting (49.62 µg NO_2/g/fresh leaf/h) and December planting (47.01 µgNO_2/g/fresh leaf/h), which were on par. Lowest value was for May planting (31.19 µg NO_2/g/fresh leaf/h). Again at 6 MAP, significantly higher nitrate reductase activity was noticed for October planting (39.22 µg NO_2/g/fresh leaf/h).This was on par with May planting (37.92 µg NO_2/g/fresh leaf/h). Lowest value was for December planting (19.94 µgNO_2/g/fresh leaf/h). At 8 MAP, significantly higher nitrate reductase activity was recorded for October planting (57.65 µg NO_2/g/fresh leaf/h). This was followed by May planting (28.65 µg NO_2/g/fresh leaf/h). Lowest value was noticed for December planting (24.45 µg NO_2/g/fresh leaf/h).

Interaction effect showed that at 2 MAP, significantly higher nitrate reductase activity was for Sree Athulya planted during October (73.50 µgNO_2/g/fresh leaf/h). This was followed by M_4 planted during October (58.40 µg NO_2/g/fresh leaf/h). Lowest value was noted for Sree Athulya (14.24 µgNO_2/g/fresh leaf/h) and M_4 (17.94 µg NO_2/g/fresh leaf/h) planted during May. At 4 MAP, significantly higher nitrate reductase activity was for Sree Athulya planted during October (57.92 µgNO_2/g/fresh leaf/h) which was on par with Sree Athulya planted during December (53.27 µgNO_2/g/fresh leaf/h). Lowest value was observed for Sree Athulya planted during May (25.92 µg NO_2/g/fresh leaf/h). Significantly higher nitrate reductase activity was recorded again for Sree Athulya planted during October (50.71 µgNO_2/g/fresh leaf/h) at 6 MAP, followed by M_4 (40.74 µg NO_2/g/ fresh leaf/h) and Sree Athulya (37.89 µg

Table 36. Nitrate reductase activity of normal-duration cassava varieties as influenced by variety and month of planting

Nitrate reductase activity (µg NO_2/g/fresh leaf/h)					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	33.23	39.50	28.26	35.90	36.77
Sree Athulya	39.60	45.71	36.46	37.93	40.40
SEd	0.96	0.59	2.35	-	-
CD (5 %)	3.06	1.89	7.49	NS	NS
Month of planting (M)					
May	16.09	31.19	37.92	28.65	24.10
October	65.95	49.62	39.22	57.65	63.40
December	27.21	47.01	19.94	24.45	28.26
SEd	1.44	1.71	2.01	1.06	1.28
CD (5 %)	3.13	3.71	4.37	2.31	2.78
Interaction (VXM)					
M_4 x May	17.94	36.46	40.74	29.40	23.20
M_4 x Oct.	58.40	41.30	19.08	56.30	60.40
M_4 x Dec.	23.36	40.74	19.08	22.00	26.70
Sree Athulya x May	14.24	25.92	37.89	27.90	25.00
Sree Athulya x Oct.	73.50	57.92	50.71	59.00	66.40
Sree Athulya x Dec.	31.05	53.27	20.79	26.90	29.81
SEd	2.04	2.41	2.84	1.50	1.81
CD (5 %)	4.43	5.25	6.18	3.27	3.94

NO_2/g/fresh leaf/h) planted during May. At 8 MAP, significantly higher nitrate reductase activity was for Sree Athulya planted during October (59.00 µgNO_2/g/fresh leaf/h) and with M_4 planted during October (56.30 µgNO_2/g/fresh leaf/h). Lowest value was noticed for M_4 planted during December (22.00 µgNO_2/g/fresh leaf/h). At 10 MAP, Sree Athulya planted during December recorded significantly higher nitrate reductase activity (66.40 µgNO_2/g/fresh leaf/h). This was followed by M_4 planted during October (60.40 µgNO_2/g/fresh leaf/h). Lowest value was recorded for M_4 planted during May (23.20 µgNO_2/g/fresh leaf/h), which was comparable with Sree Athulya planted during May (25.00 µgNO_2/g/fresh leaf/h)

I.2.7. Photosynthetic rate

a. Short-duration varieties

Data on effect of variety showed that significantly higher photosynthetic rate was observed for Sree Vijaya (7.87 µ mol CO_2 /m^2 /sec) at 2 MAP than Vellayani Hraswa (5.83 µ mol CO_2 /m^2 /sec). Photosynthetic rates were not significantly different due to effect of variety at 6 MAP (Table 37)

Considering the effect of month of planting, significantly higher photosynthetic rate was observed for May planting (7.26 µmol CO_2 /m^2 /sec) at 2 MAP. This was followed by October planting (7.09 µmol CO_2 /m^2 /sec) and lowest was recorded for December planting (6.21 µmol CO_2 /m^2 /sec). At 6 MAP, highest photosynthetic rate was observed for October planted crop (8.01 µmol CO_2 /m^2 /sec), followed by May planted crop (7.66 µmol CO_2 /m^2 /sec) and December planted crop (7.40 µmol CO_2 /m^2 /sec).

With regard to the interaction effect, at 2 MAP, significantly higher photosynthetic rate was observed for Sree Vijaya when planted during May (8.09 µ mol CO_2 /m^2 /sec), followed by October planted Sree Vijaya (7.92 µmol CO_2 /m^2 /sec). Lowest photosynthetic rate was for Vellayani Hraswa planted during October (6.26 µmol CO_2 /m^2 /sec). However at 6 MAP, significantly higher photosynthetic rate was for October planted Sree Vijaya (8.20 µmol CO_2 /m^2 /sec), followed by Sree Vijaya planted

Table 37. Photosynthetic rate of short-duration cassava varieties as influenced by variety and month of planting

Photosynthetic rate (µ mol CO_2 /m^2 /sec)		
	2 MAP	**6 MAP**
Variety (V)		
Vellayani Hraswa	5.83	7.66
Sree Vijaya	7.87	7.72
SEd	0.76	-
CD (5 %)	2.43	NS
Month of planting (M)		
May	7.26	7.66
October	7.09	8.01
December	6.21	7.40
SEd	0.03	0.02
CD (5 %)	0.07	0.06
Interaction (VXM)		
Vellayani Hraswa x May	6.42	7.41
Vellayani Hraswa x Oct.	6.26	7.81
Vellayani Hraswa x Dec.	4.81	7.75
Sree Vijaya x May	8.09	7.91
Sree Vijaya x Oct.	7.92	8.20
Sree Vijaya x Dec.	7.60	7.04
SEd	0.04	0.03
CD (5 %)	0.10	0.08

during May (7.91 µ mol CO_2 /m^2 /sec). Lowest photosynthetic rate was noticed for Sree Vijaya planted during December (7.04 µ mol CO_2 /m^2 /sec).

b. Normal-duration varieties

Data on direct effect of variety on photosynthetic rate showed that Sree Athulya recorded higher at 2 and 6 MAP than M_4. However, no significant difference among varieties was noticed at 10 MAP (Table 38)

With regard to month of planting, significantly higher photosynthetic rate was for May planting (7.81 µmol CO_2 /m^2 /sec) at 2 MAP followed by October planting (6.70 µmol CO_2 /m^2 /sec). At 6 MAP, significantly higher photosynthetic rate was observed for October planting (10.69 µmol CO_2 /m^2 /sec). Lowest photosynthetic rate was recorded for December planting for all the growth stages.

Data on interaction of variety with month of planting revealed a significantly higher photosynthetic rate at 2 MAP in Sree Athulya planted during October (7.85 µ mol CO_2 /m^2 /sec) and M_4 planted during May (7.77 µmol CO_2 /m^2 /sec). At 6 MAP, significantly higher photosynthetic rate was observed for Sree Athulya planted during May (12.40 µmol CO_2 /m^2 /sec), which was comparable with Sree Athulya planted during October (11.45 µmol CO_2 /m^2 /sec). M_4 planted during May (8.98 µ mol CO_2 /m^2 /sec) and M_4 planted during December (9.07 µmol CO_2 /m^2 /sec) recorded lowest photosynthetic rates. At 10 MAP, Sree Athulya planted during October (8.01 µmol CO_2 /m^2 /sec) recorded significantly higher photosynthetic rate, followed by Sree Athulya planted during May (7.86 µmol CO_2 /m^2 /sec). Photosynthetic rate was lowest recorded for M_4 planted during December (6.21 µmol CO_2 /m^2 /sec).

I.2.8. Stomatal conductance

a. Short-duration varieties

Data on direct effect of variety on stomatal conductance showed that significantly higher stomatal conductance was for variety Sree Vijaya at 2 MAP (0.056 mol H_2O / m^2/ sec) and 6 MAP (0.120 mol H_2O / m^2/ sec) (Table 39).

Table 38. Photosynthetic rate of normal-duration cassava varieties as influenced by variety and month of planting

Photosynthetic rate (µ mol CO_2 /m^2 /sec)			
	2 MAP	**6 MAP**	**10 MAP**
Variety (V)			
M_4	6.25	9.38	7.00
Sree Athulya	7.22	11.71	7.57
SEd	0.16	0.30	-
CD (5 %)	0.53	0.96	NS
Month of planting (M)			
May	7.81	10.69	7.62
October	6.70	10.77	7.71
December	5.70	10.1	6.52
SEd	0.06	0.03	0.03
CD (5 %)	0.14	0.06	0.08
Interaction (VXM)			
M_4 x May	7.77	8.98	7.38
M_4 x Oct.	6.93	10.08	7.40
M_4 x Dec.	4.06	9.07	6.21
Sree Athulya x May	7.85	12.40	7.86
Sree Athulya x Oct.	6.47	11.45	8.01
Sree Athulya x Dec.	7.33	11.29	6.83
SEd	0.03	0.04	0.05
CD (5 %)	0.20	0.09	0.11

Month of planting at 2 MAP recorded a significantly higher stomatal conductance rate for May planting (0.065 mol H_2O / m^2/ sec) and October planting (0.063 mol H_2O / m^2/ sec), which were on par. At 6 MAP, significantly higher stomatal conductance rate was for December planting (0.110 mol H_2O / m^2/ sec). This was followed by May and October planting (0.060 mol H_2O / m^2/ sec).

Interaction effect of variety x month of planting, showed that at 2 MAP significantly higher stomatal conductance was for Sree Vijaya planted during October (0.077 mol H_2O / m^2/ sec), which was comparable with Sree Vijaya planted during May (0.074 mol H_2O / m^2/ sec),and was followed by Vellayani Hraswa planted during May (0.056 mol H_2O / m^2/ sec). At 6 MAP, significantly higher stomatal conductance was for Sree Vijaya when planted during December (0.213 mol H_2O / m^2/ sec). This was followed by Sree Vijaya planted during October (0.079 mol H_2O / m^2/ sec) and Sree Vijaya planted during May (0.071 mol H_2O / m^2/ sec). Vellayani Hraswa planted during December recorded the lowest stomatal conductance rate (0.005 mol H_2O / m^2/ sec).

b. Normal-duration varieties

Considering the direct effect of variety on stomatal conductance, no significant effect was obtained at 2 and 10 MAP (Table 40). Sree Athulya showed significantly higher stomatal conductance rate (0.012 mol H_2O / m^2/ sec) than M_4 (0.005 mol H_2O / m^2/ sec) at 6 MAP.

With regard to month of planting at 2 MAP, significantly higher stomatal conductance rate was recorded for May planting (0.070 mol H_2O / m^2/ sec). This was on par with October planting (0.060 mol H_2O / m^2/ sec). Lowest stomatal conductance rate was noted for December planting (0.020 mol H_2O / m^2/ sec). At 6 MAP, significantly higher stomatal conductance rate was for December planting (0.120 mol H_2O / m^2/ sec). This was followed by May planting (0.08 mol H_2O / m^2/ sec) and the lowest was for October planting (0.060 mol H_2O / m^2/ sec). Similar trend was maintained at 10 MAP.

Table 39. Stomatal conductance of short-duration cassava varieties as influenced by variety and month of planting

Stomatal conductance (mol H_2O / m^2/ sec)		
	2 MAP	**6 MAP**
Variety (V)		
Vellayani Hraswa	0.039	0.040
Sree Vijaya	0.056	0.120
SEd	0.005	0.010
CD (5 %)	0.017	0.031
Month of planting (M)		
May	0.065	0.060
October	0.063	0.060
December	0.015	0.110
SEd	0.002	0.004
CD (5 %)	0.004	0.008
Interaction (VXM)		
Vellayani Hraswa x May	0.056	0.057
Vellayani Hraswa x Oct.	0.048	0.050
Vellayani Hraswa x Dec.	0.012	0.005
Sree Vijaya x May	0.074	0.071
Sree Vijaya x Oct.	0.077	0.079
Sree Vijaya x Dec.	0.018	0.213
SEd	0.002	0.006
CD (5 %)	0.005	0.012

Table 40. Stomatal conductance of normal-duration cassava varieties as influenced by variety and month of planting

Stomatal conductance (mol H_2O / m^2/ sec)			
	2 MAP	**6 MAP**	**10 MAP**
Variety (V)			
M4	0.050	0.050	0.190
Sree Athulya	0.051	0.120	0.210
SEd	0.001	0.005	0.022
CD (5 %)	0.003	0.017	0.071
Month of planting (M)			
May	0.070	0.080	0.170
October	0.060	0.060	0.150
December	0.020	0.120	0.280
SEd	0.001	0.004	0.004
CD (5 %)	0.003	0.008	0.009
Interaction (VXM)			
M_4 x May	0.069	0.073	0.168
M_4 x Oct.	0.061	0.060	0.151
M_4 x Dec.	0.013	0.008	0.256
Sree Athulya x May	0.075	0.082	0.177
Sree Athulya x Oct.	0.052	0.061	0.157
Sree Athulya x Dec.	0.017	0.222	0.298
SEd	0.002	0.006	0.006
CD (5 %)	0.005	0.012	0.012

Considering the interaction effect, at 2 MAP, significantly higher stomatal conductance rate was for Sree Athulya planted during May (0.075 mol H_2O / m^2/ sec). This was followed by M_4 planted during May (0.069 mol H_2O / m^2/ sec). Lowest stomatal conductance was for M_4 (0.013 mol H_2O / m^2/ sec) and Sree Athulya (0.017 mol H_2O / m^2/ sec) planted during December, which were comparable with each other. At 6 MAP, significantly higher stomatal conductance rate was for Sree Athulya planted during December (0.222 mol H_2O / m^2/ sec). This was followed by Sree Athulya planted during May (0.082 mol H_2O / m^2/ sec) which was comparable with M_4 planted during May (0.073 mol H_2O / m^2/ sec). Lowest value was noted for M_4 planted during December (0.008 mol H_2O/m^2/sec). At 10 MAP, significantly higher stomatal conductance rate was observed for Sree Athulya planted during December (0.298 mol H_2O / m^2/ sec). The lowest value was recorded for M_4 planted during October (0.151 mol H_2O / m^2/ sec) and Sree Athulya planted during October (0.157 mol H_2O / m^2/ sec), which were on par.

I.3. Growth analysis

Crop-weather relations of four different cassava varieties of varying duration on different physiological growth indices were studied for May, October and December planted crops and the data are presented below.

I.3.1. Net assimilation rate

a. Short-duration varieties

No significant difference in net assimilation rate was noted for both varieties at stage I (0-60 DAP), II (60-120 DAP) and III (120-180 DAP) (Table 41).

Considering the direct effect of month of planting, at 2 MAP, significantly higher net assimilation rate was registered for October planting (3.16 g/g/day). NAR for December (2.69 g/g/day) and May (2.54 g/g/day) plantings were on par. At 4 MAP, significantly higher net assimilation rate was found for May planting (3.26 g/g/day), and October planting (3.23 g/g/day), which were comparable, and the lowest value was noted for December planting (2.15 g/g/day). However at 6 MAP, December planting recorded significantly higher net assimilation rate (8.71 g/g/day). This was followed by May planting (3.56 g/g/day). The lowest value was recorded for October planting (3.07 g/g/day).

The interaction effect of varieties with months of planting showed that a significantly higher net assimilation rate was achieved for Vellayani Hraswa planted during October (3.46 g/g/day). This was on par with Vellayani Hraswa planted during December (3.15 g/g/day). This was followed by Sree Vijaya planted during October (2.86 g/g/day) and Vellayani Hraswa planted during May (2.50 g/g/day), which were on par. Lowest net assimilation rate was observed for Sree Vijaya planted during December (2.23 g/g/day). At 4 MAP, October planted Sree Vijaya, recorded significantly higher net assimilation rate (3.73 g/g/day). This was on par with Sree Vijaya when planted during May (3.70 g/g/day). Lowest net assimilation rate was observed for Sree Vijaya planted during December (1.96 g/g/day). At 6 MAP, Vellayani Hraswa (8.96 g/g/day) and Sree Vijaya (8.46 g/g/day) when planted during December recorded significantly higher net assimilation rate.

b. Normal-duration varieties

At stage I (0-60 DAP), significantly higher net assimilation rate was recorded for M_4 (2.61 g/g/day) and was followed by Sree Athulya (2.11 g/g/day). No significant difference was recorded for net assimilation rate at stage II (60-120 DAP), II (120-180 DAP), IV (180-240 DAP) and V (240-300 DAP) (Table 42).

With regards to, data on months of planting, at stage I, significantly higher net assimilation rate was recorded for October planting (2.78 g/g/day). This was followed by May planting (2.30 g/g/day). Lowest net assimilation rate was recorded for December (2.00 g/g/day). At stage II , significantly higher net assimilation rate was registered for May planting (4.75 g/g/day) which was on par with October planting (4.72 g/g/day). At stage III, significantly higher net assimilation rate was recorded for December planting (5.12 g/g/day). It was followed by October planting (3.90 g/g/day), and lowest value was for May planting (3.47 g/g/day). Similar trend was observed at stage V. At stage IV, December planting recorded significantly higher NAR (7.64 g/g/day).This was followed by October planting (3.09 g/g/day) and May planting (2.93 g/g/day) which were on par.

Table 41. Net assimilation rate of short-duration cassava varieties as influenced by variety and month of planting

	Net assimilation rate (g/g/day)		
	Stage I (0-60 DAP)	**Stage II (60-120 DAP)**	**Stage III (120-180 DAP)**
Variety (V)			
Vellayani Hraswa	3.04	2.63	5.25
Sree Vijaya	2.56	3.13	4.97
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	2.54	3.26	3.56
October	3.16	3.23	3.07
December	2.69	2.15	8.71
SEd	0.11	0.04	0.18
CD (5 %)	0.25	0.10	0.39
Interaction (VXM)			
Vellayani Hraswa x May	2.50	2.82	3.38
Vellayani Hraswa x Oct.	3.46	2.73	3.40
Vellayani Hraswa x Dec.	3.15	2.33	8.96
Sree Vijaya x May	2.58	3.70	3.73
Sree Vijaya x Oct.	2.86	3.73	2.73
Sree Vijaya x Dec.	2.23	1.96	8.46
SEd	0.16	0.06	0.25
CD (5 %)	0.36	0.14	0.56

With regard to the interaction effect, at stage I, significantly higher net assimilation rate was recorded for M_4 when planted during October (3.50 g/g/day). Lowest value was for Sree Athulya when planted during December (1.96 g/g/day). At stage II, significantly higher net assimilation rate was recorded for Sree Athulya planted during May (5.02 g/g/day) and was on par with M_4 planted during December (4.90 g/g/day). Lowest value was recorded for Sree Athulya planted during December (3.26 g/g/day). At stage III, significantly higher net assimilation rate was noted for M_4 planted in December (5.90 g/g/day). This was followed by Sree Athulya planted during October (4.53 g/g/day). Net assimilation rate was lowest for M_4 planted during October (3.26 g/g/day). At stage IV, significantly higher net assimilation rate was recorded for December planted M_4 variety (8.51 g/g/day). This was followed by Sree Athulya planted during December (6.77 g/g/day). Same trend was followed at stage V. However net assimilation rate was lowest for Sree Athulya planted during May planting (5.08 g/g/day).

I.3.2. Crop growth rate

a. Short-duration varieties

Varieties had no significant effect on crop growth rate at stage I (0-60 DAP), stage II (60-120 DAP) and stage III (120-180 DAP) (Table 43).

At stage I, significantly higher crop growth rate was recorded for October planting (1.69 g/m^2/day). This was followed by May planting (1.59 g/m^2/day). Lowest value was observed in December planting (1.11 g/m^2/day). At stage II, significantly higher crop growth rate was recorded for May planting (10.41 g/m^2/day). This was followed by October planting (9.99 g/m^2/day). Lowest value was noted for December (5.56 g/m^2/day). On the other hand, at stage III, December planted crops had significantly higher CGR (16.62 g/m^2/day), followed by October planting (7.45 g/m^2/day), and lowest value was observed for May planting (3.56 g/m^2/day).

Table 42. Net assimilation rate of normal-duration cassava varieties as influenced by variety and month of planting

Net assimilation rate (g/g/day)					
	Stage I (0-60 DAP)	**Stage II (60-120 DAP)**	**Stage III (120-180 DAP)**	**Stage IV (180-240 DAP)**	**Stage V (240-300 DAP)**
Variety (V)					
M_4	2.61	4.36	4.21	4.82	8.52
Sree Athulya	2.11	4.27	4.10	4.28	7.41
SEd	0.09	-	-	-	-
CD (5 %)	0.28	NS	NS	NS	NS
Month of planting (M)					
May	2.30	4.75	3.47	2.93	5.12
October	2.78	4.72	3.90	3.09	5.72
December	2.00	3.48	5.12	7.64	13.06
SEd	0.08	0.04	0.05	0.15	0.25
CD (5 %)	0.18	0.09	0.10	0.33	0.55
Interaction (VXM)					
M_4 x May	2.29	4.47	3.48	2.82	5.15
M_4 x Oct.	3.50	4.90	3.26	3.12	5.90
M_4 x Dec.	2.03	3.70	5.90	8.51	14.49
Sree Athulya x May	2.31	5.02	3.45	3.03	5.08
Sree Athulya x Oct.	2.06	4.53	4.53	3.05	5.53
Sree Athulya x Dec.	1.96	3.26	4.33	6.77	11.62
SEd	0.12	0.06	0.07	0.22	0.36
CD (5 %)	0.25	0.13	0.15	0.46	0.78

Interaction effect of varieties and months of planting resulted in a significantly higher crop growth rate for Sree Vijaya when planted during May (1.87 g/m^2/day) at stage I. This was followed by Sree Vijaya planted during December (1.21 g/m^2/day). Lowest crop growth rate was recorded for Vellayani Hraswa when planted during December (1.01 g/m^2/day). At stage II, significantly higher crop growth rate was recorded for October planted Sree Vijaya (11.19 g/m^2/day) and May planted Sree Vijaya (11.14 g/m^2/day), which were on par. This was followed by Vellayani Hraswa planted during May (9.67 g/m^2/day). Lowest value was noted for Sree Vijaya when planted during December (5.33 g/m^2/day) and Vellayani Hraswa planted during December (5.78 g/m^2/day), which were comparable. At stage III, significantly higher crop growth rate was recorded for Vellayani Hraswa planted during December (18.02 g/m^2/day). This was followed by Sree Vijaya planted during December (15.21 g/m^2/day). Lowest value was recorded for Vellayani Hraswa planted during May (3.38 g/m^2/day) and Sree Vijaya planted during May (3.73 g/m^2/day), which were on par.

b. Normal-duration varieties

Crop growth rate was non-significant for both the varieties at all stages (Table 44).

Data on crop growth rate as affected by the month of planting revealed that significantly higher crop growth rate at stage I was for May planting (2.16 g/m^2/day) followed by October planting (1.99 g/m^2/day) and the lowest was for December planting (1.64 g/m^2/day). The same trend was maintained at 4 MAP. But, December planting showed a significantly higher crop growth rate (12.47 g/m^2/day) at stage III. This was followed by October (9.89 g/m^2/day) and May (3.47 g/m^2/day) planting, wherein the latter showed significantly lower crop growth rate. Similar trend was followed at 8 and 10 MAP. However, May planting was found to be on par with October planting.

Table 43. Crop growth rate of short-duration cassava varieties as influenced by variety and month of planting

Crop growth rate (g/m^2/day)			
	Stage I (0-60 DAP)	**Stage II (60-120 DAP)**	**Stage III (120-180 DAP)**
Variety (V)			
Vellayani Hraswa	1.30	8.08	9.49
Sree Vijaya	1.63	9.22	8.92
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	1.59	10.41	3.56
October	1.69	9.99	7.45
December	1.11	5.56	16.62
SEd	0.01	0.17	0.38
CD (5 %)	0.04	0.37	0.83
Interaction (VXM)			
Vellayani Hraswa x May	1.31	9.67	3.38
Vellayani Hraswa x Oct.	1.57	8.79	7.08
Vellayani Hraswa x Dec.	1.01	5.78	18.02
Sree Vijaya x May	1.87	11.14	3.73
Sree Vijaya x Oct.	1.80	11.19	7.81
Sree Vijaya x Dec.	1.21	5.33	15.21
SEd	0.03	0.24	0.55
CD (5 %)	0.06	0.52	1.18

Interaction effect of varieties and months of planting showed a significantly higher crop growth rate value for Sree Athulya planted during May (2.30 g/m^2/day) at stage I. Similar trend was followed at stage II. However at stage III, significantly higher crop growth rate was recorded for M_4 planted during December (14.03 g/m^2/day), followed by Sree Athulya planted during December (10.91 g/m^2/day) and October (10.05 g/m^2/day) respectively. Lowest crop growth rate was for Sree Athulya and M_4 planted during May (3.45and 3.48 g/m^2/day respectively). At stage IV, significantly higher crop growth rate was recorded for M_4 planted during December (16.78 g/m^2/day). This was followed by Sree Athulya when planted during December (14.22 g/m^2/day). Lowest crop growth rate was for M_4 planted during October (8.12 g/m^2/day), M_4 planted during May (8.42 g/m^2/day) and Sree Athulya planted in October (8.68 g/m^2/day). Similar trend was followed at stage V.

I.3.3. Relative growth rate

Relative growth rate was computed during the growing period of the four different cassava varieties separately and the results are given in Table 45 and Table 46.

a. Short-duration varieties

No significant difference in relative growth rate was recorded due to effect of variety at Stage I (60-120 DAP) and stage II (120-180 DAP).With regard to the month of planting, at Stage I (60-120 DAP) significantly higher relative growth rate was recorded for May (0.033 g/g/day), followed by October (0.026 g/g/day). Lowest value was recorded for December planting (0.018 g/g/day). For Stage II, same trend was seen. Relative growth rate was found to be significantly higher for May planting (0.019 g/g/day) followed by October planting (0.016 g/g/day). The lowest value was obtained for December planting (0.009 g/g/day).

Data on interaction effect showed that significantly higher relative growth rate was for Sree Vijaya when planted during May (0.039 g/g/day), and was followed by Sree Vijaya planted during October (0.030 g/g/day). Lowest RGR was recorded for Vellayani Hraswa planted during December (0.016 g/g/day). Almost similar trend was maintained for Stage II (120-180 DAP).

Table 44. Crop growth rate of normal-duration cassava varieties as influenced by variety and month of planting

Crop growth rate (g/m^2/day)					
	Stage I (0-60 DAP)	**Stage II (60-120 DAP)**	**Stage III (120-180 DAP)**	**Stage IV (180-240 DAP)**	**Stage V (240-300 DAP)**
Variety (V)					
M_4	1.84	10.40	9.08	11.11	11.75
Sree Athulya	2.02	10.83	8.14	10.65	11.37
SEd	-	-	0.10	-	-
CD (5 %)	NS	NS	0.34	NS	NS
Month of planting (M)					
May	2.16	12.73	3.47	8.74	6.96
October	1.99	11.48	9.89	8.40	6.68
December	1.64	7.64	12.4	15.50	21.05
SEd	0.01	0.13	0.23	0.22	0.47
CD (5 %)	0.03	0.29	0.50	0.49	1.02
Interaction (VXM)					
M_4 x May	2.02	12.40	3.48	8.42	6.60
M_4 x Oct.	1.98	11.40	9.73	8.12	6.32
M_4 x Dec.	1.53	7.40	14.03	16.78	22.32
Sree Athulya x May	2.30	13.05	3.45	9.06	7.32
Sree Athulya x Oct.	2.00	11.56	10.05	8.68	7.03
Sree Athulya x Dec.	1.75	7.87	10.91	14.22	19.77
SEd	0.02	0.19	0.33	0.32	0.67
CD (5 %)	0.04	0.42	0.718	0.702	1.45

a. Normal-duration varieties

At Stage I Sree Athulya variety recorded significantly higher RGR (0.036 g/g/day), followed by M_4 (0.033 g/g/day). The same trend was followed in stage II (120-180 DAP). No-significant relation on relative growth rate was recorded in Stage III (180 DAP).

With regard to month of planting, at Stage I, significantly higher relative growth rate was for May planting (0.046 g/g/day). This was followed by October planting (0.034 g/g/day) and was lowest in December planting (0.024 g/g/day). The same trend was recorded for Stage III (180 DAP). At Stage II, significantly higher relative growth rate was recorded for October (0.022 g/g/day), followed by May (0.020 g/g/day) and lowest value was for December (0.016 g/g/day).

The interaction effect of variety with month of planting showed that at Stage I, significantly higher relative growth rate was for Sree Athulya planted during May (0.047 g/g/day), followed by M_4 planted during May (0.044 g/g/day). At Stage II, significantly higher relative growth rate was for Sree Athulya planted during October (0.023 g/g/day), followed by M_4 planted during October and Sree Athulya planted in May (0.021 g/g/day). However at Stage III, significantly higher relative growth rate was noted for Sree Athulya when planted during May (0.017 g/g/day), followed by Sree Athulya planted during October (0.014 g/g/day). Lowest relative growth rate was for M_4 planted during December in all the stages.

I.3.d. Leaf area index

a. Short-duration varieties

At 2 MAP, significantly higher LAI was observed for Sree Vijaya (0.63) as compared to Vellayani Hraswa (0.42). However, no significant difference in was observed between 4 and 6 MAP (Table 47).

With regard to the month of planting, LAI was significantly higher for May planting at 2 MAP (0.62).This was followed by October planting (0.52) and the lowest

Table 45. Relative growth rate of short-duration cassava varieties as influenced by variety and month of planting

Relative growth rate (g/g/day)		
	Stage I (60-120 DAP)	**Stage II (120-180DAP)**
Variety (V)		
Vellayani Hraswa	0.021	0.013
Sree Vijaya	0.030	0.016
SEd	0.003	-
CD (5 %)	0.009	NS
Month of planting (M)		
May	0.033	0.019
October	0.026	0.016
December	0.018	0.009
SEd	0.001	0.001
CD (5 %)	0.001	0.001
Interaction (VXM)		
Vellayani Hraswa x May	0.027	0.017
Vellayani Hraswa x Oct.	0.021	0.014
Vellayani Hraswa x Dec.	0.016	0.008
Sree Vijaya x May	0.039	0.020
Sree Vijaya x Oct.	0.030	0.018
Sree Vijaya x Dec.	0.020	0.010
SEd	0.001	0.001
CD (5 %)	0.002	0.001

Table 46. Relative growth rate of normal-duration cassava varieties as influenced by variety and month of planting

Relative growth rate (g/g/day)			
	Stage I (60-120 DAP)	**Stage II (120-180DAP)**	**Stage III (180DAP)**
Variety (V)			
M_4	0.033	0.018	0.011
Sree Athulya	0.036	0.020	0.014
SEd	-	-	-
CD (5 %)	NS	NS	NS
Month of planting (M)			
May	0.046	0.020	0.015
October	0.034	0.022	0.013
December	0.024	0.016	0.011
SEd	0.001	0.001	0.001
CD (5 %)	0.001	0.001	0.001
Interaction (VXM)			
M_4 x May	0.044	0.018	0.012
M_4 x Oct.	0.032	0.021	0.011
M_4 x Dec.	0.022	0.014	0.010
Sree Athulya x May	0.047	0.021	0.017
Sree Athulya x Oct.	0.035	0.023	0.014
Sree Athulya x Dec.	0.025	0.017	0.011
SEd	0.001	0.001	0.001
CD (5 %)	0.002	0.001	0.001

Table 47. Leaf area index of short-duration cassava varieties as influenced by variety and month of planting

Leaf area index			
	2 MAP	**4 MAP**	**6 MAP**
Variety (V)			
Vellayani Hraswa	0.42	3.03	2.20
Sree Vijaya	0.63	2.90	2.41
SEd	0.05	-	-
CD (5 %)	0.18	NS	NS
Month of planting (M)			
May	0.62	3.19	2.58
October	0.52	3.11	2.45
December	0.43	2.60	1.90
SEd	0.006	0.01	0.02
CD (5 %)	0.01	0.04	0.06
Interaction (VXM)			
Vellayani Hraswa x May	0.52	3.41	2.56
Vellayani Hraswa x Oct.	0.42	3.20	2.06
Vellayani Hraswa x Dec.	0.32	2.50	2.00
Sree Vijaya x May	0.72	2.98	2.60
Sree Vijaya x Oct.	0.63	3.02	2.84
Sree Vijaya x Dec.	0.54	2.71	1.80
SEd	0.01	0.03	0.04
CD (5 %)	0.01	0.05	0.08

value was recorded for December planting (0.43). Similar trend was maintained at 4 and 6 MAP.

Data on interaction effect revealed that at 2 MAP, significantly higher LAI was for Sree Vijaya planted during May (0.72) and Sree Vijaya planted during October (0.63), which were on par. Lowest LAI at this stage was recorded for Vellayani Hraswa planted during December (0.32), which was comparable to Vellayani Hraswa planted during October (0.42). At 4 MAP, significantly higher LAI was observed for Vellayani Hraswa planted during May (3.41), followed by Vellayani Hraswa planted in October (3.20). Leaf area index was lowest for Vellayani Hraswa when planted during December (2.50). However, at 6 MAP, significantly higher LAI was noted for October planted Sree Vijaya (2.84), followed by Sree Vijaya and Vellayani Hraswa planted during May (2.60 and 2.56 respectively). Lowest LAI was for Sree Vijaya when planted during December (1.80).

b. Normal-duration varieties

Leaf area index of normal-duration varieties are given in Table 48. It was observed that at Sree Athulya recorded significantly higher leaf area index at both 2 and 4 MAP as compared to Vellayani Hraswa. Non- significant difference in LAI was observed for varieties at 6, 8 and 10 MAP.

Considering the month of planting, at 2 MAP, May planting recorded significantly higher LAI (0.94). This was followed by December planting (0.82) and October planting with LAI of 0.76, which were comparable. At 4 MAP, significantly higher LAI was for May planting (2.69), followed by October planting (2.39) and the lowest was noted for December planting (2.21). The same trend was followed at 6 and 8 MAP. But at 10 MAP, December planting had significantly higher LAI (1.62), followed by May planting (1.35) and October planting (1.17).

Table 48. Leaf area index of normal-duration cassava varieties as influenced by variety and month of planting

Leaf area index					
	2 MAP	**4 MAP**	**6 MAP**	**8 MAP**	**10 MAP**
Variety (V)					
M_4	0.73	2.34	2.79	2.51	1.29
Sree Athulya	0.95	2.52	2.87	2.67	1.47
SEd	0.01	0.05	-	-	-
CD (5 %)	0.04	0.16	NS	NS	NS
Month of planting (M)					
May	0.94	2.69	3.06	2.99	1.35
October	0.76	2.39	2.99	2.75	1.17
December	0.82	2.21	2.43	2.03	1.62
SEd	0.02	0.01	0.01	0.02	0.01
CD (5 %)	0.06	0.02	0.03	0.06	0.02
Interaction (VXM)					
M_4 x May	0.88	2.78	3.01	2.98	1.26
M_4 x Oct.	0.56	2.23	2.99	2.60	1.07
M_4 x Dec.	0.75	2.01	2.37	1.97	1.54
Sree Athulya x May	1.00	2.60	3.12	3.00	1.44
Sree Athulya x Oct.	0.96	2.56	3.00	2.91	1.27
Sree Athulya x Dec.	0.89	2.41	2.50	2.10	1.70
SEd	0.04	0.02	0.02	0.04	0.02
CD (5 %)	0.08	0.03	0.05	0.09	0.04

Interaction effect of varieties and months of planting on LAI was recorded and it was seen that at 2 MAP significantly higher LAI was for May planted Sree Athulya variety (1.00), and the lowest registered was for M_4 planted during October (0.56). At 4 MAP, significantly higher LAI was for M_4 planted during May (2.78), followed by Sree Athulya planted during May (2.60) and Sree Athulya planted during October (2.56), which were on par. Lowest LAI was for M_4 planted during December (2.01). At 6 MAP, significantly higher LAI was for Sree Athulya planted during May (3.12), followed by Sree Athulya planted during October (3.00). At 8 MAP, Sree Athulya planted during May recorded significantly higher LAI (3.00), and was comparable with M_4 planted during May (2.98) and Sree Athulya planted during October (2.91). Lowest LAI was noted for M_4 planted during December at both 6 and 8 MAP. However at 10 MAP, Sree Athulya planted during December recorded significantly higher LAI (1.70), followed by Sree Athulya planted during May (1.44). Lowest value was noted for M_4 planted during October (1.07).

I.4. Quality parameters

I.4.1. Starch content

Among varieties, long-duration variety Sree Athulya had significantly higher starch content (26.26 %), followed by Sree Vijaya (23.97 %) and M_4 (23.28 %), which were on par. Lowest starch content was recorded or Vellayani Hraswa (21.81 %) (Table 49).

Starch content was found to be significantly higher for May planting (26.28 %). This was followed by October planting (23.98 %). Lowest starch content was recorded for December planting (21.20 %).

Data on interaction effects of varieties with the month of planting showed that Sree Athulya planted during May showed significantly higher starch content (29.73 %) and was comparable with M_4 planted during May (27.16 %). This was followed by Sree Athulya planted during October (26.36%), which was on par with Vellayani Hraswa planted during May and Sree Vijaya planted during December (24.83 %).

Table 49. Starch content (%) of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	25.97	22.26	27.16	29.73	26.28
October	21.03	24.80	23.69	26.36	23.98
December	18.43	24.83	18.96	22.56	21.20
Mean	21.81	23.97	23.28	26.22	
Variety (V)	**SEd**	0.66			
	CD (5%)	1.78			
Month of planting (M)	**SEd**	0.77			
	CD (5%)	1.59			
V x M	**SEd**	1.55			
	CD (5%)	3.19			

I.4.2. Total sugar content

Significantly higher total sugar content was recorded for variety Sree Vijaya (0.74 %), and was followed by Vellayani Hraswa (0.65 mg/g). Lowest values were recorded for Sree Athulya (0.56 mg/g) and M_4 (0.58 mg/g), were on par

The mean values for month of planting revealed that significantly higher total sugar content in tubers was recorded for December (0.88 mg/g) followed by October (0.65 mg/g). Lowest total sugar content was for May planting (0.37 mg/g).

Sree Vijaya and Vellayani Hraswa planted during December recorded significantly higher total sugar content (0.99 and 0.90 mg/g respectively). This was followed by M_4 (0.80 mg/g) and Sree Athulya planted in December (0.79 mg/g), and Sree Vijaya planted during October (0.76 mg/g). Lowest total sugar content was recorded for Vellayani Hraswa (0.36 mg/g), M_4 (0.32 mg/g) and Sree Athulya (0.32 mg/g) planted during May (Table 50).

Table 50. Total sugar content (mg/g) of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	0.36	0.47	0.32	0.32	0.37
October	0.67	0.76	0.60	0.56	0.65
December	0.90	0.99	0.80	0.79	0.88
Mean	0.65	0.74	0.58	0.56	
Variety (V)	**SEd**	0.02			
	CD (5%)	0.04			
Month of planting (M)	**SEd**	0.02			
	CD (5%)	0.04			
V x M	**SEd**	0.04			
	CD (5%)	0.09			

I.4.3. Reducing sugar

Among varieties, significantly higher reducing sugar content was recorded for Sree Athulya (0.51 mg/g) and Vellayani Hraswa (0.49 mg/g), which were comparable. Lowest value was observed for M_4 (0.44 mg/g).

December planting showed significantly higher reducing sugar content (0.65 mg/g) in cassava varieties and was on par with October planting (0.50 mg/g). May planting recorded the lowest reducing sugar content (0.28 mg/g) among the three plantings. (Table 51)

The interaction effects revealed that significantly higher reducing sugar content was present in Sree Athulya (0.73 mg/g) and was comparable with Vellayani Hraswa (0.67 mg/g) of December planting. This was followed by M_4 (0.63 mg/g) of December planting. Lowest reducing sugar content was recorded for Sree Athulya (0.23 mg/g), followed by Vellayani Hraswa (0.26 mg/g) of May planting.

Table 51. Reducing sugar content (mg/g) of cassava varieties as influenced by variety and month of planting

Month of planting	**Variety**				
	Vellayani Hraswa	**Sree Vijaya**	**M_4**	**Sree Athulya**	**Mean**
May	0.26	0.36	0.23	0.23	0.28
October	0.52	0.43	0.46	0.56	0.50
December	0.67	0.57	0.63	0.73	0.65
Mean	0.49	0.46	0.44	0.51	
Varieties (V)	**SEd**	0.01			
	CD (5%)	0.04			
Month of planting (M)	**SEd**	0.02			
	CD (5%)	0.03			
V x M	**SEd**	0.03			
	CD (5%)	0.06			

I.4.4. Crude protein content

Among varieties, significantly higher crude protein content was for M_4 (1.75%) and was on par with Sree Athulya (1.71 %). This was followed by Sree Vijaya (1.60 %). Lowest value was recorded for Vellayani Hraswa (1.41 %).

Significantly higher crude protein content was recorded for the month of May (1.74%) and was on par with October (1.73 %). Crude protein was significantly lower for December planting (1.36 %).

Interaction of varieties with planting month on crude protein content revealed a significantly higher crude protein content for M_4 planted during May (1.87 %) which was on par with Sree Athulya (1.73 %), M_4 (1.79 %), Sree Vijaya (1.70 %) and Vellayani Hraswa (1.68 %) planted during October (Table 52).

Table 52. Crude protein content (%) of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	1.53	1.70	1.87	1.86	1.74
October	1.66	1.70	1.79	1.73	1.73
December	1.03	1.40	1.57	1.52	1.38
Mean	1.41	1.60	1.75	1.71	
Variety (V)	SEd	0.05			
	CD (5%)	0.12			
Month of planting (M)	SEd	0.06			
	CD (5%)	0.11			
V x M	SEd	0.11			
	CD (5%)	0.22			

I.4.5.Cyanogenic glucoside content

Among varieties, significantly lower cyanogenic glucoside content was recorded for Sree Vijaya (65.80 ppm), followed by and Vellayani Hraswa (68.45 ppm) and M_4 (70.39 ppm). Highest value was observed for Sree Athulya (90.76 ppm), which was significantly higher than other varieties.

The cyanogenic glucoside content was lowest was noted for cassava varieties planted during May (57.83 ppm), followed by October planting (74.75 ppm). HCN content was significantly higher for varieties planted during December (88.97 ppm).

Significantly lower cyanogenic glucoside content was recorded for M_4 (45.14 ppm)and Vellayani Hraswa(43.19 ppm) varieties planted during May. Sree Athulya planted during December recorded significantly higher cyanogenic glucoside content (190.12 ppm) among interactions (Table 53).

Table 53.Cyanogenic glucoside content (ppm) of cassava varieties as influenced by variety and month of planting

Month of planting	**Variety**				
	Vellayani Hraswa	**Sree Vijaya**	**M_4**	**Sree Athulya**	**Mean**
May	43.19	63.03	45.14	79.96	57.83
October	70.06	61.60	84.13	83.20	74.75
December	92.10	72.76	81.90	109.12	88.97
Mean	68.45	65.80	70.39	90.76	
Variety (V)	**SEd**	2.66			
	CD (5%)	7.14			
Month of planting (M)	**SEd**	2.28			
	CD (5%)	4.71			
V x M	**SEd**	4.57			
	CD (5%)	9.42			

I.5. Yield and yield attributes

I.5.1. Tuber length

Among varieties, significantly longer tubers were observed Athulya (44.89 cm) followed by M_4 (40.69 cm). Tuber length was lowest for varieties Vellayani Hraswa (33.27 cm) and Sree Vijaya (32.46 cm), which were on par.

Tuber length of different cassava varieties was significantly influenced by the month of planting (Table 54). Data on tuber length showed that significantly greater length was recorded for cassava varieties planted during May (41.21 cm) followed by December (37.80 cm). Lowest tuber length was observed during October planting (34.36 cm).

Sree Athulya when planted in December produced significantly longer tuber length (51.13 cm). This was followed by M_4 (45.40 cm) and Sree Athulya (44.33 cm) when planted in May. Tuber length was lowest for Vellayani Hraswa (25.95 cm) when planted during October.

Table 54. Tuber length (cm) of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	40.68	34.43	45.40	44.33	41.21
October	25.95	32.00	40.45	39.04	34.36
December	33.16	30.93	36.23	51.13	37.8
Mean	33.27	32.46	40.69	44.89	
Variety(V)	**SEd**	1.45			
	CD (5%)	3.90			
Month of planting (M)	**SEd**	1.06			
	CD (5%)	2.18			
V x M	**SEd**	2.12			
	CD (5%)	4.37			

I.5.2.Tuber girth

Data on varieties revealed that significantly greater tuber girth was recorded for variety Sree Athulya (12.20 cm), followed by M_4 (9.56 cm) and Sree Vijaya (9.03cm). Lowest tuber girth was recorded for Vellayani Hraswa (6.46 cm).

Significantly greater tuber girth was observed in cassava varieties when planted during May (12.20 cm), followed by December (10.16 cm) and October (9.17cm) plantings (Table 55).

Sree Athulya when planted in October recorded significantly greater tuber girth (14.06 cm). This was followed by Sree Athulya (12.40 cm), Sree Vijaya (12.13 cm) and M_4 (11.63 cm) when planted in October.

Table 55. Tuber girth (cm) of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	6.26	6.36	11.63	12.40	12.20
October	6.62	12.13	7.80	14.06	9.17
December	6.49	8.60	9.25	10.13	10.16
Mean	6.46	9.03	9.56	12.20	
Varieties (V)	**SEd**	0.32			
	CD (5%)	0.86			
Month of planting (M)	**SEd**	0.29			
	CD (5%)	0.60			
V x M	**SEd**	0.59			
	CD (5%)	1.20			

I.5.3. Number of tubers per plant

Among varieties, significantly higher tuber numbers per plant was recorded for Sree Athulya (9.67) followed by M_4 (8.93) and Sree Vijaya (8.65) which were on par. Lowest value was recorded for Vellayani Hraswa (7.84).

Considering the months of planting, significantly higher number of tubers/plant was observed for October planting (10.20), followed by December planting (8.12) and May planting (7.99).

Interaction effect of variety x month of planting showed that significantly higher number of tubers was for Sree Vijaya (12.97), followed by Sree Athulya planted during October (11.00) and M_4 planted during December (10.00). Lowest number was recorded for Sree Vijaya planted during May (5.97) and Vellayani Hraswa planted during December (6.49), which were on par (Table 56).

Table 56. Tuber number per plant of cassava varieties as influenced by variety and month of planting

Month of planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	8.00	5.97	9.00	9.00	7.99
October	9.02	12.97	7.80	11.00	10.20
December	6.49	7.00	10.00	9.00	8.12
Mean	7.84	8.65	8.93	9.67	
Varieties (V)	SEd	0.33			
	CD (5%)	0.76			
Month of planting (M)	SEd	0.24			
	CD (5%)	0.513			
V x M	SEd	0.51			
	CD (5%)	1.06			

I.5.4.Fresh tuber yield

Considering the varieties, significantly higher fresh tuber yield was recorded by Sree Athulya (2.49 kg/plant) .This was followed by Vellayani Hraswa (2.19 kg/plant), which was comparable with M_4 (2.16 kg/plant).

Among planting seasons, Mayplanted cassava varieties recorded significantly higher fresh tuber yield (2.57 kg/plant) followed by October (2.23 kg/plant) and December (1.72 kg/plant) planting, respectively (Table 57)

Significantly higher fresh tuber yield was recorded for Sree Athulya when planted during May (3.62 kg/plant). This was followed by May planted Vellayani Hraswa (2.75 kg/plant) and October planted M_4 variety (2.61 kg/plant), which were on par.

Table 57. Fresh tuber yield (kg/plant) of cassava varieties as influenced by variety and month of planting

Monthof planting	Variety				
	Vellayani Hraswa	Sree Vijaya	M_4	Sree Athulya	Mean
May	2.75	1.97	1.93	3.62	2.57
October	2.07	2.01	2.61	2.22	2.23
December	1.75	1.58	1.93	1.62	1.72
Mean	2.19	1.86	2.16	2.49	
Variety(V)	SEd	0.08			
	CD (5%)	0.21			
Month of planting (M)	SEd	0.07			
	CD (5%)	0.15			
V x M	SEd	0.15			
	CD (5%)	0.30			

I.5.5.Tuber yield

From the results, presented in Table 58 ,it was observed that long duration variety Sree Athulya had significantly higher yield of 27.67 t/ha, followed by M_4 (23.58 t/ha) and Sree Vijaya (20.61 t/ha). Short duration variety, Vellayani Hraswa was observed to have lowest yield (18.11 t/ha).

Month of planting had significant influence on the yield of different cassava varieties. Among the planting seasons, significantly higher yield was observed for May (27.82 t/ha) followed by October (21.82 t/ha). Lowest yield was observed for December planting (17.84 t/ha).

Considering the interaction effect of planting time and varieties, significantly higher yield was recorded for Sree Athulya when planted in May (36.00 t/ha) and was followed by May planted M_4 variety (32.57 t/ha). Among short-duration varieties, Sree Vijaya planted in October recorded significantly higher yield (25.39 t/ha) and was on par with Sree Athulya planted in October (23.86 t/ha). Lowest yields were observed for Sree Vijaya (15 t/ha) and Vellayani Hraswa (14.80 t/ha) planted in December.

Table 58. Tuber yield (t/ha) of cassava varieties as influenced by variety and month of planting

Month of planting	**Variety**				
	Vellayani Hraswa	**Sree Vijaya**	**M_4**	**Sree Athulya**	**Mean**
May	21.26	21.43	32.57	36.00	27.82
October	18.25	25.39	19.76	23.86	21.82
December	14.80	15.00	18.40	23.13	17.84
Mean	18.11	20.61	23.58	27.67	
Variety (V)	**SEd**	0.89			
	CD (5%)	2.40			
Month of planting (M)	**SEd**	0.64			
	CD (5%)	1.32			
V x M	**SEd**	1.28			
	CD (5%)	2.65			

I.5.6. Harvest index

Data on harvest index of cassava varieties are depicted in Table 59. Short duration varieties, Sree Vijaya and Vellayani Hraswa recorded significantly higher harvest index (0.56 and 0.52, respectively). This was followed by long-duration varieties, which were on par.

Month of planting had significant influence on harvest index with May and October planting showing a significantly higher harvest index (0.49 and 0.48, respectively). Lowest value was recorded for December planting (0.43).

Interaction effect of variety x month of planting showed that significantly higher harvest index was recorded for Sree Vijaya when planted during October (0.63). This was followed by Sree Vijaya planted during May (0.59) and Vellayani Hraswa planted during October (0.59). Lowest harvest index was recorded for Sree Athulya planted during October (0.33) and was comparable with M_4 planted during October (0.36) and Sree Athulya planted during December (0.37).

Table 59. Harvest index of cassava varieties as influenced by variety and month of planting

Month of planting	**Variety**				
	Vellayani Hraswa	**Sree Vijaya**	**M_4**	**Sree Athulya**	**Mean**
May	0.47	0.59	0.44	0.43	0.49
October	0.59	0.63	0.36	0.33	0.48
December	0.48	0.45	0.42	0.37	0.43
Mean	0.52	0.56	0.41	0.38	
Variety (V)	**SEd**	0.02			
	CD (5%)	0.05			
Month of planting	**SEd**	0.01			
	CD (5%)	0.03			
V x M	**SEd**	0.03			
	CD (5%)	0.08			

Plate 4. Tubers from May planting

Plate 5.Tubers from October planting

Plate 6. Tubers from December planting

I.6. Sensory evaluation

Sensory evaluation of cassava tubers was conducted for cassava varieties in the different growing seasons.

I.6.1. May planted cassava

Mean acceptance score of different attributes for May planted cassava varieties are depicted in Table 60. For May planted cassava, significantly different values were recorded for all the attributes, except flavour. Sree Vijaya scored higher acceptance for appearance and colour, followed by variety M_4. The normal-duration variety M_4 exhibited higher acceptance in case of texture and taste, and was followed by the Sree Vijaya in short-duration. Significantly higher overall acceptability was observed for variety M_4, and was followed by the variety Sree Vijaya. Least acceptability was observed for Sree Athulya.

Table 60. Sensory characteristics*of May planted cassava varieties

Treatments	Appearance	Colour	Flavour	Texture	Taste	Overall acceptability
T_1-Vellayani Hraswa	6.33	6.43	7.00	6.72	7.11	6.40
T_2-Sree Vijaya	8.20	8.40	7.16	7.32	7.81	7.60
T_3-M_4	7.70	7.45	7.33	7.82	8.00	7.82
T_4-Sree Athulya	6.47	6.22	6.50	5.37	5.68	5.68
CD (0.05)	**0.16**	**0.03**	**NS**	**0.03**	**0.02**	**0.028**

*Average of scored data

I.6.2. October planted cassava

Sree Vijaya scored higher acceptance for appearance and colour followed by variety M_4. Variety Vellayani Hraswa had higher acceptance for texture and taste, followed by the short-duration varieties M_4 and Sree Vijaya respectively. Highest overall acceptability was observed for Sree Vijaya and Vellayani Hraswa followed by the variety M_4. Least acceptability was observed for variety Sree Athulya (Table 61).

Table 61. Sensory characteristics *of tubers of October planted cassava varieties

Treatments	**Appearance**	**Colour**	**Flavour**	**Texture**	**Taste**	**Overall acceptability**
T_1-Vellayani Hraswa	6.65	6.03	5.88	7.03	8.00	6.63
T_2-Sree Vijaya	7.31	7.32	6.31	6.66	7.65	6.65
T_3-M_4	7.00	6.65	5.61	6.32	5.67	5.88
T_4-Sree Athulya	5.32	6.32	6.03	4.67	4.31	5.30
CD (0.05)	**0.02**	**0.06**	**NS**	**0.05**	**0.02**	**0.20**

*Average of scored data.

I.6.3. December planted cassava

In December planted cassava varieties, Sree Vijaya scored higher acceptance for all the characters, followed by M_4 and Vellayani Hraswa. As previously recorded, there was no significant difference for flavour among all the four varieties. Short duration variety Vellayani Hraswa showed least acceptability for all the six characters (Table 62).

Table 62. Sensory characteristics* of December planted cassava varieties

Treatments	Appearance	Colour	Flavour	Texture	Taste	Overall acceptability
T_1-Vellayani Hraswa	5.81	5.67	6.22	5.67	5.12	6.31
T_2-Sree Vijaya	7.16	7.01	5.10	6.65	6.51	8.00
T_3-M_4	7.76	7.23	7.00	8.33	8.07	6.30
T_4-Sree Athulya	6.11	6.75	5.13	5.72	5.88	5.88
CD (0.05)	**0.03**	**0.02**	**NS**	**0.04**	**0.07**	**0.03**

*Average of scored data

I.7. Soil moisture

Soil samples from a depth of 30 cm were collected and analyzed using gravimetric method.

I.7.1. May planted crop

Soil moisture content (SMC) at initial stage was to be 11.20 %. But, when observed at 15 DAP, SMC was found to be significantly higher for treatment M_4 (16.33 %) and Vellayani Hraswa (15.56 %), which were on par (Table 63).

SMC observed at 30, 45, 90, 120, 150, 165, 225, 240, 255, 270 and 285 for all the varieties were found to be non-significant. At 60 DAP, significantly higher SMC

Table 63. Soil moisture content at fortnightly intervals for May planted cassava varieties

Treatments	Soil moisture content (%)																			
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**	**105 DAP**	**120 DAP**	**135 DAP**	**150 DAP**	**165 DAP**	**Harvest**	**195 DAP**	**210 DAP**	**225 DAP**	**240 DAP**	**255 DAP**	**270 DAP**	**285 DAP**	**Harvest**
T_1-Vellayani Hraswa	15.56	13.90	17.20	20.50	14.10	19.43	23.60	14.40	12.00	12.70	11.90	10.70	-	-	-	-	-	-	-	-
T_2-Sree Vijaya	14.00	14.80	15.30	16.90	15.30	24.00	20.60	15.10	11.10	12.10	13.00	11.80	-	-	-	-	-	-	-	-
T_3- M_4	16.33	16.30	15.00	11.20	15.40	19.70	16.20	13.60	12.40	10.50	12.30	11.50	14.20	17.70	12.22	8.70	9.80	6.70	7.00	5.60
T_4-Sree Athulya	13.30	15.70	14.90	20.20	20.20	16.56	16.90	16.00	16.00	11.10	12.40	13.40	12.30	15.70	12.40	8.90	10.50	6.80	7.20	6.70
CD (0.05)	**1.70**	**NS**	**NS**	**4.40**	**3.90**	**NS**	**4.90**	**NS**	**3.00**	**NS**	**NS**	**NS**	**S**	**S**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

was observed in plots planted with Vellayani Hraswa (20.53 %) and Sree Athulya (20.20 %). Similarly at 75 DAP, higher SMC was observed Sree Athulya (20.20 %) followed by M_4 (15.40 %), Sree Vijaya (15.30 %) and Vellayani Hraswa (14.10 %).

At 105 DAP, significantly higher SMC was recorded from plots planted with f Vellayani Hraswa (23.60 %) and Sree Vijaya (20.60 %), followed by Sree Athulya (16.90 %) and M_4 (16.20 %), which were on par. Significantly higher soil moisture content was recorded for Sree Athulya at 135 DAP (16.00 %) and was followed by the other treatments, which were on par.

Comparing the two normal-duration varieties, plots under M_4 had significantly higher SMC than Sree Athulya at 195 and 210 DAP (14.20 % and 17.70 % respectively).

I. 7.2. October planted crop

Soil moisture content just before October planting `was found to be 10.80 %. No significant difference in SMC was observed at 15, 30, 75, 90, 155, 170, 195, 210, 240, 255, and 285 DAP.

At 60 DAP, significantly higher SMC was recorded in plots with Sree Athulya (10.90 %) and Vellayani Hraswa (8.90 %). Soils under Sree Vijaya were observed to have significantly higher SMC at 105 DAP (15.50 %). At 120 DAP, plots with Sree Vijaya (11.20 %) and Sree Athulya (9.20 %) were comparable and found to have significantly higher SMC. At 135 DAP, higher SMC was observed in plots grown with Sree Vijaya (6.90 %), M_4 (6.80 %) and Sree Athulya (5.70 %), which were on par with each other.

While comparing the two normal-duration varieties, plots under Sree Athulya had higher SMC than M_4 at 225 and 270 DAP (12.30 % and 12.50 % respectively (Table 64).

I.7.3. December planted crop

No significant difference was observed for SMC among varieties at 15, 30, 75, 105,135, 155, 170, 210, 240, 255, 270, 285 and harvest (for both short and normal-duration).

Significantly higher SMC was observed for Sree Athulya at 45 (9.80 %) and 60 DAP (13.60 %). Plots with Vellayani Hraswa (12.80 %) and Sree Vijaya (12.10 %) recorded higher SMC at 120 DAP.

Comparing the two normal-duration varieties, Sree Athulya was found to have more SMC compared to M_4 at 195 and 225 DAP (12.80 % and 13.40 % respectively) (Table 65).

I.8. Economics of crop production

Gross cost and income were computed. Based on these net return and benefit-cost ratio of the varieties were compared during the three plantings (May, October and December)

I.8.1. May planted cassava varieties

Cost of cultivation for short-duration varieties during May planting was Rs. 1,05,132 and that for normal-duration varieties was Rs. 1,15,419. Total income calculated was more from the normal-duration variety Sree Athulya (Rs.5,40,000). Among short duration varieties, cultivation of Sree Vijaya generated higher income (Rs.3,21,300). Benefit-cost ratio was high for Sree Athulya variety (3.67), followed by M_4 (3.25). Vellayani Hraswa had the lowest B:C ratio of 2.03 (Table 66).

Table 64. Soil moisture content at fortnightly intervals for October planted cassava varieties

Treatments	Soil moisture content (%)																			
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**	**105 DAP**	**120 DAP**	**135 DAP**	**155 DAP**	**170 DAP**	**Harvest**	**195 DAP**	**210 DAP**	**225 DAP**	**240 DAP**	**255 DAP**	**270 DAP**	**285 DAP**	**Harvest**
T_1-Vellayani Hraswa	13.30	10.20	20.70	8.90	16.40	10.80	9.40	6.10	4.50	7.20	5.90	7.80	-	-	-	-	-	-	-	-
T_2-Sree Vijaya	12.10	7.00	22.00	6.70	15.80	11.30	15.50	11.20	6.90	7.60	5.00	8.40	-	-	-	-	-	-	-	-
T_3- M_4	11.40	9.00	17.90	8.50	16.10	10.70	11.00	8.90	6.80	7.40	5.60	9.80	6.90	4.80	11.10	12.00	12.00	11.30	12.40	14.30
T_4-Sree Athulya	9.80	9.60	19.40	10.90	15.40	9.90	11.20	9.20	5.70	7.20	6.90	11.30	7.00	4.60	12.30	12.10	12.20	12.50	12.80	14.30
CD (0.05)	**NS**	**NS**	**NS**	**2.01**	**NS**	**NS**	**3.00**	**2.20**	**1.40**	**NS**	**NS**	**2.19**	**NS**	**NS**	**S**	**NS**	**NS**	**S**	**NS**	**NS**

Table 65. Soil moisture content at fortnightly intervals for December planted cassava varieties

Treatments	Soil moisture content (%)																		
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	105 DAP	120 DAP	135 DAP	155 DAP	170 DAP	Harvest	195 DAP	210 DAP	225 DAP	240 DAP	255 DAP	270 DAP	285 DAP	Harvest
T_1-Vellayani Hraswa	12.10	10.10	6.50	9.20	9.60	8.90	4.70	12.80	12.00	10.90	13.80	10.10	-	-	-	-	-	-	-	-
T_2-Sree Vijaya	12.60	11.20	6.00	5.60	11.70	8.20	5.00	12.10	12.30	10.40	13.00	9.20	-	-	-	-	-	-	-	-
T_3- M_4	12.80	11.00	7.90	7.60	10.60	10.90	4.40	10.00	12.40	11.20	13.80	9.40	11.90	10.20	12.40	8.70	9.10	8.00	7.30	6.50
T_4-Sree Athulya	12.00	11.30	9.80	13.60	10.40	11.10	5.60	9.10	12.50	11.80	13.80	9.80	12.80	10.20	13.40	9.00	8.70	8.20	7.40	6.90
CD (0.05)	**NS**	**NS**	**1.70**	**2.20**	**NS**	**2.20**	**NS**	**2.70**	**NS**	**NS**	**NS**	**NS**	**S**	**NS**	**S**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 66. Economics of crop production for May planted cassava varieties

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1- Vellayani Hraswa	105132	318900	213777	2.03
T_2- Sree Vijaya	105132	321300	216177	2.05
T_3 –M_4	115419	491400	375981	3.25
T_4- Sree Athulya	115419	540000	424581	3.67

I.8.2. October planted cassava varieties

Cost of cultivation for the short-duration varieties, Vellayani Hraswa and Sree Vijaya during October planting season was Rs. 95,392 and it was Rs.102937 for the normal-duration varieties, M_4 and Sree Athulya (Table 67). Gross income was more from short-duration variety, Sree Vijaya (Rs.3,80,700). Sree Athulya generated the next higher income (Rs.3,57,750). Benefit-cost ratio was higher for Sree Vijaya (2.99) followed by Sree Athulya (2.47), M_4 (1.87) and Vellayani Hraswa (1.86)

Table 67. Economics of crop production for October planted cassava varieties

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1- Vellayani Hraswa	95392	273750	207839	1.86
T_2- Sree Vijaya	95392	380700	285308	2.99
T_3 –M_4	102937	296400	193463	1.87
T_4- Sree Athulya	102937	357750	254813	2.47

I.8.3. December planted cassava varieties

Cost of cultivation for the short-duration varieties, Vellayani Hraswa and Sree Vijaya during December planting season was Rs. 9,74,37 and it was Rs.1,02,937 for the normal - duration varieties, M_4 and Sree Athulya. Among the normal - duration varieties, Sree Athulya generated highest gross income of Rs. 3,47,100, while Sree Vijaya chalked up highest gross income of Rs. 2,25,150 among short duration varieties. Net returns and benefit : cost ratio were highest for Sree Athulya followed by M_4. Among short duration varieties, Sree Vijaya was more economical than Vellayani Hraswa (Table 68).

Table 68. Economics of crop production for December planted cassava varieties

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1- Vellayani Hraswa	97437	222450	125013	1.28
T_2- Sree Vijaya	97437	225150	127713	1.31
T_3 –M_4	102937	281100	178163	1.73
T_4- Sree Athulya	102937	347100	244163	2.37

10. Crop-weather relation studies in cassava

Correlation study was done to understand the interaction of varieties in reference to yield with major weather parameters *viz.*, maximum temperature, minimum temperature, rainfall, mean evaporation, relative humidity, wind speed and mean sunshine hours. Short-duration and long-duration varieties were analyzed separately and correlated with weather at different growth stages for all the three plantings.

a. Short-duration varieties

Significant positive correlation between yield and minimum temperature and also rainfall was observed at two months after planting. Significantly negative correlation between yield and maximum temperature was recorded during this stage of growth.

At four months after planting, correlation study revealed significantly negative correlation of tuber yield with maximum temperature and minimum temperature, but a positive correlation with total rainfall only at 10 percent level. Significantly negative correlation with minimum temperature was recorded at six month growth stage (Table 69).

Table 69. Correlation analysis of yield of short-duration varieties with max-min temperature and rainfall

Months after planting	Max. temperature (^oC)	Min. temperature (^oC)	Rainfall (mm)
2MAP	-0.721**	0.692**	0.515*
4MAP	-0.644**	-0.691**	0.393
6 MAP	-0.160	-0.670**	-0.160

In case of short-duration varieties, significant positive correlation was observed between yield and relative humidity at 2 MAP. Mean evaporation, wind speed and mean sunshine hours recorded a significant negative correlation at early stages of establishment. No significant relation was observed between yield and weather parameters *viz.*, mean relative humidity, evaporation, sunshine hours and wind speed, at the later stages (Table 70).

Table 70. Correlation of yield of short-duration varieties with mean relative humidity, mean evaporation, wind speed and mean sunshine hours

Months after planting	Mean Relative humidity (%)	Mean evaporation (mm)	Wind speed (km/hr)	Mean Sunshine hours
2 MAP	0.704**	-0.738**	-0.733**	-0.662**
4 MAP	0.293	-0.432	0.255	-0.393
6 MAP	-0.159	-0.110	-0.190	-0.229

b. Normal-duration varieties

Correlation of yield of two long duration varieties *viz.*, M_4 and Sree Athulya, with weather parameters (maximum-minimum temperature and rainfall) were studied for 2, 4, 6, 8 and 10 MAP.

Significant negative correlation was recorded between yield of normal-duration varieties and maximum temperature between tuber yield of long duration varieties and maximum temperature except at 10 MAP (Table 71). Minimum temperature was positively correlated with yield at 2 MAP and negatively correlated at 6 MAP. Rainfall was found to be positively correlated with tuber yield up to 6 MAP, after which negative correlation was observed.

Table 71. Correlation of yield of normal-duration varieties with max-min temperature and rainfall

Months after planting	Max. temperature (^oC)	Min. temperature (^oC)	Rainfall (mm)
2 MAP	-0.540*	0.657**	0.835**
4 MAP	-0.727**	-0.152	0.867**
6 MAP	-0.836**	-0.683**	0.650**
8 MAP	-0.055	0.063	-0.504*
10 MAP	0.861**	0.349	-0.569*

Correlation for yield with other weather parameters including mean relative humidity, mean evaporation, wind speed and mean sun shine hours were studied (Table 72). Significant positive correlation between yield and mean relative humidity was recorded for normal-duration varieties at 2, 4 and 6 MAP. A negative correlation between mean evaporation, wind speed and mean sunshine hours was recorded for the same. A positive correlation between yield, wind speed, mean evaporation and mean sunshine hours was recorded at 8 and 10 MAP. It signifies that relative humidity at early stages of crop growth had a more significant influence on yield

Table 72. Correlation of yield of normal-duration varieties with mean relative humidity, mean evaporation, wind speed and mean sunshine hours

Months after planting	Mean Relative humidity (%)	Mean evaporation (mm)	Wind speed (km/hr)	Mean Sunshine hours
2 MAP	0.623**	-0.422	-0.499*	-0.709**
4 MAP	0.866**	-0.862**	-0.573*	-0.868**
6 MAP	0.656**	-0.817**	-0.857**	0.284
8 MAP	-0.594**	0.092	0.824**	0.280
10 MAP	0.857**	0.845**	0.866**	0.764**

Experiment II. Effect of foliar application of potassium, silicon, and calcium on growth and productivity of cassava in moisture stressed condition

For the second experiment, effect of various chemical treatments along with recommended package of practices on mitigating water stress was observed in the short duration variety Vellayani Hraswa planted in October 2015, and a confirmatory experiment was done in the next year (2016) also. Analysis was done to test the homogeneity of variance, and pooled using R- software.

II.1. Biometric observations for experiment II

General growth of the crop was recorded at 2, 4 and 6 months after planting in both the years. Mean monthly rainfall of about 310.30 mm was recorded during the cropping season of 2015, whereas 98.00 mm rainfall was recorded during the 2016 cropping season, which was 213.00 % less than the previous crop growing season.

a. Plant height

Pooled analysis of the data indicated that various chemical treatments alone and in combination could bring about significant influence on cassava plant height during all the stages of growth (Table 73).

At 2 MAP, significantly taller plant height was noted for all the treatments as compared to control in which water spray alone was applied.

As per the data recorded at 4 MAP, the treatments POP + KCl + silicic acid + $CaCl_2$ (72.80 cm), and POP + $CaCl_2$ (69.35 cm) resulted in significantly taller plants compared to control (51.86 cm). This was followed by treatments POP + silicic acid + $CaCl_2$ (68.00 cm) and POP + KCl (65.20 cm) , which were on par.

At 6 MAP, tallest plants were observed for treatments POP + KCl + silicic acid + $CaCl_2$ (80.48 cm), POP + KCl + $CaCl_2$ (77.77 cm), POP alone (75.78 cm), POP + silicic acid + $CaCl_2$ (75.62 cm), and POP + $CaCl_2$ (75.54 cm). For all the three stages of observation, lowest plant height was observed for water spray alone (T_{10}).

Table 73. Pooled analysis (weighted mean) of the effect of chemical treatments on plant height of cassava in 2015-16 and 2016-17

Treatments	Plant height (cm)		
	2 MAP	4 MAP	6 MAP
T_1-POP	48.70	63.71	75.78
T_2-POP + KCl	52.08	65.20	73.52
T_3-POP + silicic acid	54.86	60.08	71.00
T_4-POP + $CaCl_2$	57.58	69.35	75.54
T_5-POP + KCl + silicic acid	51.70	61.01	69.50
T_6-POP + KCl+ $CaCl_2$	53.88	64.15	77.77
T_7-POP + silicic acid + $CaCl_2$	55.15	68.00	75.62
T_8-POP + KCl + silicic acid + $CaCl_2$	56.73	72.80	80.48
T_9-POP + water spray	58.48	64.43	70.43
T_{10}-Water spray alone	41.96	51.86	58.60
SEd	**2.48**	**2.14**	**2.80**
CD (0.05)	**5.22**	**4.51**	**5.88**

b. Number of leaves per plant

Number of leaves per plant indicates the response of a plant to drought. During initial stage of observation *i.e.*, 2 MAP, highest number of leaves were recorded for POP + KCl + silicic acid + $CaCl_2$ (80.48), POP + KCl+ $CaCl_2$ (77.77), POP alone (75.78), POP + $CaCl_2$ (75.54) and lowest number recorded for water spray alone (58.60).

Significantly higher number of leaves per plant compared to control was noticed for all the treatments except for treatments POP + silicic acid + $CaCl_2$ (33.16), POP + silicic acid (32.00), POP + $CaCl_2$ (32.00), water spray alone (31.16) and POP+ water spray (29.00) at 4 MAP (Table 74).

At 6 MAP, treatments POP + KCl (30.50), POP + KCl + silicic acid+ $CaCl_2$ (29.66), POP + KCl + $CaCl_2$ (29.65) , POP + silicic acid + $CaCl_2$ (26.83) and POP +

KCl + silicic acid (26.83) were observed to have significantly higher number of leaves per plant as compared to other treatments.

Table 74. Pooled analysis (weighted mean) of the effect of chemical treatments on number of leaves per plant of cassava in 2015-16 and 2016-17

Treatments	No. of leaves per plant		
	2 MAP	4 MAP	6 MAP
T_1-POP	75.78	38.83	24.16
T_2-POP + KCl	73.52	39.66	30.50
T_3-POP + silicic acid	71. 00	32.00	25.00
T_4-POP + $CaCl_2$	75.54	32.00	23.22
T_5-POP + KCl + silicic acid	69.50	34.00	26.83
T_6-POP + KCl+ $CaCl_2$	77.77	37.83	29.65
T_7-POP + silicic acid + $CaCl_2$	75.62	33.16	26.83
T_8-POP + KCl + silicic acid + $CaCl_2$	80.48	38.16	29.66
T_9-POP + water spray	70.43	29.00	22.50
T_{10}-Water spray alone	58.60	31.16	22.50
SEd	**2.80**	**2.77**	**2.50**
CD (0.05)	**5.88**	**5.82**	**5.25**

c. Number of branches per plant

Significantly higher number of branches per plant was observed in all the treatments over POP + water spray (T_9) and water spray alone (T_{10}). This was similar for all the 3 stages of observations (Table 75). All treatments except T_9 and T_{10} were seen to be on par.

Table 75. Pooled analysis (weighted mean) of the effect of chemical treatments on number of branches per plant of cassava in 2015-16 and 2016-17

Treatments	No. of branches per plant		
	2 MAP	4 MAP	6 MAP
T_1-POP	1.66	1.66	1.66
T_2-POP + KCl	1.83	1.83	1.83
T_3-POP + silicic acid	1.66	1.66	1.66
T_4-POP + $CaCl_2$	1.83	1.83	1.83
T_5-POP + KCl + silicic acid	2.00	2.00	2.00
T_6-POP + KCl+ $CaCl_2$	1.66	1.66	1.66
T_7-POP + silicic acid + $CaCl_2$	1.83	1.83	1.83
T_8-POP + KCl + silicic acid + $CaCl_2$	2.00	2.00	2.00
T_9-POP + water spray	1.50	1.50	1.50
T_{10}-Water spray alone	1.33	1.33	1.33
SEd	**0.22**	**0.22**	**0.22**
CD (0.05)	**0.47**	**0.47**	**0.47**

d. Stem girth

The data shows that there was significant difference in stem girth due to the effect of chemical treatments for all the growth stages, with treatment POP + silicic acid + $CaCl_2$ (7.99 cm), POP + KCl + silicic acid (7.78 cm), and POP+ KCl (7.34 cm) and POP + KCl + silicic acid+ $CaCl_2$ (7.35 cm) recording significantly higher stem girth than control (Table 76).

At 4 MAP, significantly higher stem girth was realized for treatment POP + silicic acid + $CaCl_2$ (9.86 cm) and was followed by treatments POP + KCl (8.94 cm), POP + KCl + silicic acid + $CaCl_2$ (8.90 cm), POP + KCl + silicic acid (8.82 cm) and POP + $CaCl_2$ (8.19 cm).

Stem girth was significantly higher for treatments POP + KCl + silicic acid + $CaCl_2$ (10.58 cm), POP + silicic acid + $CaCl_2$ (10.37 cm), and POP + KCl (10.33 cm) at 6 MAP. Lowest girth was recorded for control (7.30 cm).

Table 76. Pooled analysis (weighted mean) of the effect of chemical treatments on stem girth of cassava in 2015-16 and 2016-17

Treatments	Stem girth (cm)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	5.47	7.77	8.33
T_2-POP + KCl	7.34	8.94	10.33
T_3-POP + silicic acid	6.42	7.76	8.01
T_4-POP + $CaCl_2$	6.05	8.19	8.77
T_5-POP + KCl + silicic acid	7.78	8.82	8.99
T_6-POP + KCl+ $CaCl_2$	6.66	7.51	8.70
T_7-POP + silicic acid + $CaCl_2$	7.99	9.86	10.37
T_8-POP + KCl + silicic acid + $CaCl_2$	7.35	8.90	10.58
T_9-POP + water spray	6.40	7.17	7.66
T_{10}-Water spray alone	5.33	6.60	7.30
SEd	**0.36**	**0.41**	**0.57**
CD (0.05)	**0.76**	**0.87**	**1.20**

e. Number of leaf scars per plant

Number of leaf scars or leaves fallen was influenced by chemical treatments. At 2 MAP significantly higher number of leaf scars per plant was on par for all the treatments except for POP + KCl + $CaCl_2$ (1.94).

At 4 MAP, significantly lower number of leaves fallen was recorded for treatment POP + KCl+ silicic acid + $CaCl_2$ (28.41) followed by POP + $CaCl_2$ (31.83). Control recorded significantly higher number of leaf scars (58.91) (Table 77).

At 6 MAP, significantly less number of scars was observed for treatments, POP + KCl + silicic acid + $CaCl_2$ (39.66) and POP + $CaCl_2$ (41.33). Significantly higher number of leaf scars was observed for treatments water spray alone (69.66), POP + KCl + $CaCl_2$ (68.33), POP + KCl + silicic acid (63.66) and POP + water spray (61.00),

Table 77. Pooled analysis (weighted mean) of the effect of chemical treatments on leaf scars per plant of cassava in 2015-16 and 2016-17

Treatments	No. of leaf scars per plant		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	2.25	44.98	54.50
T_2-POP + KCl	2.96	41.55	56.33
T_3-POP + silicic acid	2.66	37.31	49.00
T_4-POP + $CaCl_2$	2.39	31.83	41.33
T_5-POP + KCl + silicic acid	2.24	36.14	63.66
T_6-POP + KCl+ $CaCl_2$	1.94	42.23	68.33
T_7-POP + silicic acid + $CaCl_2$	2.72	41.55	56.66
T_8-POP + KCl + silicic acid + $CaCl_2$	2.78	28.41	39.66
T_9-POP + water spray	2.68	47.36	61.00
T_{10}-Water spray alone	2.44	58.91	69.66
SEd	**0.47**	**4.07**	**6.18**
CD (0.05)	**0.99**	**8.55**	**12.98**

f. Root length

Under various chemical treatments root length of the varieties showed significant difference at all the stages of growth. At 2 MAP, root length was significantly higher for treatment POP + silicic acid (17.38 cm) and POP + KCl+ silicic acid + $CaCl_2$ (16.32 cm), which were on par (Table 78).

The observations at 4 MAP and 6 MAP revealed that the treatment POP + KCl+ silicic acid + $CaCl_2$ (35.79 cm and 32.77 cm respectively) recorded significantly higher root length. Lowest root length was recorded for treatments POP + water spray

(15.72 cm and 16.31 cm respectively) and water spray alone (15.75 cm and 14.96 cm respectively).

Table 78. Pooled analysis (weighted mean) of the effect of chemical treatments on root length of cassava in 2015-16 and 2016-17

Treatments	Root length (cm)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	10.86	17.46	17.06
T_2-POP + KCl	10.48	18.59	19.79
T_3-POP + silicic acid	17.38	22.85	25.69
T_4-POP + $CaCl_2$	13.90	17.64	20.18
T_5-POP + KCl + silicic acid	15.82	22.17	20.62
T_6-POP + KCl + $CaCl_2$	12.82	24.83	22.29
T_7-POP + silicic acid + $CaCl_2$	14.49	29.09	27.87
T_8-POP + KCl + silicic acid + $CaCl_2$	16.32	35.79	32.77
T_9-POP + water spray	10.32	15.72	16.31
T_{10}-Water spray alone	9.77	15.75	14.96
SEd	**0.69**	**0.65**	**0.76**
CD (0.05)	**1.45**	**1.37**	**1.60**

g. Root diameter

Root diameter at 2 MAP was significantly higher for treatments POP + KCl+ silicic acid + $CaCl_2$ (1.35 cm), POP + silicic acid + $CaCl_2$ (1.30 cm) and POP + KCl + $CaCl_2$ (1.22 cm).

At 4 MAP higher root diameter was observed for treatment POP + KCl + $CaCl_2$ (9.71 cm) and was followed by POP + KCl (8.19 cm), POP + silicic acid + $CaCl_2$ (8.18 cm), POP + KCl + silicic acid (7.99 cm) and POP + KCl+ silicic acid +$CaCl_2$ (7.74 cm).

Significantly higher root diameter was observed for treatments POP + KCl + silicic acid + $CaCl_2$ (12.47 cm) and POP + KCl+ $CaCl_2$ (12.05 cm) at 6 MAP. Lowest root diameter for all the 3 stages was observed for treatment T_{10} *i.e.*, water spray alone (8.42 cm) (Table 79).

Table 79. Pooled analysis (weighted mean) of the effect of chemical treatments on root diameter of cassava in 2015-16 and 2016-17

Treatments	Root diameter (cm)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	0.87	6.45	10.6
T_2-POP + KCl	1.12	8.19	10.95
T_3-POP + silicic acid	1.17	6.81	9.57
T_4-POP + $CaCl_2$	1.05	6.05	11.00
T_5-POP + KCl + silicic acid	1.07	7.99	10.27
T_6-POP + KCl+ $CaCl_2$	1.22	9.71	12.05
T_7-POP + silicic acid + $CaCl_2$	1.30	8.18	10.51
T_8-POP + KCl + silicic acid + $CaCl_2$	1.35	7.74	12.47
T_9-POP + water spray	0.87	6.80	9.90
T_{10}-Water spray alone	0.85	5.55	8.42
SEd	**0.07**	**0.44**	**0.46**
CD (0.05)	**0.16**	**0.94**	**0.97**

h. Shoot fresh weight

Significantly higher shoot fresh weight was recorded for treatments POP + KCl (46.65 g/plant) at 2 MAP.

At 4 MAP and 6 MAP, shoot fresh weight was found to be significantly higher for treatment POP + $CaCl_2$ (60.91 g/plant and 69.88 g/plant respectively). Lowest shoot fresh weight was recorded for water spray alone (39.94 g/plant), POP + water spray (43.26 g/plant) and POP alone (47.74 g/plant) at 6 MAP (Table 80).

Table 80. Pooled analysis (weighted mean) of the effect of chemical treatments on shoot fresh weight of cassava in 2015-16 and 2016- 17

Treatment	Shoot fresh weight (g/plant)		
	2 MAP	4 MAP	6 MAP
T_1-POP	36.13	50.82	47.74
T_2-POP + KCl	46.65	52.71	61.67
T_3-POP + silicic acid	35.53	48.39	48.69
T_4-POP + $CaCl_2$	36.57	60.91	69.88
T_5-POP + KCl + silicic acid	38.84	41.68	54.37
T_6-POP + KCl+ $CaCl_2$	28.26	49.36	54.67
T_7-POP + silicic acid + $CaCl_2$	38.29	38.77	51.04
T_8-POP + KCl + silicic acid + $CaCl_2$	33.65	49.72	61.59
T_9-POP + water spray	35.89	39.61	43.26
T_{10}-Water spray alone	33.2	34.88	39.94
SEd	1.72	1.81	2.76
CD (0.05)	3.63	3.81	5.80

i. Root fresh weight

At 2 MAP, root fresh weight was significantly higher for treatments POP + silicic acid (35.06 g/plant) and KCl + silicic acid (34.32 g/plant).

Significantly higher root fresh weight was recorded for treatments, POP + KCl+ silicic acid + $CaCl_2$ (58.72 g/plant) and POP + silicic acid + $CaCl_2$ (52.84 g/plant) compared to other treatments at 4 MAP.

Observations at 6 MAP revealed that significantly higher root fresh weight was for treatment POP + KCl + silicic acid (108.51 g/plant). Lowest root fresh weight was observed for treatments water spray alone (64.17 g/plant) and POP + water spray (66.51 g/plant) at 6 MAP (Table 81)

Table 81. Pooled analysis (weighted mean) of the effect of chemical treatments on root fresh weight of cassava in 2015-16 and 2016-17

Treatment	Root fresh weight (g/plant)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	18.17	49.57	77.66
T_2-POP + KCl	14.46	45.26	72.69
T_3-POP + silicic acid	35.06	46.98	62.96
T_4-POP + $CaCl_2$	14.60	42.28	72.81
T_5-POP + KCl + silicic acid	34.32	50.70	108.51
T_6-POP + KCl + $CaCl_2$	9.75	34.92	76.88
T_7-POP + silicic acid + $CaCl_2$	19.84	52.84	91.40
T_8-POP + KCl + silicic acid + $CaCl_2$	14.01	58.72	82.69
T_9-POP + water spray	12.30	21.81	66.51
T_{10}-Water spray alone	8.90	24.00	64.17
SEd	**1.25**	**2.89**	**2.89**
CD (0.05)	**2.63**	**6.08**	**8.20**

j. Total dry matter production

At 2 MAP, significantly higher dry matter production was recorded for POP + silicic acid + $CaCl_2$ (10.52 g/plant) and POP + KCl+ silicic acid (9.94 g/plant).

At 4 MAP, significantly higher DMP was recorded for POP + KCl+ silicic acid + $CaCl_2$ (59.38 g/plant), POP+ silicic acid + $CaCl_2$ (57.23 g/plant), and POP + KCl (57.09 g/plant) and POP + silicic acid (56.31 g/plant). The trend was very similar at 6 MAP (Table 82)

Table 82. Pooled analysis (weighted mean) of the effect of chemical treatments on total dry matter production of cassava in 2015-16 and 2016-17

Treatment	Total dry matter production (g/plant)		
	2 MAP	4 MAP	6 MAP
T_1-POP	5.23	34.43	48.36
T_2-POP + KCl	8.88	57.09	90.84
T_3-POP + silicic acid	8.94	56.31	73.04
T_4-POP + $CaCl_2$	6.53	44.54	57.69
T_5-POP + KCl + silicic acid	9.94	59.38	85.66
T_6-POP + KCl+ $CaCl_2$	4.51	42.99	56.04
T_7-POP + silicic acid + $CaCl_2$	10.52	57.23	84.45
T_8-POP + KCl + silicic acid + $CaCl_2$	8.66	52.41	85.60
T_9-POP + water spray	4.42	30.45	39.80
T_{10}-Water spray alone	6.56	30.80	40.12
SEd	**0.55**	**3.90**	**5.20**
CD (0.05)	**1.17**	**8.21**	**10.92**

II.2. Physiological parameters

Physiological parameters like relative leaf water content, proline content, NRase activity, leaf sugar content, chlorophyll content, photosynthetic activity and stomatal conductance were recorded at regular intervals.

a. Relative leaf water content

At 2 MAP, significantly higher relative leaf water content was observed for treatments POP alone (77.81 %) and POP + KCl (73.44 %).

However at 4 MAP significantly higher RLWC was recorded for treatments POP + KCl + silicic acid + $CaCl_2$ (69.23 %), POP + silicic acid + $CaCl_2$ (61.33) and POP + KCl (60.36 %). Lowest value was recorded for POP alone (46.33 %), water spray alone (46.43 %), POP + silicic acid (46.34 %) and POP + water spray (50.06 %)

Treatment combinations POP+ KCl+ silicic acid + $CaCl_2$ (77.75 %) and POP + $CaCl_2$ (74.84 %) recorded significantly higher RLWC at 6 MAP. The treatments, POP alone (57.38 %) and water spray alone (53.46 %) were observed to record lowest RLWC at 6 MAP (Table 83).

Table 83. Pooled analysis (weighted mean) of the effect of chemical treatments on relative leaf water content of cassava in 2015-16 and 2016- 17

Treatments	Relative leaf water content (%)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	77.81	46.33	57.38
T_2-POP + KCl	73.44	60.36	63.43
T_3-POP + silicic acid	59.51	46.34	54.35
T_4-POP + $CaCl_2$	57.31	60.06	74.84
T_5-POP + KCl + silicic acid	53.06	54.55	63.83
T_6-POP + KCl+ $CaCl_2$	54.96	50.06	47.78
T_7-POP + silicic acid + $CaCl_2$	59.15	61.33	64.83
T_8-POP + KCl + silicic acid + $CaCl_2$	59.50	69.23	77.75
T_9-POP + water spray	62.01	50.06	63.91
T_{10}-Water spray alone	56.60	46.43	53.46
SEd	**3.73**	**3.80**	**3.99**
CD (0.05)	**7.84**	**8.38**	**8.38**

b. Proline content

Proline content was significantly higher for POP alone (40.15 mg/g) and POP + KCl (38.97 mg/g) at 2 MAP (Table 84).

At 4 MAP, significantly higher proline was recorded for water spray alone (91.88 mg/g) and was followed by treatments POP + water spray (85.31 mg/g) and POP alone (80.62 mg/g). Lowest proline content was observed for POP + KCl+ silicic acid (68.21 mg/g).

During the later stages of observation at 6 MAP, treatment POP alone (42.62 mg/g) indicated a higher proline content, whereas application of combinations of all chemicals, POP + KCl + silicic acid + $CaCl_2$ (26.42 mg/g) recorded lowest proline content.

Table 84. Pooled analysis (weighted mean) of the effect of chemical treatments on proline content of cassava in 2015-16 and 2016-17

Treatments	Proline content (mg/g)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	40.15	80.62	42.62
T_2-POP + KCl	38.97	70.31	27.92
T_3-POP + silicic acid	38.16	73.49	27.10
T_4-POP + $CaCl_2$	38.17	78.62	27.95
T_5-POP + KCl + silicic acid	36.27	68.21	27.89
T_6-POP + KCl+ $CaCl_2$	37.47	75.73	28.98
T_7-POP + silicic acid + $CaCl_2$	36.46	73.75	28.22
T_8-POP + KCl + silicic acid + $CaCl_2$	37.39	70.27	26.42
T_9-POP + water spray	36.94	85.31	33.68
T_{10}-Water spray alone	37.69	91.88	38.03
SEd	**0.74**	**2.25**	**0.98**
CD (0.05)	**1.56**	**4.97**	**2.07**

c. Nitrate reductase activity

At 2 MAP, significantly higher nitrate reductase activity was recorded for POP + KCl + $CaCl_2$ (16.88 µg NO_2/g/fresh leaf/h) at 2 MAP (Table 85).

At 4 MAP, significantly higher NRase activity was recorded for treatments, POP+ KCl + silicic acid + $CaCl_2$ (26.03 µg NO_2/g/fresh leaf/h), followed by the treatments POP + $CaCl_2$ (22.58 µg NO_2/g/fresh leaf/h) and POP + KCl (21.65 µg NO_2/g/fresh leaf/h) at 4 MAP. Lowest NRase was noted for control (16.65 µg NO_2/g/fresh leaf/h).

At 6 MAP, treatments T_8 (POP + KCl + silicic acid + $CaCl_2$ (15.19 µg NO_2/g/fresh leaf/h), POP + KCl (14.26 µg NO_2/g/fresh leaf/h), POP + silicic acid (14.07 µg NO_2/g/fresh leaf/h), POP + silicic acid + $CaCl_2$ (13.22 µg NO_2/g/fresh leaf/h), POP + KCl + $CaCl_2$ (13.21 µg NO_2/g/fresh leaf/h) and POP + KCl + silicic acid (12.49 µg NO_2/g/fresh leaf/h) recorded significantly higher NRase activity, and lowest value was recorded for POP + water spray (9.09 µg NO_2/g/fresh leaf/h),

Table 85. Pooled analysis (weighted mean) of the effect of chemical treatments on nitrate reductase activity content of cassava in 2015-16 and 2016- 17

Treatments	**Nitrate reductase activity (µg NO_2/g/fresh leaf/h)**		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	8.79	18.67	12.16
T_2-POP + KCl	9.38	21.65	14.26
T_3-POP + silicic acid	7.82	20.94	14.07
T_4-POP + $CaCl_2$	12.19	22.58	11.91
T_5-POP + KCl + silicic acid	11.85	20.26	12.49
T_6-POP + KCl+ $CaCl_2$	16.88	19.95	13.21
T_7-POP + silicic acid + $CaCl_2$	9.17	21.05	13.22
T_8-POP + KCl + silicic acid + $CaCl_2$	12.26	26.03	15.19
T_9-POP + water spray	7.32	19.28	9.09
T_{10}-Water spray alone	10.56	16.65	9.42
SEd	**0.63**	**0.54**	**1.40**
CD (0.05)	**1.33**	**1.41**	**2.95**

d. Leaf sugar content

All the treatments except POP alone (1.84 %) and water spray alone (1.79%) recorded significantly higher leaf sugar content at 2 MAP.

At 4 MAP, POP alone (9.22 %) recorded significantly lower leaf sugar content compared to all other treatments which were on par. No significant difference in leaf sugar content was observed at 6 MAP (Table 86).

Table 86. Pooled analysis (weighted mean) of the effect of chemical treatments on leaf sugar content of cassava in 2015-16 and 2016- 17

Treatments	Leaf sugar content (%)		
	2 MAP	**4 MAP**	**6 MAP**
T_1-POP	1.84	9.22	7.30
T_2-POP + KCl	2.06	10.14	7.86
T_3-POP + silicic acid	1.95	9.96	7.81
T_4-POP + $CaCl_2$	2.05	9.86	7.89
T_5-POP + KCl + silicic acid	1.95	9.83	7.72
T_6-POP + KCl+ $CaCl_2$	2.17	10.16	8.01
T_7-POP + silicic acid + $CaCl_2$	1.95	9.83	7.75
T_8-POP + KCl + silicic acid + $CaCl_2$	2.17	10.38	8.24
T_9-POP + water spray	1.92	9.64	7.49
T_{10}-Water spray alone	1.79	9.52	7.23
SEd	**0.12**	**0.47**	**-**
CD (0.05)	**0.27**	**1.00**	**NS**

e. Chlorophyll content

Significantly higher chlorophyll a content at 2 MAP was observed for the treatments POP+ KCl + silicic acid + $CaCl_2$ (1.76 mg/g), POP + silicic acid (1.73 mg/g) and POP+ water spray (1.59 mg/g). Treatments POP + silicic acid + $CaCl_2$ (3.79 mg/g), POP + KCl+ $CaCl_2$ (3.75 mg/g), POP + silicic acid (3.69 mg/g) and POP alone (3.67 mg/g) recorded highest chl a at 4 MAP. Lowest value was observed for treatments POP + water spray (2.61 mg/g) and water spray alone (2.64 mg/g). Treatment POP + KCl + silicic acid + $CaCl_2$ (1.13 mg/g) was noted for its significantly higher chl a content at 6 MAP than other treatments. Lowest Chl a content was observed for water spray alone (0.70 mg/g).

Higher Chl b content was recorded for POP+ KCl + silicic acid + $CaCl_2$ at 2, 4 and 6 MAP (1.07 mg/g, 3.08 mg/g and 1.82 mg/g respectively). The treatment was on par with POP + KCl (3.05 mg/g) at 4 MAP. Lowest Chl b content was recorded for water spray alone for all the three stages of observations (Table 87).

Table 87. Pooled analysis (weighted mean) of the effect of chemical treatments on chlorophyll content of cassava in 2015-16 and 2016-17

Treatments	Chlorophyll content (mg/g)					
	Chlorophyll a			Chlorophyll b		
	2 MAP	4 MAP	6 MAP	2 MAP	4 MAP	6 MAP
T_1-POP	1.28	3.67	0.71	0.73	2.01	0.99
T_2-POP + KCl	1.25	2.88	0.81	0.68	3.05	0.98
T_3-POP + silicic acid	1.73	3.69	0.83	0.88	2.65	1.03
T_4-POP + $CaCl_2$	1.28	3.04	0.78	0.69	2.16	1.12
T_5-POP + KCl + silicic acid	1.30	1.91	0.71	0.73	1.38	1.00
T_6-POP + KCl+ $CaCl_2$	1.46	3.75	0.86	0.83	2.21	1.09
T_7-POP + silicic acid + $CaCl_2$	1.30	3.79	0.87	0.73	2.71	1.06
T_8-POP + KCl + silicic acid + $CaCl_2$	1.76	3.35	1.13	1.07	3.08	1.82
T_9-POP + water spray	1.59	2.61	0.96	0.86	1.86	0.93
T_{10}-Water spray alone	1.27	2.64	0.70	0.71	1.80	0.91
SEd	**0.09**	**0.20**	**0.05**	**0.04**	**0.15**	**0.08**
CD (0.05)	**0.19**	**0.42**	**0.11**	**0.10**	**0.33**	**0.17**

f. Photosynthetic activity

Significantly higher photosynthetic activity was recorded for POP + KCl + silicic acid + $CaCl_2$ (12.25 μ mol CO_2/m^2 /sec) and POP+ KCl (11.42 μ mol CO_2/m^2 /sec) at 2 MAP (Table 87).

Treatments POP + KCl + silicic acid + $CaCl_2$ (12.62 μ mol CO_2/m^2 /sec), POP + KCl (11.53 μ mol CO_2 /m^2 /sec) and POP + silicic acid (11.50 μ mol CO_2 /m^2 /sec) recorded significantly higher photosynthetic rate at 6 MAP. Lowest value was observed for water spray alone (8.34 μ mol CO_2 /m^2 /sec).

g. Stomatal conductance

Stomatal conductance was significantly higher for treatments T_8, POP+ KCl+ silicic acid + $CaCl_2$ (0.074 mol H_2O / m^2/ sec and 1.71 mol H_2O / m^2/ sec respectively) and POP + KCl (0.066 mol H_2O / m^2/ sec and 1.57 mol H_2O / m^2/ sec respectively) at 2 MAP and 6 MAP (Table 88). Treatment POP + silicic acid (1.61 mol H_2O / m^2/ sec) were also found to be on par with the above treatments at 6 MAP. Lowest stomatal conductance was observed for control (0.40 mol H_2O / m^2/ sec).

Table 88. Pooled analysis (weighted mean) of the effect of chemical treatments on photosynthetic activity and stomatal conductance of cassava in 2015-16 and 2016-17

Treatments	Photosynthetic activity (µ mol CO_2 /m^2 /sec)		Stomatal conductance (mol H_2O / m^2/ sec)	
	2 MAP	**6 MAP**	**2 MAP**	**6 MAP**
T_1-POP	8.99	9.88	0.055	0.810
T_2-POP + KCl	11.42	11.53	0.066	1.570
T_3-POP + silicic acid	8.91	11.50	0.058	1.610
T_4-POP + $CaCl_2$	9.82	10.10	0.046	1.130
T_5-POP + KCl + silicic acid	6.28	9.09	0.039	0.940
T_6-POP + KCl+ $CaCl_2$	9.51	9.84	0.053	0.520
T_7-POP + silicic acid + $CaCl_2$	6.69	10.16	0.049	0.640
T_8-POP + KCl + silicic acid + $CaCl_2$	12.25	12.62	0.074	1.710
T_9-POP + water spray	9.64	9.69	0.058	1.470
T_{10}-Water spray alone	8.67	8.34	0.050	0.400
SEd	**0.67**	**0.69**	**0.004**	**0.080**
CD (0.05)	**1.42**	**1.45**	**0.009**	**0.17**

II.3. Growth analysis

Effect of chemical treatments in combination and alone on different growth parameters were recorded for the two seasons 2015-16 and 2016-17, and the data were pooled and analyzed.

a. Net assimilation rate

A significant increase in net assimilation rate was recorded for treatments POP + KCl + silicic acid + $CaCl_2$ (3.46 g/g/day), POP + silicic acid + $CaCl_2$ (3.24 g/g/day) and POP + silicic acid (3.11 g/g/day) at 2 MAP.

At 4 MAP, treatments, KCl + silicic acid (7.09 g/g/day) POP + KCl + silicic acid + $CaCl_2$ (6.98 g/g/day and POP + KCl (6.33 g/g/day) were observed to have significantly higher NAR and were followed by treatment POP + $CaCl_2$ (6.20 g/g/day). Lowest value was noted for treatment, POP + water spray (4.93 g/g/day) and water spray alone (5.04 g/g/day).

Again treatments KCl+ silicic acid (8.31 g/g/day), POP + KCl+ silicic acid + $CaCl_2$ (8.29 g/g/day), POP+ $CaCl_2$ (7.94 g/g/day) and POP + silicic acid (7.88 g/g/day) produced significantly higher NAR at 6 MAP with lowest values recorded for treatments water spray alone (6.49 g/g/day) and POP + water spray (6.62 g/g/day) (Table 89).

b. Crop growth rate

At 2 MAP significantly higher crop growth rate was observed for POP + $CaCl_2$ + KCl + silicic acid (5.31 g/m^2/day) and the lowest CGR was recorded for treatments water spray alone (3.15 g/m^2/day), POP alone (3.35 g/m^2/day), POP + water spray (3.50 g/m^2/day), which were on par.

Significantly higher CGR was noted for treatments POP+ KCl (5.02 g/m^2/day), POP + KCl + silicic acid + $CaCl_2$ (4.75 g/m^2/day) and POP + KCl + silicic acid (4.51 g/m^2/day), and at 4 MAP. Lowest CGR was observed for water spray alone (3.74 g/m^2/day). No significant difference for crop growth rate was recorded among treatments at 6 MAP (Table 90).

Table 89. Pooled analysis (weighted mean) of the effect of chemical treatments on net assimilation rate of cassava in 2015-16 and 2016-17

Treatments	Net assimilation rate (g/g/day)		
	Stage I (0-60 DAP)	**Stage II (60-120 DAP)**	**Stage III (120-180 DAP)**
T_1-POP	1.20	6.07	7.02
T_2-POP + KCl	2.69	6.33	7.25
T_3-POP + silicic acid	3.11	6.06	7.88
T_4-POP + $CaCl_2$	2.27	6.20	7.94
T_5-POP + KCl + silicic acid	2.66	7.09	8.31
T_6-POP + KCl+ $CaCl_2$	2.71	5.27	6.94
T_7-POP + silicic acid + $CaCl_2$	3.24	5.66	7.21
T_8-POP + KCl + silicic acid + $CaCl_2$	3.46	6.98	8.29
T_9-POP + water spray	2.49	4.93	6.62
T_{10}-Water spray alone	2.39	5.04	6.49
SEd	**0.17**	**0.40**	**0.47**
CD (0.05)	**0.36**	**0.84**	**1.00**

c. Relative growth rate

Significantly higher relative growth rate was recorded for treatment POP + KCl + silicic acid + $CaCl_2$ (0.023 and 0.019 g/g/day) in both the growth phases *i.e.* stage I (60-120 DAP) and stage II (120-180 DAP). The lowest was recorded for treatment water spray alone (0.012 g/g/day and 0.009 g/g/day respectively) for the two stages (Table 91).

Table 90. Pooled analysis (weighted mean) of the effect of chemical treatments on crop growth rate of cassava in 2015-16 and 2016-17

Treatments	Crop growth rate (g/m^2/day)		
	Stage I (0-60 DAP)	Stage II (60-120 DAP)	Stage III (120-180 DAP)
T_1-POP	3.35	4.02	6.06
T_2-POP + KCl	4.11	5.02	6.35
T_3-POP + silicic acid	4.61	4.30	6.75
T_4-POP + $CaCl_2$	4.09	4.24	6.53
T_5-POP + KCl + silicic acid	4.40	4.51	6.42
T_6-POP + KCl+ $CaCl_2$	4.30	4.41	6.36
T_7-POP + silicic acid + $CaCl_2$	4.64	4.21	6.28
T_8-POP + KCl + silicic acid + $CaCl_2$	5.31	4.75	6.89
T_9-POP + water spray	3.50	4.16	6.38
T_{10}-Water spray alone	3.15	3.74	5.86
SEd	**0.26**	**0.29**	**-**
CD (0.05)	**0.56**	**0.61**	**NS**

d. Leaf Area Index

At 2 MAP significantly higher leaf area index was recorded for treatments POP + KCl + silicic acid (0.88) and POP + silicic acid + $CaCl_2$ (0.83).

At 4 MAP significantly higher leaf area index was observed for treatment POP + KCl + silicic acid + $CaCl_2$ (4.22) and the lowest value was for water spray alone (2.19).

Treatments, POP + KCl + silicic acid + $CaCl_2$ (1.42) and POP + KCl + silicic acid (1.32), recorded significantly higher LAI at 6 MAP and were on par (Table 92).

Table 91. Pooled analysis (weighted mean) of the effect of chemical treatments on relative growth rate of cassava in 2015-16 and 2016-17

Treatments	Relative growth rate (g/g/day)	
	Stage I (60-120 DAP)	**Stage II (120-180 DAP)**
T_1-POP	0.016	0.010
T_2-POP + KCl	0.020	0.014
T_3-POP + silicic acid	0.019	0.014
T_4-POP + $CaCl_2$	0.017	0.012
T_5-POP + KCl + silicic acid	0.020	0.015
T_6-POP + KCl+ $CaCl_2$	0.020	0.016
T_7-POP + silicic acid + $CaCl_2$	0.018	0.016
T_8-POP + KCl + silicic acid + $CaCl_2$	0.023	0.019
T_9-POP + water spray	0.015	0.011
T_{10}-Water spray alone	0.012	0.009
SEd	**0.001**	**0.001**
CD (0.05)	**0.002**	**0.002**

II.4. Quality parameters

Data on effect of treatments on the quality parameters of Vellayani Hraswa are presented in Table 93.

Starch content was significantly higher for treatments POP+ KCl+ $CaCl_2$ (15.56 %), POP + KCl+ silicic acid + $CaCl_2$ (14.62 %), POP+ silicic acid + $CaCl_2$ (14.28 %) and the lowest starch content was recorded for water spray alone (9.62 %).

Table 92. Pooled analysis (weighted mean) of the effect of chemical treatments on leaf area index of cassava in 2015-16 and 2016-17

Treatments	Leaf area index		
	2 MAP	4 MAP	6 MAP
T_1-POP	0.57	2.76	0.96
T_2-POP + KCl	0.21	2.68	1.21
T_3-POP + silicic acid	0.62	3.14	1.2
T_4-POP + $CaCl_2$	0.72	2.88	1.05
T_5-POP + KCl + silicic acid	0.88	3.70	1.32
T_6-POP + KCl+ $CaCl_2$	0.71	3.30	1.16
T_7-POP + silicic acid + $CaCl_2$	0.83	3.40	1.28
T_8-POP + KCl + silicic acid + $CaCl_2$	0.75	4.22	1.42
T_9-POP + water spray	0.57	2.52	0.94
T_{10}-Water spray alone	0.64	2.19	0.96
SEd	**0.03**	**0.38**	**0.13**
CD (0.05)	**0.08**	**2.76**	**0.96**

Total sugar and reducing contents in tubers were significantly higher for treatments water spray alone (0.62 and 2.46 mg/g respectively) and POP + water spray (0.61 and 2.36 mg/g respectively). Lowest total sugar content was observed for treatment POP + KCl (0.42 mg/g), and lowest reducing sugar content was recorded for treatment POP + KCl+ silicic acid + $CaCl_2$ (1.56 mg/g)

Crude protein content in tubers was significantly higher for treatments, POP + KCl+ silicic acid + $CaCl_2$ (1.62 %), POP + KCl + silicic acid (1.62 %), POP + KCl + $CaCl_2$ (1.59 %), POP + silicic acid + $CaCl_2$ (1.56 %), POP + silicic acid (1.52 %) and POP+ $CaCl_2$ (1.51 %). Lowest crude protein content was recorded for treatments water spray (1.16 %) and POP alone (1.18 %).

The cyanogenic glucoside content was significantly lower for treatment POP + KCl + silicic acid + $CaCl_2$ (36.33 ppm), and followed by treatment POP + KCl +

silicic acid (39.26 ppm). High HCN content was recorded for treatments water spray alone (51.26 ppm) and POP + water spray (48.30 ppm).

Table 93. Pooled analysis (weighted mean) of the effect of chemical treatments on quality parameters of cassava in 2015-16 and 2016-17

Treatments	Quality parameters				
	Starch (%)	Total sugar (mg/g)	Reducing sugar (mg/g)	Crude protein (%)	HCN (ppm)
T_1-POP	10.25	0.56	2.1	1.18	47.23
T_2-POP + KCl	13.34	0.42	1.58	1.42	40.36
T_3-POP + silicic acid	13.1	0.49	1.98	1.52	42.85
T_4-POP + $CaCl_2$	11.87	0.49	1.85	1.51	42.85
T_5-POP + KCl + silicic acid	13.56	0.55	2.16	1.62	39.26
T_6-POP + KCl+ $CaCl_2$	15.56	0.47	1.79	1.59	42.26
T_7-POP + silicic acid + $CaCl_2$	14.28	0.48	1.63	1.56	44.32
T_8-POP + KCl + silicic acid + $CaCl_2$	14.62	0.44	1.56	1.62	36.33
T_9-POP + water spray	10.87	0.61	2.36	1.3	48.3
T_{10}-Water spray alone	9.62	0.62	2.46	1.16	51.22
SEd	**0.97**	**0.01**	**0.10**	**0.05**	**1.59**
CD (0.05)	**2.04**	**0.03**	**0.22**	**0.11**	**3.34**

II.5. Yield and yield attributes

Yield and different yield attributes of the crops were studied during the crop growing period 2015-16 and 2016-17. Pooled analysis of two seasons revealed significant differences among various treatments (Table 94).

Tuber length was significantly higher for the treatments water spray alone (13.84 cm) POP + $CaCl_2$ (13.44 cm), POP + silicic acid (13.15 cm), POP + water spray (12.48 cm), POP + KCl+ silicic acid + $CaCl_2$ (11.54 cm), POP + KCl+ silicic acid (11.30 cm), followed by POP alone (10.01 cm) and POP + KCl (9.90 cm).

Table 94. Pooled analysis (weighted mean) of the effect of chemical treatments on yield and yield attributes of cassava in 2015-16 and 2016-17

Treatments	Yield and yield attributes				
	Tuber length (cm)	Tuber girth (cm)	No. of tubers per plant	Mean tuber weight (g/plt.)	Fresh tuber yield (t/ha)
T_1-POP	10.01	7.39	2.66	0.69	8.57
T_2-POP + KCl	9.90	8.30	3.80	0.87	10.75
T_3-POP + silicic acid	13.15	6.73	5.00	0.78	9.73
T_4-POP + $CaCl_2$	13.44	8.33	5.33	0.79	9.72
T_5-POP + KCl + silicic acid	11.30	8.66	5.00	0.94	11.66
T_6-POP + KCl+ $CaCl_2$	8.53	9.33	5.66	0.77	9.59
T_7-POP + silicic acid + $CaCl_2$	9.64	7.46	4.66	0.75	9.31
T_8-POP + KCl + silicic acid + $CaCl_2$	11.54	9.00	6.33	0.97	12.09
T_9-POP + water spray	12.48	7.00	4.66	0.71	8.84
T_{10}-Water spray alone	13.84	5.66	3.65	0.59	7.38
SEd	**1.31**	**0.60**	**0.52**	**0.05**	**0.68**
CD (0.05)	**2.77**	**1.26**	**1.11**	**0.10**	**1.43**

Tuber girth was significantly higher for treatments POP + KCl + $CaCl_2$ (9.33 cm), POP + KCl + silicic acid + $CaCl_2$ (9.00 cm), POP + KCl+ silicic acid (8.66 cm), POP + $CaCl_2$ (8.33 cm) and POP + KCl (8.30 cm). Lowest value was recorded for treatment water spray alone (5.66 cm).

Considering the number of tubers per plant significantly higher number of tubers were recorded for treatments for POP + KCl + silicic acid + $CaCl_2$ (6.33), POP + KCl + $CaCl_2$ (5.66) and POP + $CaCl_2$ (5.33), followed by treatments POP + KCl + silicic acid (5.00), POP + silicic acid (5.00) and POP+ silicic acid + $CaCl_2$ (4.66).

Fresh tuber yield per plant was observed to be significantly higher for POP + KCl + silicic acid + $CaCl_2$ (0.97 g/plant) and POP + KCl + silicic acid (0.94 g/plant). Lowest mean tuber weight was recorded for water spray alone (0.59 g/plant).

Pooled data mean of tuber yield for the two seasons indicated a significantly higher yield for treatments POP + KCl + silicic acid + $CaCl_2$ (12.09 t/ha), POP + KCl+ silicic acid (11.66 t/ha) and POP+ KCl (10.75 t/ha). Lowest fresh tuber yield was recorded for water spray alone (7.38 t/ha)

II.6. Nutrient uptake

Studies on influence of various chemical treatments on the nutrient uptake of cassava variety Vellayani Hraswa was studied for the years 2015-16 and 2016-17.

a. Primary nutrient uptake by crop

Data on pooled analysis effect of treatments on primary nutrient uptake by plants for two seasons are presented in Table 95.

Considering the N uptake of the plant, significantly higher uptake in leaf was recorded for treatments POP + KCl+ silicic acid + $CaCl_2$ (17.62 kg/ha), POP + KCl + silicic acid (17.59 kg/ha) and POP + KCl + $CaCl_2$ (16.82 kg/ha) and the lowest was noted for water spray alone (9.54 kg/ha) and POP alone (9.79 kg/ha). Stem N uptake was significantly higher for treatment POP + KCl + silicic acid + $CaCl_2$ (21.43 kg/ha) followed by POP + silicic acid + $CaCl_2$ (16.41 kg/ha) and POP+ KCl (12.88 kg/ha). Lowest values were recorded for treatments water spray alone (4.91 kg/ha), POP+ water spray (5.51 kg/ha) and POP alone (5.57 kg/ha). Significantly higher N uptake in tuber was recorded for treatments POP + KCl + $CaCl_2$ (14.65) and was followed by treatment POP + KCl (10.60 kg/ha). Lowest N uptake in tuber was observed for treatment water spray alone (5.09 kg/ha).

Total N uptake was significantly higher for treatment POP + KCl + silicic acid + $CaCl_2$ (33.50 kg/ha) and followed by treatments POP + KCl + $CaCl_2$ (28.80), POP + silicic acid + $CaCl_2$ (26.76 kg/ha), and POP + KCl + silicic acid (27.05 kg/ha). Lowest total N uptake was for water spray alone (13.09 kg/ha), POP + silicic acid (14.30), POP alone (15.34 kg/ha), and POP + water spray (15.13 kg/ha).

P uptake of leaf, stem and tuber were recorded and significantly higher uptake in leaf was observed for the treatment POP + $CaCl_2$ (8.19 kg/ha), whereas P uptake in stem was observed to be significantly higher for treatment POP + KCl + silicic acid + $CaCl_2$ (5.56 kg/ha) followed by POP + KCl + $CaCl_2$ (5.00 kg/ha) and POP+ $CaCl_2$ (4.67 kg/ha). Tuber P uptake was higher for POP + KCl+ silicic acid + $CaCl_2$ (7.55 kg/ha) and POP+ KCl+ silicic acid (7.39 kg/ha). Total P uptake in cassava was recorded to be significantly higher for treatments POP+ KCl + silicic acid (10.76 kg/ha), POP + $CaCl_2$ (10.29 kg/ha), POP + KCl + silicic acid + $CaCl_2$ (10.60 kg/ha), POP + silicic acid + $CaCl_2$ (9.92 kg/ha), and POP + silicic acid (9.91 kg/hag). Lowest was for water spray alone (5.29 kg/ha).

Treatments POP + KCl (23.59 kg/ha), POP + KCl + $CaCl_2$ (23.56 kg/ha), POP + KCl + silicic acid (22.77 kg/ha) and POP + KCl + silicic acid + $CaCl_2$ (22.67 kg/ha) recorded significantly higher K uptake in leaf, and treatments POP + KCl + silicic acid + $CaCl_2$ (9.56 kg/ha), POP+ $CaCl_2$ (8.82 kg/ha) and POP + silicic acid + $CaCl_2$ (8.59 kg/ha) had significantly higher stem K uptake. Higher tuber K uptake was observed for treatment POP + KCl+ silicic acid + $CaCl_2$ (11.16 kg/ha) followed by POP + silicic acid + $CaCl_2$ (9.02 kg/ha). POP + silicic acid (6.37 kg/ha) had the lowest value. Highest total plant K uptake was for treatment POP + KCl+ silicic acid + $CaCl_2$ (18.61 kg/ha) and was followed by POP+ KCl+ silicic acid (15.61 kg/ha), POP + KCl (15.09 kg/ha) and POP + silicic acid + $CaCl_2$ (14.54 kg/ha). Lowest K uptake was observed for treatment water spray alone (11.07 kg/ha).

b. Secondary nutrient uptake by plant

Significant difference in Ca, Mg and S uptake by different plant parts was observed for all the treatments (Table 96)

Ca uptake in leaf was significantly higher for treatment POP + KCl+ silicic acid. + $CaCl_2$ (24.58 kg/ha), while stem Ca uptake was observed to be more for treatment POP + KCl (19.13 kg/ha) followed by POP + KCl+ silicic acid + $CaCl_2$ (17.13 kg/ha) and POP + silicic acid + $CaCl_2$ (16.34 kg/ha). Considering the tuber Ca uptake, significantly higher Ca uptake was observed for treatment POP + silicic acid + $CaCl_2$ (17.20 kg/ha). Total Ca uptake was significantly higher for treatments POP +

silicic acid + $CaCl_2$ (22.93 kg/ha), POP + KCl+ silicic acid + $CaCl_2$ (22.20 kg/ha), POP+ KCl+ silicic acid (21.80 kg/ha) and POP + $CaCl_2$ (21.41 kg/ha). Lowest values were noted for treatments POP alone (10.61 kg/ha) and water spray alone (11.36 kg/ha).

Magnesium uptake was also studied and was found to be significant. Leaf Mg uptake was more for treatment POP + $CaCl_2$ (1.39 kg/ha), POP + KCl + silicic acid + $CaCl_2$ (1.31 kg/ha). Stem and tuber Mg uptake was significantly higher for treatments POP + KCl + silicic acid + $CaCl_2$ (3.05 kg/ha and 10.88 kg/ha respectively). Treatment POP + KCl + silicic acid + $CaCl_2$ (15.26 kg/ha) also recorded significantly high total Mg uptake followed by treatments POP+ KCl+ silicic acid (12.56 kg/ha), POP + silicic acid + $CaCl_2$ (12.32 kg/ha), POP + KCl (10.81 kg/ha) and POP + KCl + $CaCl_2$ (10.21 kg/ha). Lowest was recorded for treatment POP alone (6.82 kg/ha).

S uptake recorded in leaf indicated a significant higher uptake for treatment POP+ KCl+ silicic acid (3.18 kg/ha). Treatment POP + KCl + silicic acid + $CaCl_2$ (1.53 kg/ha) recorded significantly higher uptake of S in stem. Tuber S uptake was significantly higher for treatments POP + silicic acid + $CaCl_2$ (1.69 kg/ha), POP + KCl+ silicic acid + $CaCl_2$ (1.62 kg/ha), POP + KCl (1.62 kg/ha), and POP + $CaCl_2$ (1.52 kg/ha). Treatments POP + KCl+ silicic acid + $CaCl_2$ (1.26 kg/ha), POP + $CaCl_2$ (1.20 kg/ha) and POP + KCl + $CaCl_2$ (1.15 kg/ha) recorded significantly higher total S uptake and lowest uptake was observed for water spray alone 0.71 kg/ha.

II.7. Soil characters

After final harvest soil samples from each treatment were analysed for pH, organic carbon, primary and secondary nutrients and results are presented in (Table 97 and Table 98)

a. Soil pH

In 2015-16, slight increase in soil pH was noticed in different treatments (4.66 to 5.20) compared to that before the experiment (4.50). However, treatment POP+ KCl + silicic acid (5.20) and POP+KCl+$CaCl_2$ (5.09) recorded significantly higher pH

Table 95. Pooled analysis (weighted mean) on the effect of chemical treatments on N, P and K uptake by plant parts of cassava for the years 2015-16 and 2016-17

Treatments	N (kg/ha)				P (kg/ha)				K (kg/ha)			
	Leaf	**Stem**	**Tuber**	**Total**	**Leaf**	**Stem**	**Tuber**	**Total**	**Leaf**	**Stem**	**Tuber**	**Total**
T_1-POP	9.79	5.57	9.29	15.34	4.33	2.78	4.59	7.20	15.11	7.42	6.76	13.11
T_2-POP + KCl	13.92	12.88	10.60	25.35	4.51	4.04	5.05	8.26	23.59	6.51	7.99	15.09
T_3-POP + silicic acid	11.01	8.12	6.26	14.30	5.14	3.11	6.42	9.91	14.23	7.70	6.37	12.68
T_4-POP + $CaCl_2$	14.10	9.35	7.47	23.57	8.19	4.67	4.91	10.29	17.55	8.82	8.02	14.22
T_5-POP + KCl + silicic acid	17.59	12.5	11.21	27.05	4.69	4.15	7.39	10.76	22.77	7.53	9.1	15.61
T_6-POP + KCl+ $CaCl_2$	16.82	11.58	14.65	28.80	7.02	5.00	4.41	9.19	23.56	7.10	7.93	13.18
T_7-POP + silicic acid + $CaCl_2$	15.44	16.41	7.33	26.76	5.21	3.9	5.42	9.92	17.19	8.59	9.02	14.54
T_8-POP + KCl + silicic acid + $CaCl_2$	17.62	21.43	9.72	33.50	6.73	5.56	7.55	10.60	22.67	9.56	11.16	18.61
T_9-POP + water spray	12.65	5.51	6.35	15.13	3.89	2.75	4.23	6.77	15.11	6.62	8.66	13.18
T_{10}-Water spray alone	9.54	4.91	5.09	13.09	4.53	2.43	3.99	5.29	13.41	8.21	8.66	11.07
SEd	**0.80**	**0.80**	**0.55**	**1.11**	**0.33**	**0.40**	**0.34**	**0.51**	**1.16**	**0.47**	**0.47**	**0.81**
CD (0.05)	**1.70**	**1.69**	**1.17**	**2.34**	**0.71**	**0.51**	**0.72**	**1.09**	**2.45**	**1.00**	**0.99**	**1.71**

than other treatments. Lowest value was recorded for the treatment where recommendation of POP alone was given (4.66).

Reduction in pH was noticed in the year 2016-17 after harvest to that before harvest (5.50). In this season, rainfall availability was less compared to 2015-16. However, there was no significant difference between the treatments.

b. Soil organic carbon

Organic carbon status of the soil after the harvest was found to significantly differ between the treatments. Only slight variation in organic carbon content was noticed in soil after harvest when compared to before the experiment. Significantly higher organic carbon content was noticed for POP + KCl + $CaCl_2$ (1.97 %), when applied in combination.

No significant variation in organic carbon status was noticed between treatments in 2016-17 seasons, and it ranged from 1.01 to 1.86 % compared to 1.40 % before the experiment.

c. Primary nutrients

Significant variation in primary nutrient content among different treatments was noticed in both years and data is presented in Table 96.

In 2015-16, an increase in available N content was noticed (162.40-78.40 kg/ ha), when compared to N content in soil before planting (157.20 kg/ha).Significantly higher available N content was noticed for POP alone (162.40 kg/ha) and POP + KCl + silicic acid + $CaCl_2$ (141.86 kg/ha). Similar reduction in available N content was noticed in 2016-17 cropping season also was compared to N content before planting (173.10 kg/ha).

P content in soil increased after the experiment. In 2015-16 the range of P in soil varied from 24.89 kg/ha in POP + silicic acid to 62.98 kg/ ha in POP + water spray during 2015-16.In the next year, range of P content in soil was narrower from 48.22 kg/ha to 27.42 kg/ha in POP + KCl + $CaCl_2$ and POP + KCl + silicic acid, respectively.

In case of the available K content considerable reduction in K status of soil was recorded after harvest in 2015-16 season, when compared to before harvest (312.4 kg/ha). However, only slight variations between treatments were only recorded after harvest. Significantly higher available K content was observed for all the treatments except for water spray alone (109.23 kg/ha), which recorded lowest K content.

Available K content in soil before harvest in 2016-17 was recorded to be 315.2 kg/ha soil. Variations between treatments were observed and soil available K was less compared to before harvest. Among treatments, significantly higher available K content was observed for POP + KCl + $CaCl_2$ (251.47 kg/ha). Lowest value was observed for treatment POP + $CaCl_2$ (78.22 kg/ha).

d. Secondary nutrients

Soil calcium contents for the cropping season 2015-16 and 2016-17 before harvest were 214.0 mg/kg and 218.20 mg/kg, respectively. In 2015-16, significantly higher Ca content in soil was recorded for POP + KCl + silicic acid + $CaCl_2$ (227.27 mg/kg), POP + KCl + $CaCl_2$ (217.65 mg/kg) and POP + KCl + silicic acid (210.98 mg/kg), which were comparable with each other. In 2016-17, calcium content in soil ranged from 353.65.27-255.97 mg/kg. Significantly higher calcium content was recorded for combination application of POP + KCl + $CaCl_2$ (353.65 mg/kg), POP + KCl (330.80 mg/kg), POP + silicic acid (317.55 mg/kg) POP alone (299.70 mg/kg), and POP + KCl + silicic acid (297.65 mg/kg), which were on par.

In 2015-16, significant variation between treatments for available S content was seen. Significantly higher S content was observed for POP + KCl + silicic acid + $CaCl_2$ (3.27 mg/kg), POP + silicic acid + $CaCl_2$ (3.20 mg/kg), POP + KCl + $CaCl_2$ (3.10 mg/kg), POP + KCl (3.04 mg/kg) and POP + silicic acid (3.00 mg/kg), which were on par, and followed by other treatments, all of which were on par.

No significant difference between treatments was recorded for available S content during 2016-17 (Table 97).

Table 96. Pooled analysis (weighted mean) on the effect of chemical treatments on Ca, Mg and S uptake by plant parts of cassava for the years 2015-16 and 2016-17

Treatments	Ca (kg/ha)				Mg (kg/ha)				S (kg/ha)			
	Leaf	Stem	Tuber	Total	Leaf	Stem	Tuber	Total	Leaf	Stem	Tuber	Total
T_1-POP	8.80	9.08	5.23	10.61	1.09	1.50	4.23	6.82	1.21	0.23	0.80	0.51
T_2-POP + KCl	9.26	19.13	10.23	18.29	0.93	2.47	7.02	10.81	1.59	0.97	1.62	0.95
T_3-POP + silicic acid	12.49	12.72	13.80	17.41	0.94	2.09	7.47	10.50	1.57	0.75	1.44	0.84
T_4-POP + $CaCl_2$	15.74	14.12	11.92	21.41	1.39	2.06	6.27	9.71	2.74	0.93	1.52	1.20
T_5-POP + KCl + silicic acid	20.58	14.72	14.51	21.80	1.15	2.33	9.07	12.56	2.15	1.10	1.53	1.03
T_6-POP + KCl+ $CaCl_2$	17.35	11.99	15.63	19.65	1.08	2.30	6.83	10.21	3.18	0.79	1.25	1.15
T_7-POP + silicic acid + $CaCl_2$	17.14	16.34	17.20	22.93	1.07	2.10	9.13	12.32	2.04	0.82	1.69	1.03
T_8-POP + KCl + silicic acid + $CaCl_2$	24.58	17.13	14.11	22.20	1.31	3.05	10.88	15.26	2.67	1.53	1.62	1.26
T_9-POP + water spray	19.17	6.65	8.97	16.06	1.13	1.75	6.37	9.26	1.75	0.64	1.21	1.00
T_{10}-Water spray alone	14.77	8.36	7.19	11.36	1.00	1.41	8.41	10.81	1.97	0.53	0.70	0.71
SEd	**1.13**	**0.79**	**0.67**	**1.47**	**0.06**	**0.11**	**0.46**	**0.64**	**0.12**	**0.07**	**0.07**	**0.05**
CD (0.05)	**2.39**	**1.66**	**1.42**	**3.10**	**0.14**	**0.25**	**0.98**	**1.36**	**0.27**	**0.15**	**0.15**	**0.12**

Table 97. Effect of treatments on pH, organic carbon and primary nutrients of soil after harvest during 2015-16 and 2016-17

Treatments	2015-16					2016-17				
	PH	Organic Carbon (%)	N	P	K	PH	Organic Carbon (%)	N	P	K
			kg/ha					kg/ha		
T_1-POP	4.66	1.38	162.40	41.29	122.45	5.03	1.24	119.94	36.00	111.07
T_2-POP + KCl	4.96	1.58	117.60	34.32	124.81	5.16	1.55	114.88	44.65	161.17
T_3-POP + silicic acid	4.96	1.04	95.20	24.89	122.85	5.10	1.25	114.56	42.08	133.31
T_4-POP + $CaCl_2$	4.89	1.28	106.40	31.53	131.68	5.00	1.55	125.76	31.14	78.22
T_5-POP + KCl + silicic acid	5.20	1.31	78.40	27.89	130.89	5.30	1.01	123.89	27.42	169.87
T_6-POP + KCl+ $CaCl_2$	5.09	1.97	117.60	25.53	126.61	5.10	1.18	128.96	48.22	251.47
T_7-POP + silicic acid + $CaCl_2$	5.00	1.32	95.20	34.64	123.07	4.96	1.86	128.58	35.43	106.38
T_8-POP + KCl + silicic acid + $CaCl_2$	5.04	1.22	141.86	30.68	128.02	5.23	1.44	114.18	28.14	178.61
T_9-POP + water spray	4.94	1.34	134.40	62.98	122.51	4.90	1.32	124.64	44.29	114.67
T_{10}-Water spray alone	4.92	1.52	128.80	34.86	109.23	4.76	1.17	123.14	37	124.08
SEd	**0.06**	**0.76**	**12.47**	**4.70**	**4.49**	**-**	**-**	**2.83**	**5.77**	**11.81**
CD (0.05)	**0.14**	**0.16**	**26.19**	**9.89**	**9.43**	**NS**	**NS**	**5.95**	**12.12**	**24.82**

Table 98. Effect of treatments on secondary nutrient content in soil after harvest during 2015-16 and 2016-17

Treatments	2015-16			2016-17		
	Ca	Mg	S	Ca	Mg	S
	mg/kg			mg/kg		
T_1-POP	180.35	135.37	2.77	299.70	137.07	1.73
T_2-POP + KCl	173.65	135.62	3.04	330.80	135.20	2.42
T_3-POP + silicic acid	169.32	131.87	3.00	317.55	133.00	1.71
T_4-POP + $CaCl_2$	177.60	134.62	2.80	287.5	133.75	1.02
T_5-POP + KCl + silicic acid	210.98	136.87	2.85	297.65	136.52	1.53
T_6-POP + KCl+ $CaCl_2$	217.65	137.75	3.10	353.65	134.17	2.05
T_7-POP + silicic acid + $CaCl_2$	172.15	136.25	3.20	277.10	132.92	1.73
T_8-POP + KCl + silicic acid + $CaCl_2$	227.27	137.62	3.27	274.12	131.97	2.03
T_9-POP + water spray	206.67	136.50	2.77	297.82	134.82	1.77
T_{10}-Water spray alone	183.77	134.37	2.81	255.97	129.47	1.48
SEd	**8.40**	**-**	**0.16**	**12.22**	**1.06**	**-**
CD (0.05)	**17.64**	**NS**	**0.34**	**25.68**	**2.23**	**NS**

II.8. Soil moisture content

Soil moisture content was determined by sampling soils collected from a depth of 30 cm after planting and subsequently at 15 days interval till harvest. Initially irrigation was provided for two weeks after planting till sprouting. Data of SMC for the crop growing season 2015-16 is presented in Table 99.

a. Soil moisture content in 2015-16

Initial soil moisture content in the field was recorded to be 10.78 per cent. After planting, no significant difference in SMC was noted at 15, 30, 60 and 150 DAP. At 45 DAP, significantly higher SMC was observed for POP + KCl + $CaCl_2$ (18.20 %).

At 75 DAP, significantly higher SMC was recorded for POP + KCl +silicic acid (10.40 %), and was followed by treatments POP + KCl + silicic acid + $CaCl_2$ (9.7 %), and POP + KCl (8.60 %). Reduction in SMC was observed at 90 DAP and significantly higher SMC was recorded for POP + $CaCl_2$ (9.20 %). At 105 DAP, significantly higher SMC was recorded for treatment POP + KCl + $CaCl_2$ (8.10 %). Lowest SMC was recorded for POP + silicic acid + $CaCl_2$ (3.50 %).

At 120 DAP, all treatments were found to be on par except for treatments T_6, T_3 and T_1, in which values were significantly less. At 150 DAP; there was no significant effect of treatments on SMC. Reduction in SMC was noted at harvest. All treatments were on par except water spray alone (9.86 %) and POP + water spray (9.80 %). Lowest SMC was recorded for POP alone (9.86 %).

b. Soil moisture during 2016-17

In 2016 -17, soil moisture content during planting was observed to be 9.2 per cent. At 15 DAP, significantly higher soil moisture content was recorded for treatments POP + KCl + silicic acid +$CaCl_2$ (21.20 %), POP + KCl (19.20 %), POP+ silicic acid+ $CaCl_2$ (18.80 %), POP + silicic acid (18.20 %) and POP + $CaCl_2$ (17.70 %) which were on par. No significant difference was noted at 45, 75,105 and 165 DAP and at harvest. Significantly higher SMC was recorded for POP+ KCl + silicic acid (27.80 %) and POP + KCl + silicic acid + $CaCl_2$ (23.90 %) and at 30 DAP. POP + water spray (9.30 %) recorded lowest SMC at 30 DAP.

At 60 DAP, there was a decline in soil moisture content. It was observed that, significantly higher SMC was recorded for treatments POP + KCl (9.20 %), POP + KCl + $CaCl_2$ (9.20 %), POP alone (9.00 %) and POP + KCl + $CaCl_2$ + silicic acid (8.70 %) For 90 DAP, all the treatments were found to be comparable except for POP alone (4.40 %). At 120 DAP, significantly higher SMC was or POP + KCl + $CaCl_2$ + silicic acid (5.80 %), POP + KCl + $CaCl_2$ (5.70 %), POP + $CaCl_2$ (5.40 %), POP+ silicic acid (5.00) and lowest was recorded for water spray alone (4.00 %). At 135 DAP, treatments, POP + KCl + $CaCl_2$ (4.90 %), POP + KCl + $CaCl_2$ + silicic acid (4.90 %), POP + $CaCl_2$ (4.60 %) and POP + silicic acid (4.30 %) recorded significantly higher SMC. At 150 DAP; significantly higher SMC was recorded for all the treatments except for POP alone (3.20 %), water spray alone (3.60 %) and POP + water spray (3.70 %).

In general, in 2016-17, a reduction in soil moisture content was recorded throughout the crop growing period when compared to the previous year. Severe reduction in SMC was observed for 90, 105, 120,135 and 150 DAP, due to low receipt of rainfall (Table 100)

II.9. Economics of crop production in 2015-16

Data on the effect of various treatments on the economics of crop production are presented in Table 101. Among treatments, the cost of cultivation was highest (Rs. 98,833) for the treatment T_8 (POP+ KCl + silicic acid + $CaCl_2$), and lowest was for water spray alone (Rs 90,392).

All chemical treatments resulted in a higher income, when compared to water spray alone (T_{10}). Among the combination application of chemicals, high income was observed for treatment POP + KCl + silicic acid + $CaCl_2$ (Rs.3,71,850) followed by POP + KCl + silicic acid (Rs.3,46,350), POP alone (T_1), recorded lowest income (Rs.2,30,55)

Table 99. Effect of treatments on soil moisture content during crop growing period of 2015-16

Treatments	Soil moisture content (%)											
	15 DAP	30 DAP	45 DAP	60 DAP	75 DAP	90 DAP	105 DAP	120 DAP	135 DAP	150 DAP	165 DAP	Harvest
T_1-POP	15.40	10.20	4.30	8.00	7.10	6.80	6.80	6.70	5.60	5.40	15.40	10.20
T_2-POP + KCl	14.50	10.46	11.90	10.00	8.60	7.90	7.20	7.10	10.20	7.00	14.50	10.46
T_3-POP + silicic acid	11.50	10.00	12.80	8.10	4.70	6.40	4.20	6.20	8.90	6.20	11.50	10.00
T_4-POP + $CaCl_2$	15.60	10.06	12.10	9.20	2.70	9.20	6.90	6.70	8.60	6.10	15.60	10.06
T_5-POP + KCl + silicic acid	15.60	9.80	11.60	8.30	10.40	8.30	4.20	6.20	7.20	6.50	15.60	9.80
T_6-POP + KCl+ $CaCl_2$	15.70	12.03	18.70	8.20	5.40	7.40	8.10	6.60	11.30	5.90	15.70	12.03
T_7-POP + silicic acid + $CaCl_2$	15.90	11.10	10.90	6.60	6.70	8.70	3.50	6.90	7.30	7.00	15.90	11.10
T_8-POP + KCl + silicic acid + $CaCl_2$	16.80	11.00	8.70	7.00	9.70	7.70	4.50	6.80	7.90	6.00	16.80	11.00
T_9-POP + water spray	13.90	10.23	9.10	6.00	7.00	8.90	5.00	5.80	5.30	5.00	13.90	10.23
T_{10}-Water spray alone	12.80	9.86	10.2	7.00	6.70	7.80	4.90	3.50	6.000	4.70	12.80	9.86
SEd	**-**	**-**	**0.61**	**-**	**1.09**	**0.76**	**0.71**	**0.80**	**0.57**	**-**	**0.71**	**0.52**
CD (0.05)	**NS**	**NS**	**1.30**	**NS**	**2.30**	**1.6**	**1.50**	**1.68**	**1.20**	**NS**	**1.50**	**1.10**

Table 100. Effect of treatments on soil moisture content during crop growing period of 2016-17

Treatments	Soil moisture content (%)											
	15 DAP	**30 DAP**	**45 DAP**	**60 DAP**	**75 DAP**	**90 DAP**	**105 DAP**	**120 DAP**	**135 DAP**	**150 DAP**	**165 DAP**	**Harvest**
T_1-POP	14.70	14.30	8.80	9.00	8.10	4.40	5.03	4.30	2.50	3.20	6.00	6.10
T_2-POP + KCl	19.20	15.90	9.10	9.20	10.10	6.00	5.96	4.60	3.80	4.60	8.300	8.70
T_3-POP + silicic acid	18.20	13.60	8.20	5.50	9.00	6.80	6.13	5.00	4.30	5.30	7.10	7.40
T_4-POP + $CaCl_2$	17.70	18.80	8.10	7.80	9.00	6.20	6.06	5.40	4.60	5.30	7.30	7.80
T_5-POP + KCl + silicic acid	13.70	27.80	8.20	7.80	8.30	6.10	5.76	4.70	3.90	4.50	6.50	7.30
T_6-POP + KCl+ $CaCl_2$	10.80	12.40	8.80	9.20	9.00	6.70	6.46	5.70	4.90	5.20	7.50	7.70
T_7-POP + silicic acid + $CaCl_2$	18.80	13.00	8.70	7.60	7.90	6.00	5.66	4.40	3.50	4.50	6.80	8.10
T_8-POP + KCl + silicic acid + $CaCl_2$	21.20	23.90	9.00	8.70	9.50	6.20	6.16	5.80	4.90	5.30	7.30	7.90
T_9-POP + water spray	8.50	9.30	8.20	6.70	7.70	6.00	4.86	4.10	3.10	3.70	6.30	7.40
T_{10}-Water spray alone	16.10	16.40	7.80	5.10	7.50	5.60	4.99	4.00	2.50	3.60	6.20	7.30
SEd	**1.66**	**2.19**	**-**	**0.72**	**-**	**0.57**	**-**	**0.42**	**0.33**	**0.42**	**-**	**-**
CD (0.05)	**3.5**	**4.6**	**NS**	**1.6**	**NS**	**1.2**	**NS**	**0.90**	**0.70**	**0.9**	**NS**	**NS**

Table 101. Effect of treatments on economics of crop production in 2015-16

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	B:C raio
T_1-POP	95392	230550	135158	1.41
T_2-POP + KCl	98512	328200	229688	2.33
T_3-POP + silicic acid	95393	302850	207457	2.17
T_4-POP + $CaCl_2$	95712	286800	191088	1.99
T_5-POP + KCl + silicic acid	98513	346350	247837	2.51
T_6-POP + KCl+ $CaCl_2$	98832	248550	149718	1.51
T_7-POP + silicic acid + $CaCl_2$	98514	281850	183336	1.86
T_8-POP + KCl + silicic acid + $CaCl_2$	98833	371850	273017	2.76
T_9-POP + water spray	94392	267750	173358	1.83
T_{10}-Water spray alone	90392	262400	172008	1.90

The B:C ratio was highest for T_8 (2.76), with a net return of Rs. 273017. Among the treatments involving application of single chemicals, highest B:C ratio was recorded for POP + KCl (2.33). Lowest B: C ratio was recorded for POP alone (1.41).

II.8. Economics of crop production in 2016-17

Data on the economics of crop production for the year 2016-17 are presented in Table 102.The cost of cultivation for the year 2016-17 was similar to that for the previous year.

Table 102. Effect of treatments on economics of crop production in 2016-17

Treatments	Cost of cultivation (Rs/ha)	Gross income (Rs/ha)	Net return (Rs/ha)	B:C ratio
T_1-POP	95392	57450	-37942	-0.39
T_2-POP + KCl	98512	89400	-9112	-0.09
T_3-POP + silicic acid	95393	75750	-19643	-0.20
T_4-POP+$CaCl_2$	95712	84750	-10962	-0.11
T_5-POP + KCl + silicic acid	98513	99000	487	0.004
T_6-POP + KCl + $CaCl_2$	98832	102450	3618	0.03
T_7-POP + silicic acid + $CaCl_2$	98514	76650	-21864	-0.22
T_8-POP + KCl+ silicic acid + $CaCl_2$	98833	96300	-2533	-0.02
T_9-POP + water spray	94392	70500	-23892	-0.25
T_{10}-Water spray alone	90392	62700	-27692	-0.30

In general, total income was found to be less than the total cost of cultivation among treatments except for treatment T_6 (POP + KCl + $CaCl_2$) (10,24,50) and T_5 (POP+ KCl + silicic acid (Rs. 9,90,00), where the benefit was found only to be Rs. 487 and Rs. 3618 respectively. Among the treatments B: C ratio was found to be higher for POP + KCl + $CaCl_2$ (0.03). In general, the benefit-cost ratio for the treatments during 2016-17 was negative.

Discussion

5. Discussion

Cassava (*Manihot esculenta* Crantz.) is a typical tropical plant with its distribution confined almost entirely to the tropical zone. It is however not very fastidious or exacting in its climatic requirement. The crop is sensitive to soil water deficit during the first three months after planting, and water stress during the later stages of crop growth causes reduced yield and quality of tubers. In case supplemental irrigation is not possible, some nutrients are found to play important roles in imparting drought resistance to the crop.

Keeping this in view, a field experiment was conducted at Agronomy farm of College of Horticulture, Vellanikkara during 2015-16 and 2016-17, to study the effect of crop-weather-nutrient relations in cassava under drought stress. Two experiments were carried out during the period of study with the following objectives:

1) To understand the crop-weather relation in cassava under drought situation and to study the effect of moisture stress on varieties of varying duration

2) To study the effect of foliar application of potassium, silicon and calcium along with recommended major nutrients on growth and productivity of cassava under drought stress

The first experiment involved growing four cassava varieties two short-duration and two normal-duration in three consecutive seasons in 2015-16, while the second experiment with a single cassava short-duration variety was conducted twice in 2015-16 and 2016-17. The results of the study are discussed here under.

1.1. Crop-weather relations of cassava varieties under drought stress planted in three different seasons

Experiments were conducted by growing four different cassava varieties *viz.*, Vellayani Hraswa and Sree Vijaya (short-duration) and M_4 and Sree Athulya (normal-duration) under three different planting seasons *viz.*, May, October and December.

a. Weather conditions

Weather parameters observed during the crop growing periods, *viz.*, rainfall (mm), maximum and minimum temperature (^oC), mean relative humidity, total evaporation, sunshine hours and wind speed (km/hr), are presented in Fig.1. The main planting seasons of cassava are April-May with the onset of South-West monsoon and September-October with the onset of North-East monsoon (KAU, 2011). December planting is not usually recommended unless sufficient moisture is available.

In this study, the crops were grown purely under rainfed situation. The first crop was planted at the start of rainy season (*i.e.,* end of May), when it received a total rainfall of 2317.00 mm for the first 6 months and a total of 133.37 mm rainfall during the remaining four months. This ensured that the plant received adequate water almost throughout the cropping period.

Second planting was done during October which received comparatively less initial rainfall (310.00 mm) in the first 6 months than the previous planting and almost 1500.00 mm in the next four months. Mean monthly rainfall for the initial three months was only 45.00 mm for the December planted crop and 1538.40 mm for the remaining months. Thus the three crops were subjected to varying environmental conditions. Though a very warm and humid climate is preferred by cassava, it is subjected to highly varying temperature, precipitation, photoperiods and solar radiation in the tropics (Alves, 2002).

Mean evapotranspiration rates during the study were noted and found to be higher for December planting season (54.60 mm). This was about 34.60 per cent higher than the crops grown during the traditional planting seasons. Lower evapo-transpiration rate for May planting season was observed during the initial stages of crop growth compared to other planting seasons.

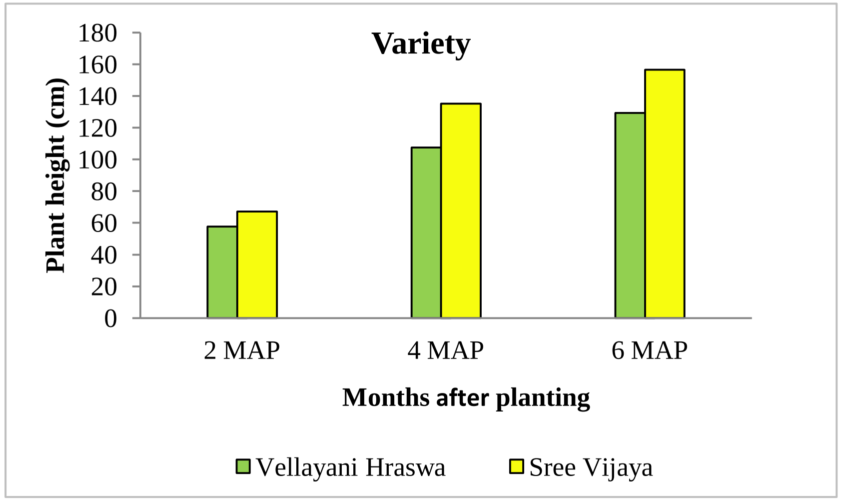
b. Growth and development

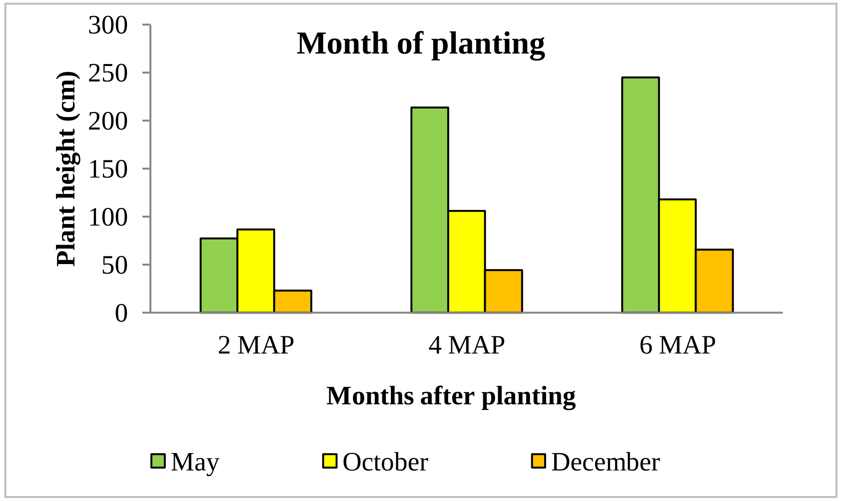
Scrutiny of the meteorological parameters (*i.e.,* rainfall, temperature, evapo-transpiration, and wind speed) showed that generally, the climatic conditions were ideal to support growth and yield, except for December planting season. The growth of the cassava varieties was appreciably higher for May and October planted varieties, whereas growth of December planted varieties was comparatively less.

Among the growth characters, plant height, number of leaves and leaf scars per plant, stem width, root length and root diameter were significantly influenced by various planting seasons. No significant influence of weather on number of branches per plant was recorded in all the three seasons, probably because it was a varietal character. Progressive increase in plant height was observed during all the crop growth stages. May planted cassava varieties recorded greatest plant height among the seasons. Considering the varieties, Sree Athulya, a normal-duration variety, and Sree Vijaya a short-duration variety, were seen to have significantly greater plant height. According to Nweke *et al.* (1994), increase in plant height may be due to genotypic variations, or time of planting and emergence of varieties (Fig. 6). Another stem parameter, stem girth varied significantly among different varieties and plantings. Vellayani Hraswa recorded significantly lower stem girth among short-duration varieties. Significantly higher stem girth during all growth stages was noted for Sree Athulya among normal-duration varieties. Considering the planting season, cassava planted during May and October was observed to have significantly higher stem girth compared to December for short-duration varieties as climate conditions during the former were ideal for cassava. For normal-duration varieties, the initial superiority of May and October planted crops with respect to stem girth was seen to be absent by 10 MAP, where stem girth of all plantings were seen to be on par. It was also noted that plant height had a positive correlation with stem girth. Water stress during December was found to reduce plant height and stem girth. This may be due to drought stress during initial phase of growth and establishment as suggested by Helal *et al.* (2013).

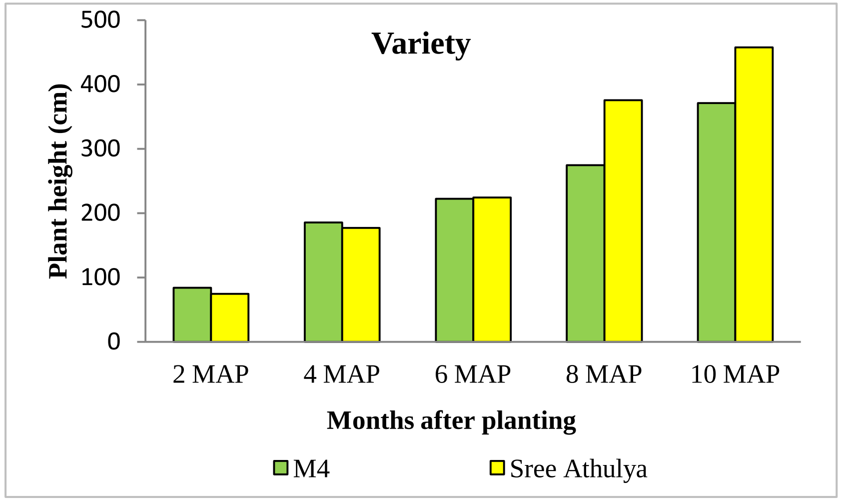
Cassava leaf growth is highly sensitive to drought (Alves and Setter, 2000). Significant differences in number of leaves per plant among the varieties were noted during the period of study (Fig.7). Significantly higher number of leaves per plant was observed in short-duration variety Sree Vijaya as compared to Vellayani Hraswa at 4 and 6 MAP. These varieties when planted in May and October showed an increase in leaf number per plant from 2 to 4 MAP and a subsequent decline. However the crop planted in December showed a decrease from 2 MAP to 4 MAP, followed by an increase at 6 MAP in number of leaves per plant. In normal-duration varieties, M_4 was seen to produce higher number of leaves than Sree Athulya throughout the growing

a. Short-duration





b. Normal-duration



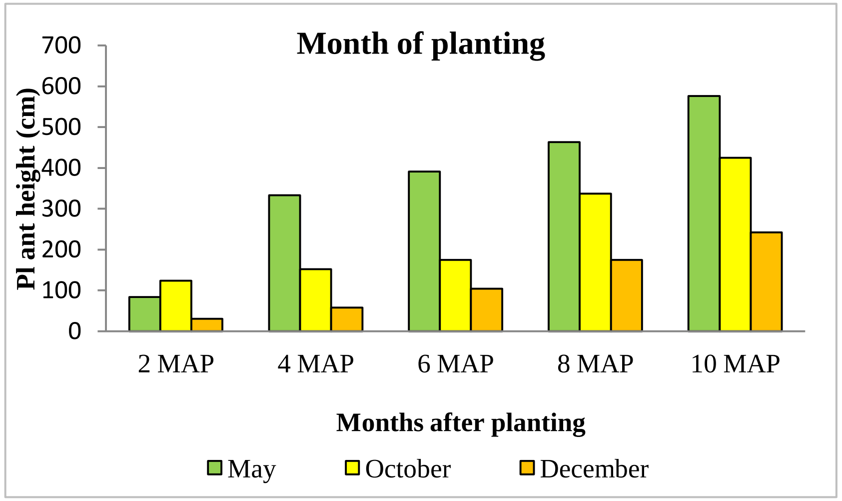
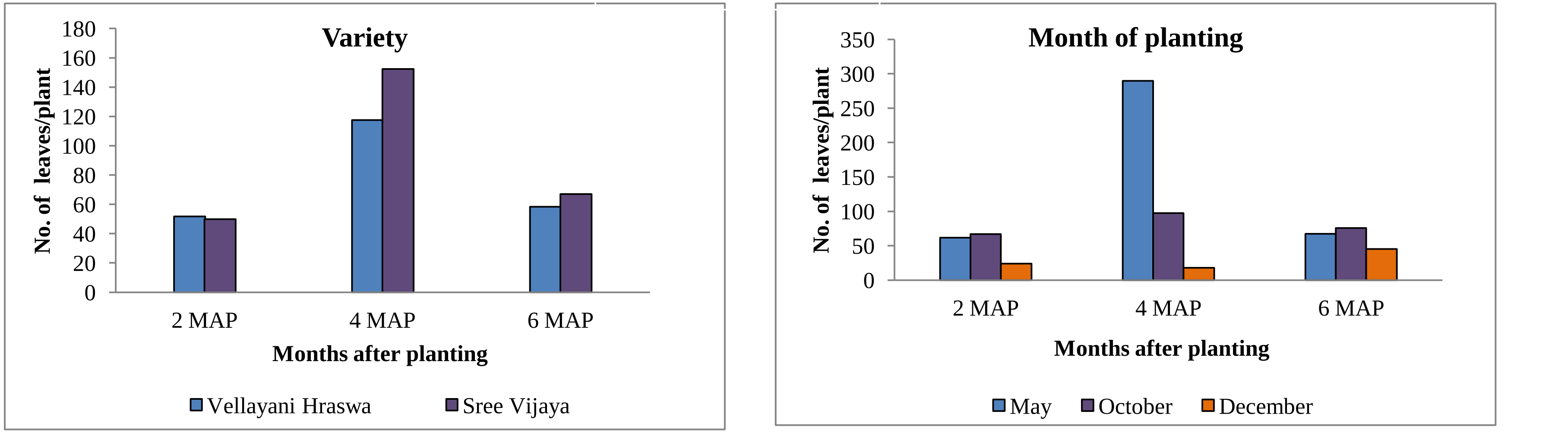


Fig. 6. Plant height of short and normal-duration cassava varieties as influenced by variety and month of planting

a. Short-duration



b. Normal-duration

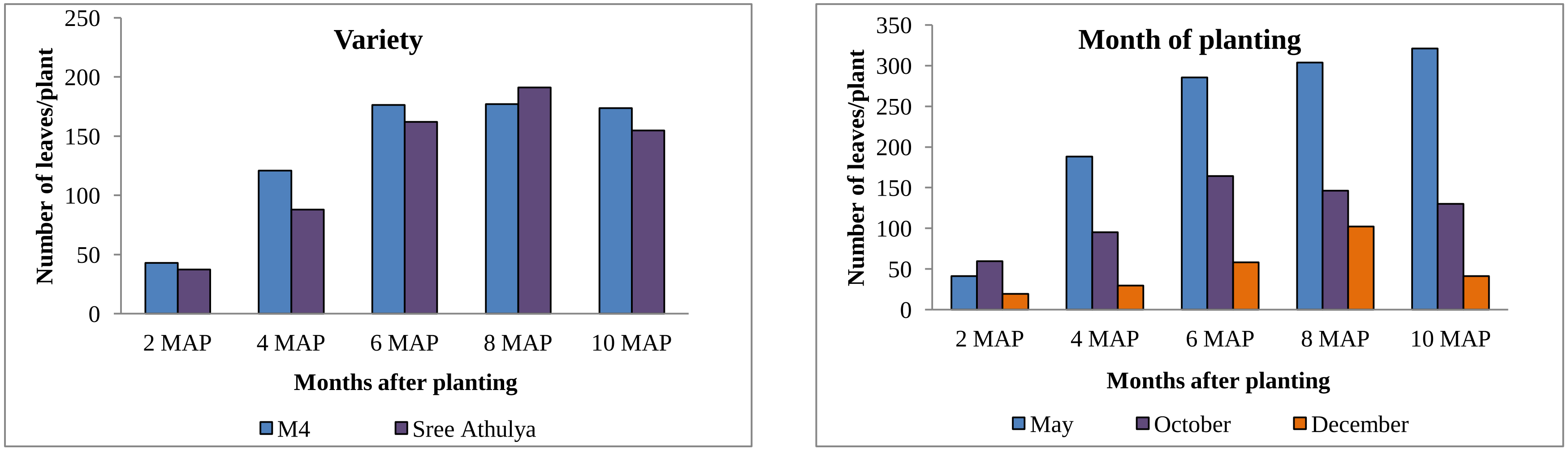
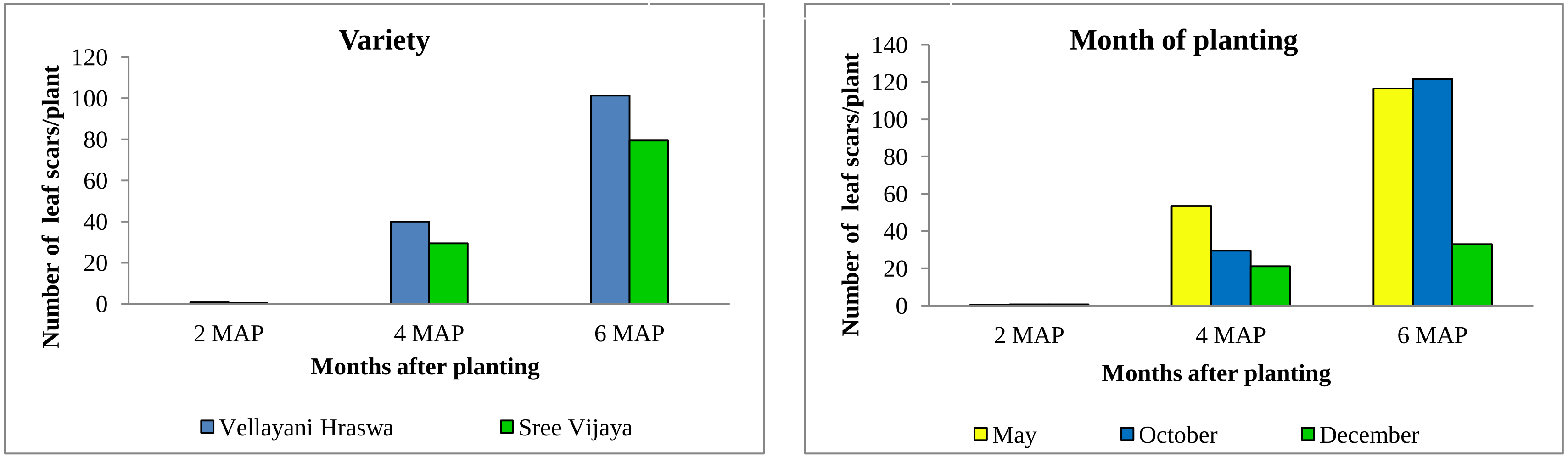


Fig. 7. Number of leaves per plant of short and normal-duration cassava varieties as influenced by variety and month of planting

period. Less number of leaves was recorded for December planting season compared to other seasons as the availability of rainfall during the initial stage was less (96.92 %) as compared to May planted crop. There was sprouting of leaves soon after the receipt of rainfall, and a sudden dip in rate of leaf production was recorded between 2 and 4 MAP for December planted short-duration cassava varieties. However, such an effect was not observed in the normal-duration varieties probably due to inherent drought tolerance ability. According to Alves and Setter (2000), leaves of plants under stressed condition have the capacity to regain growth soon after re-watering, a phenomenon noticed in Sree Athulya between 6 and 8 MAP when rains were received.

Considering the effect of variety on number of leaf scars per plant, significantly higher number of leaf scars was recorded for short-duration variety Vellayani Hraswa at all the growth stages (Fig. 8). Even though the number of leaf scars was higher for M_4 during the initial stages, indicating leaf fall, number of leaves on the plant was also found to be higher during all growth stages, indicating the ability of the variety to produce sprouts under varying rainfall. The variety may also have utilized leaf shedding as an effective drought avoidance mechanism. According to El-Sharkwary (1993), drought avoidance mechanism of cassava is its ability to shed leaves to reduce evapo-transpiration loss under water stress condition. According to Rosas *et al.* (1976), high leaf shedding in high leaf producing plants might be because under high leaf production there is a tendency for shading, and mutual shading generally limits leaf life and accelerates leaf shedding. In Vellayani Hraswa, on the other hand, both leaf production and leaf retention were less compared to other varieties. Sree Vijaya, also a short-duration variety, retained more leaves per plant than Vellayani Hraswa, indicating higher drought tolerance capability. The response of M_4 variety can be attributed to its inherent ability to withstand drought. Considering the month of planting, December planting recorded significantly higher number of leaf scars during initial stage *i.e.*, up to 2 MAP for short-duration variety. However towards the later stages, May and October planting had significantly higher number of leaf scars for both short and normal-duration varieties. This was commensurate with the higher leaf production during this period.

a. Short-duration



b. Normal-duration

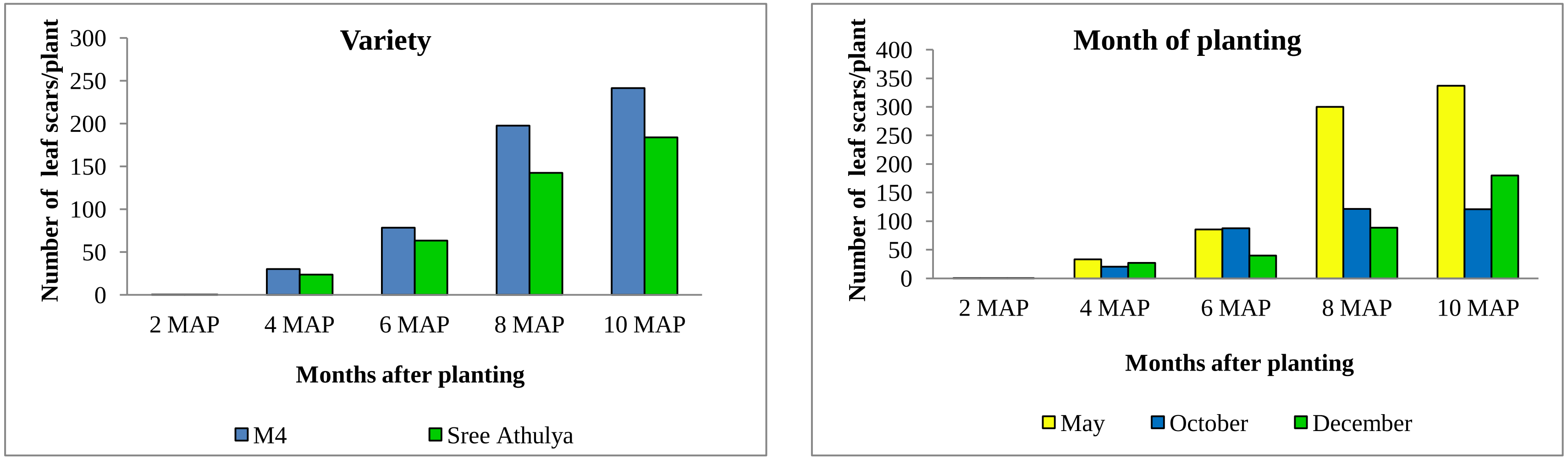


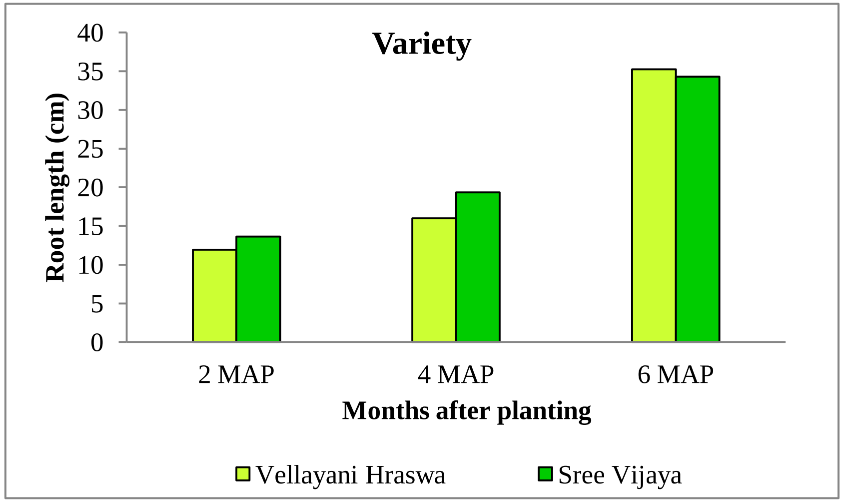
Fig. 8.Number of leaf scars per plant of short and normal-duration cassava varieties as influenced by variety and month of planting

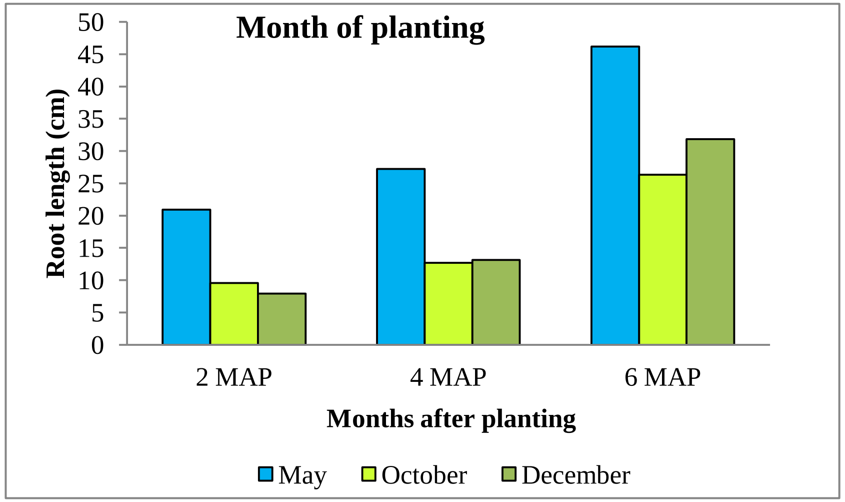
Regarding root parameters, root length and diameter varied when cassava was subjected to water stress. Root acts as the only medium for uptake of water in plants and understanding of root characteristics is of great importance in evaluating drought tolerance of varieties. Root length was significantly higher for varieties M_4 and Sree Athulya as compared to short-duration varieties during early stages of growth in May planting season. This may be related to the drought tolerant ability of the variety, the prolific root system facilitating the extraction of water from shallow soil layers, which would otherwise have been lost through evapo-transpiration. This is in accordance with the findings of Odubanjo *et al.* (2011). Similar findings were observed in short-duration variety Sree Vijaya which was observed to be superior in root length to Vellayani Hraswa during May planting (Fig.9). Root length of short-duration varieties was greater for May planting, and the greater growth could be attributed to ideal growing condition. A similar trend was seen in normal-duration varieties up to 6 MAP; after which October planted cassava produced significantly longer roots. This could be correlated with greater rainfall received during the last four months of growth. The positive effect of rainfall on root growth in short-duration varieties was clear from the significantly longer roots produced at 6 MAP in December planting as compared to October planting, as the former crop received good rainfall from the fourth month after planting.

Root diameter was found to be superior for May planting and among varieties, Sree Vijaya of short-duration and Sree Athulya of normal-duration had significantly greater root diameter (Fig.10). The reduction or increase in root length and diameter can also be attributed to the genotypic differences, which may ultimately have an influence on the component of the total sink activity of the roots. This is in conformity with the findings of Shanmugam (1974).

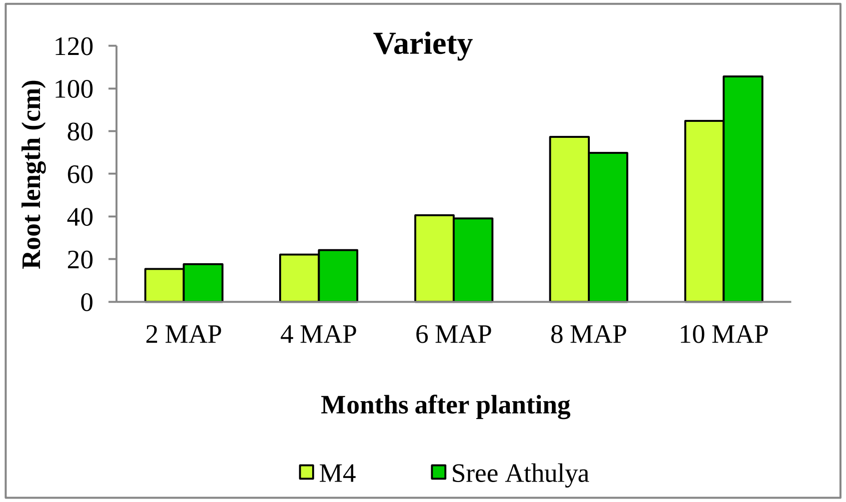
Data revealed that under water deficit situation, root and shoot fresh weights were significantly reduced. During initial stages, shoot fresh weight was found to be higher for Sree Athulya among normal-duration varieties, while Sree Vijaya recorded consistently higher values among short-duration varieties (Fig.11). This may be due to the result of better partitioning of more assimilates to the growing shoot at the active growth stages (Edet *et al*., 2015). Root fresh weight was found to be significantly

a. Short-duration





b. Normal-duration



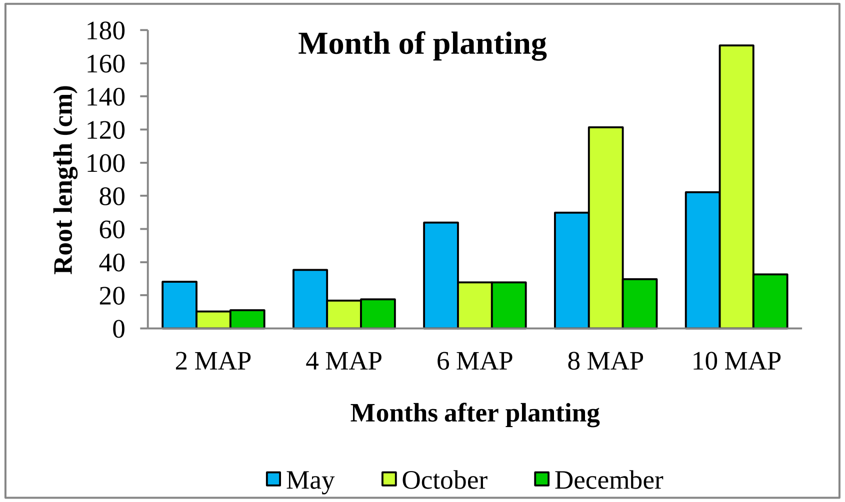
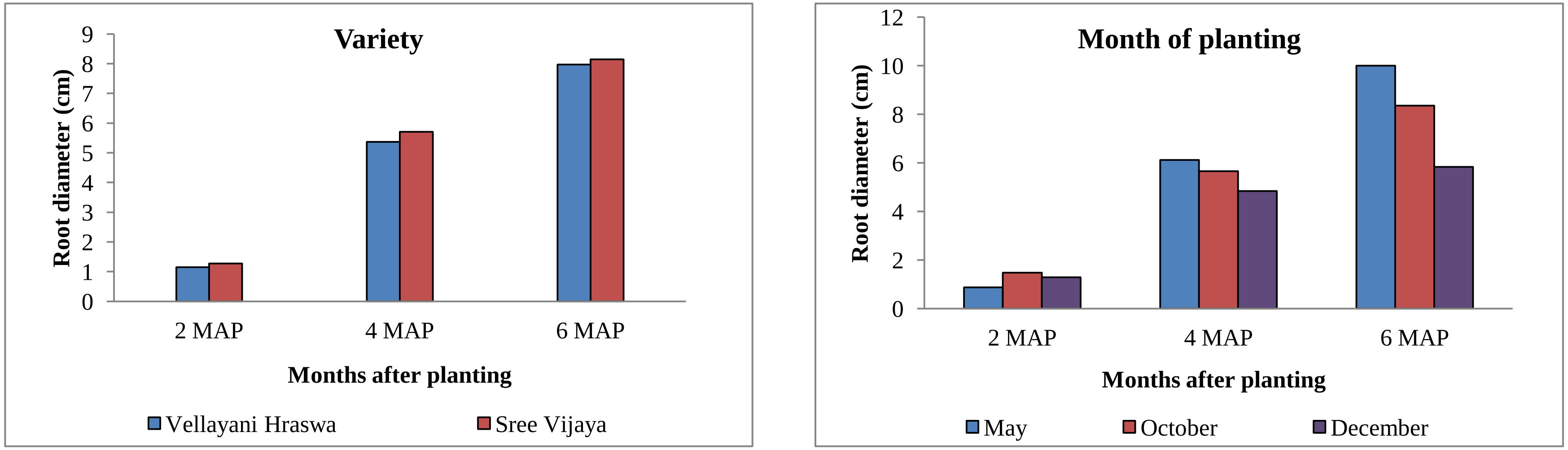


Fig.9. Root length of short and normal-duration cassava varieties as influenced by variety and month of planting

a. Short-duration



b. Long-duration

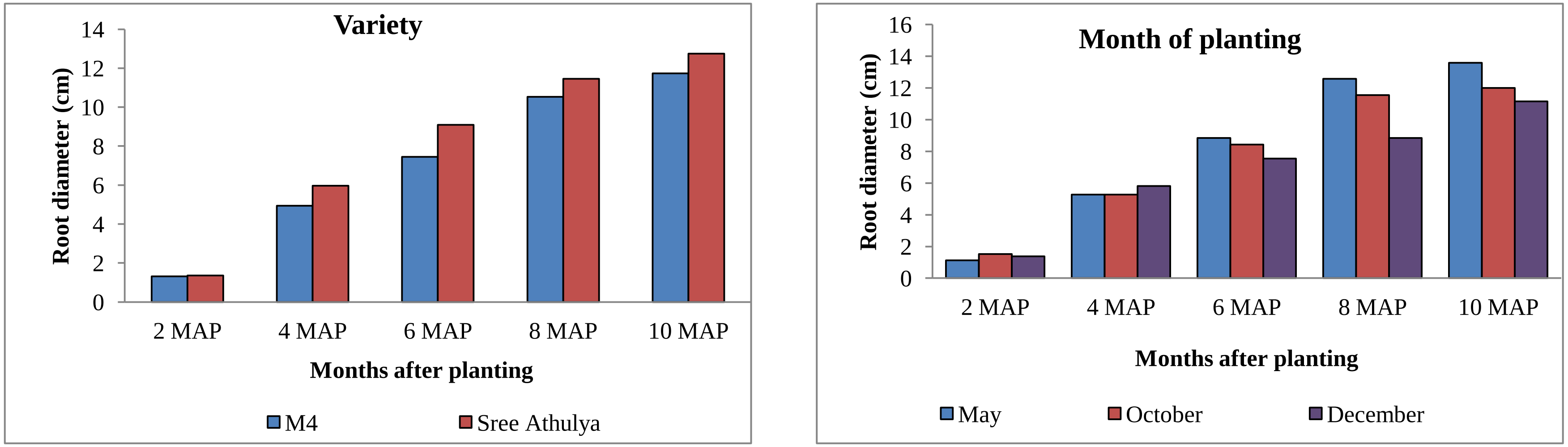
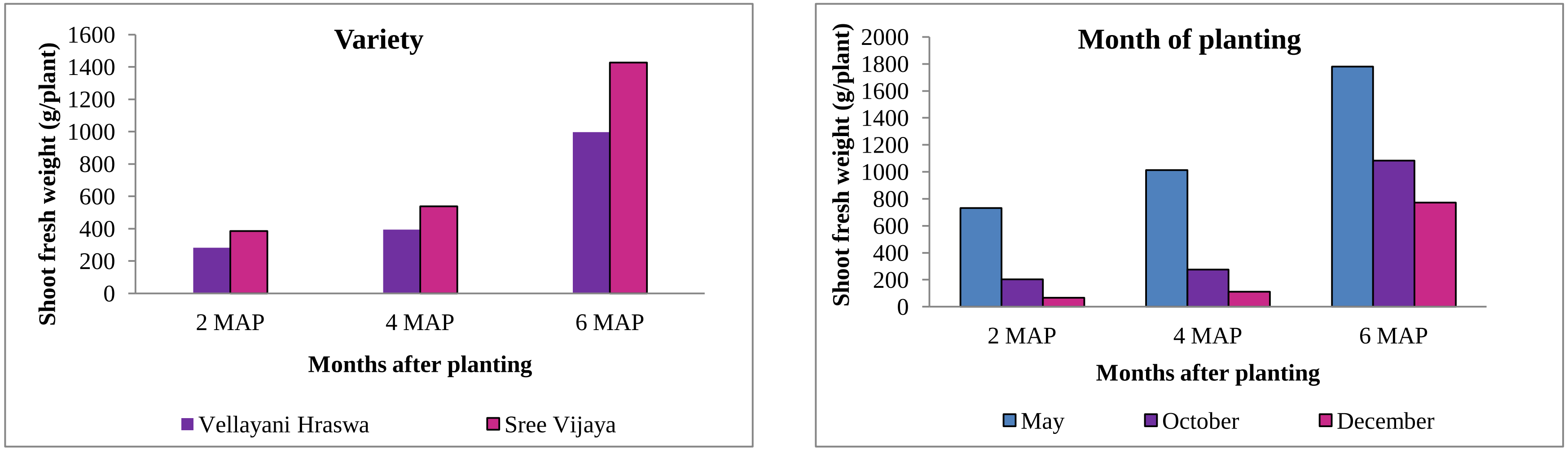


Fig. 10. Root diameter of short and normal-duration cassava varieties as influenced by variety and month of planting

a. Short-duration



b. Normal-duration

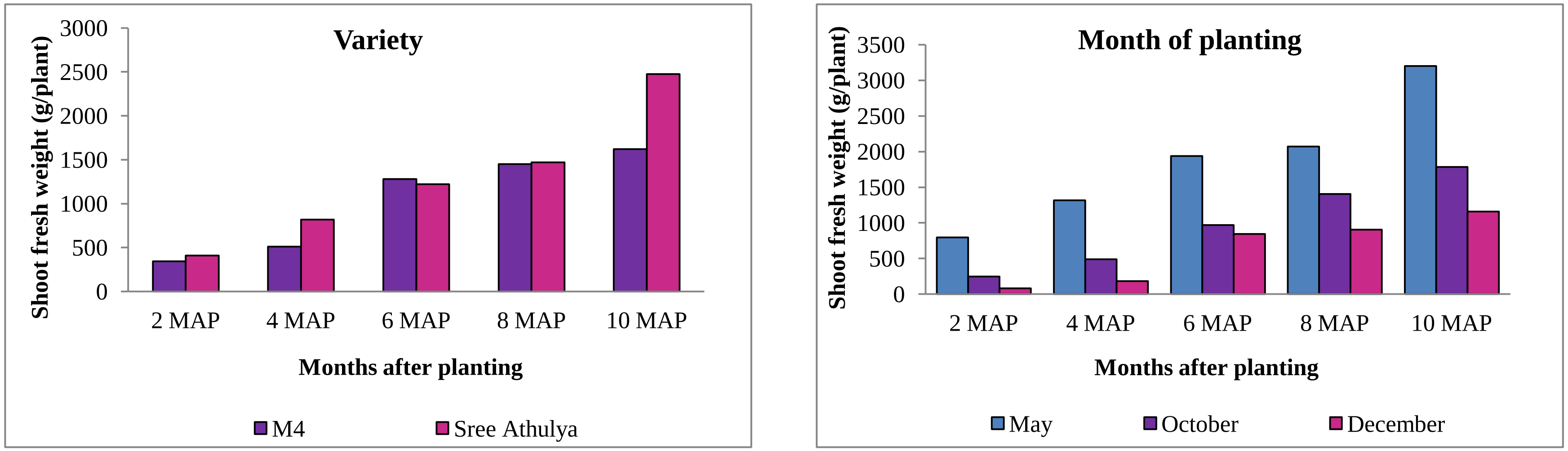


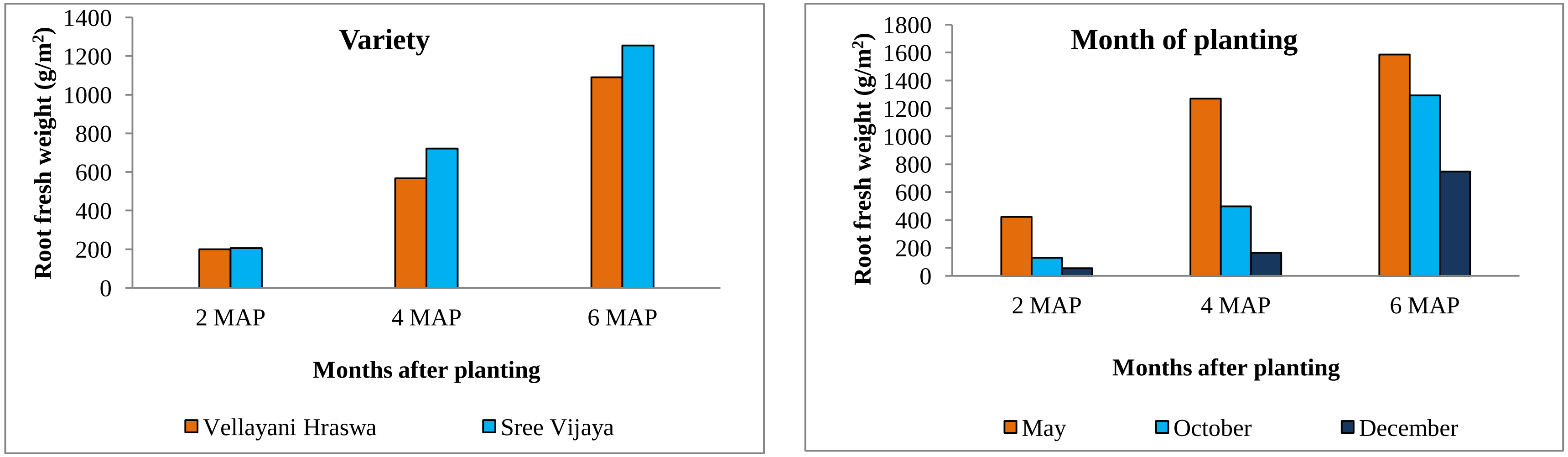
Fig.11. Shoot fresh weight of short and normal-duration cassava varieties as influenced by variety and month of planting

higher for Sree Athulya up to 6 MAP, but Sree Vijaya and Vellayani Hraswa did not differ significantly in root fresh weight at all stages. Varieties had significantly higher root fresh weight when planted during May, and lowest weights when planted during December. According to Aresta and Fukai (1984), cassava storage root development is sensitive to drought, and short term stress severely affected storage root yield. Even though normal-duration variety Sree Athulya was found to have better root yield per plant under stressed condition *i.e.,* when planted in December, for October planting, short-duration variety Sree Vijaya was observed to produce significantly higher root fresh weight than the other varieties (Fig. 12). This may be due to the ability of Sree Athulya and Sree Vijaya varieties to retain leaves under reduced water condition. This is in agreement with the observations of Setter and Fregene (2007).

Total dry matter production was found to be higher for Sree Athulya between normal-duration varieties for all the planting seasons (Fig.13). Between short-duration varieties, Sree Vijaya was found to be superior to Vellayani Hraswa. Dry matter production was significantly higher for May planting for short-duration varieties, while for normal-duration varieties, May planting was superior up to 6 MAP, after which May and October planting were on par. Productivity of a crop is closely related to the dry matter partitioning and biomass distribution (Kage *et al.,* 2004). Varieties respond well to environmental conditions and varying water availability may be the reason for significantly higher shoot and root fresh weight, and dry matter production.

Photosynthetic pigment content is an important indicator of plant drought stress. Farooq *et al.* (2009) reported that chlorophyll a and b contents varied under drought stress. Comparing the varieties, no significant trend in chl a and chl b contents could be noticed for both short and normal-duration crops. Among the different plantings, significantly lower Chl b contents were recorded for the crops planted in December, compared to those planted in May and October. Drought stress has been reported to inhibit the Chl a/b binding protein leading to reduction of the light harvesting pigment protein associated with photosystem II (Sayed, 2003)**.** A contradictory statement was reported by Pirzad *et al.* (2011), that higher chlorophyll content was recorded under water stressed condition in *Matricaria chamomilla* L.

a. Short-duration



b. Normal-duration

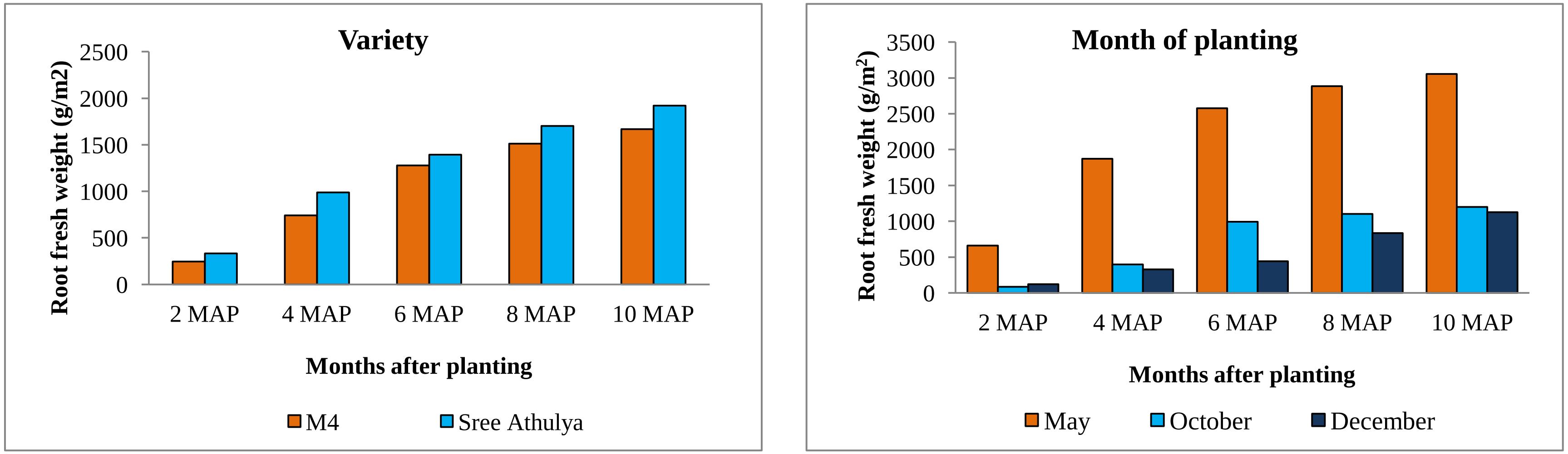
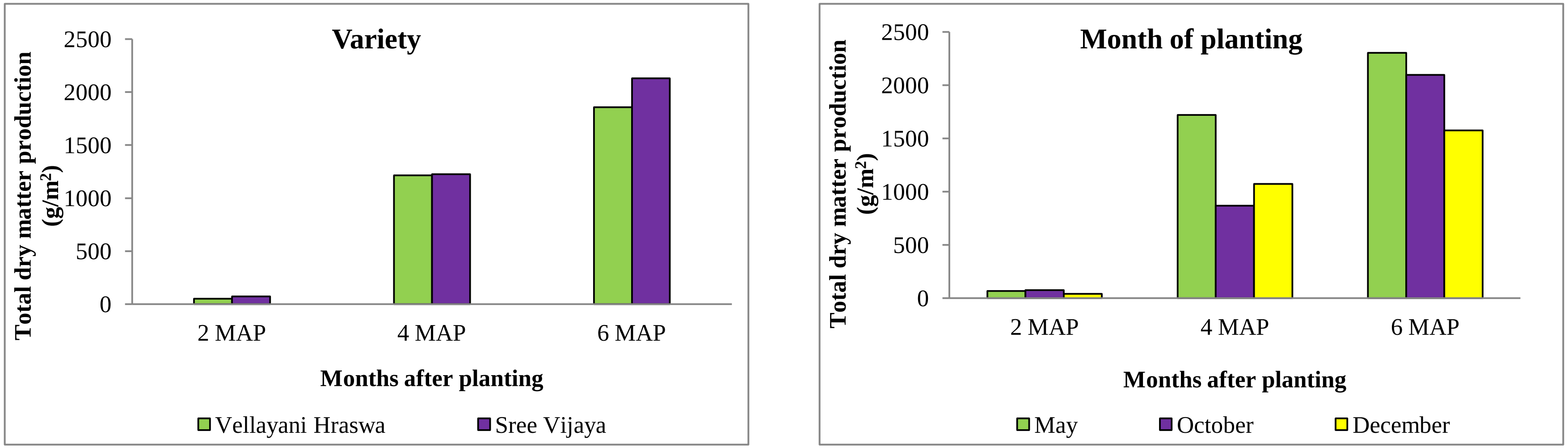


Fig. 12. Root fresh weight of short and normal-duration cassava varieties as influenced by variety and month of planting

a. Short-duration



b. Normal-duration

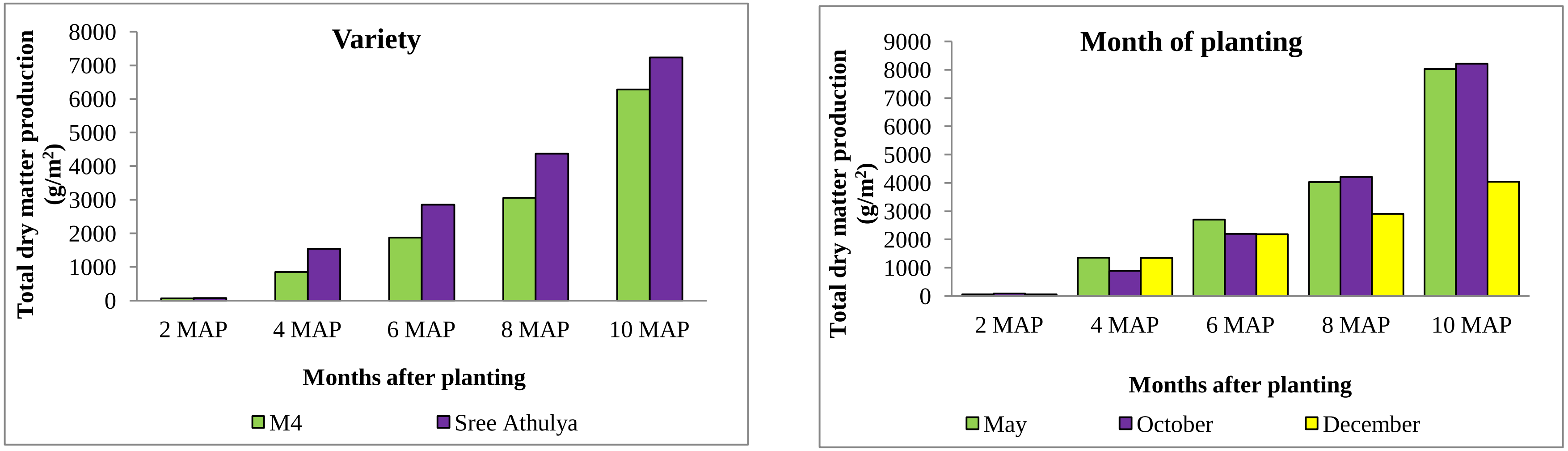


Fig.13. Total dry matter production of short and normal-duration cassava varieties as influenced by variety and month of planting

However, adverse effect of water stress on chlorophyll concentration has been previously observed in young peach trees by Kirnak *et al*. (2001) and has been linked to the increased electrolyte leakage leading to reductions in chlorophyll concentrations.

Accumulation of proline in plants can be considered as a consequence of various environmental stresses. In this study, short-duration variety Vellayani Hraswa was observed to have significantly higher proline content when planted during October and December and variety M_4 was found to have more proline content compared to Sree Athulya among normal-duration varieties at 2 and 6 MAP. Considering the month of planting, October planting resulted in higher proline content in normal-duration varieties while the values were higher in December planting from 6 to 10 MAP. Low rainfall was recorded in December compared to other planting seasons. A two-fold increase in proline content was observed in Vellayani Hraswa during December compared to May planting at harvest stage, whereas only 15 % increase in proline content was recorded for Sree Athulya, indicating that the short-duration variety, Vellayani Hraswa was more susceptible to drought compared to other varieties. Comparative effects of higher proline content accumulation in several species have been accounted and reported by Hanson *et al*. (1979) and Uahi and Dorffling (1982). Stewart and Boggess (1978) opined that accumulation of proline in drought stressed plants maybe due to the reduced activity of proline oxidase (Fig. 14).

Leaf nitrate reductase activity was found to be decreased under water stress. Among the normal-duration varieties, Sree Athulya recorded significantly higher nitrate reductase activity when planted in October, but when planted in May, no specific trend could be detected. Normal-duration variety Sree Athulya had significantly higher NRase activity up to 6 MAP, while Sree Vijaya had significantly higher leaf nitrate reductase activity at all stages. This could be related to the decreased availability of rainfall during the initial period of crop growth along with low soil moisture content and the better drought tolerance of Sree Athulya and Sree Vijaya (Fig. 15). According to Rychert and Skuijina (1973), nitrate nitrogen levels are largely dependent upon season. Sree Athulya and Sree Vijaya can be considered to be better performers under drought condition, since nitrate reductase is known to be a

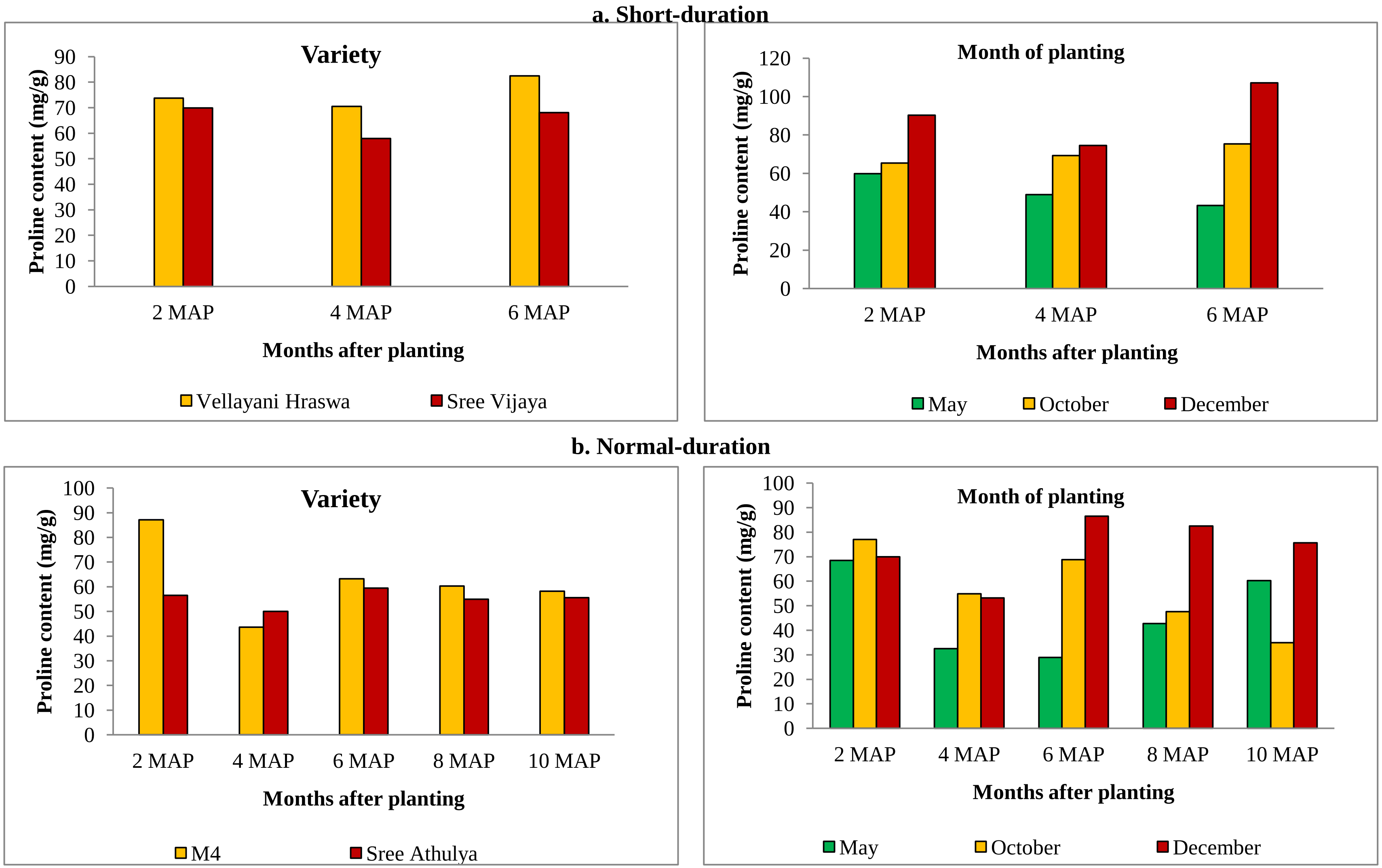
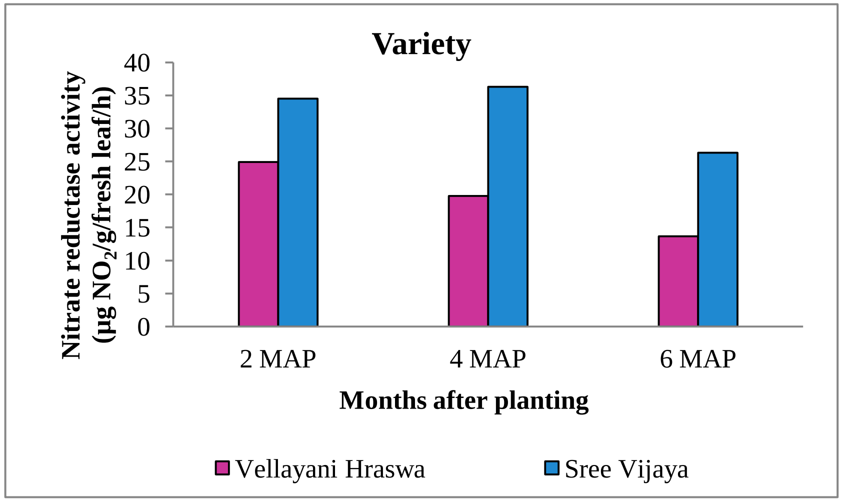
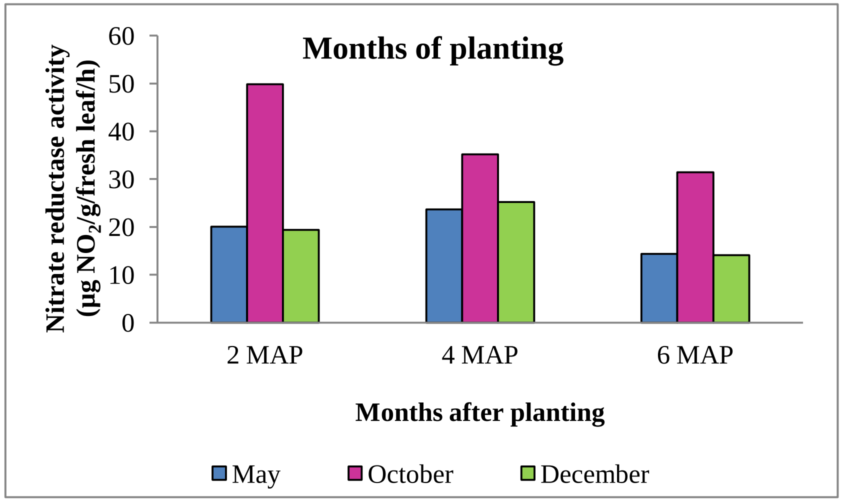


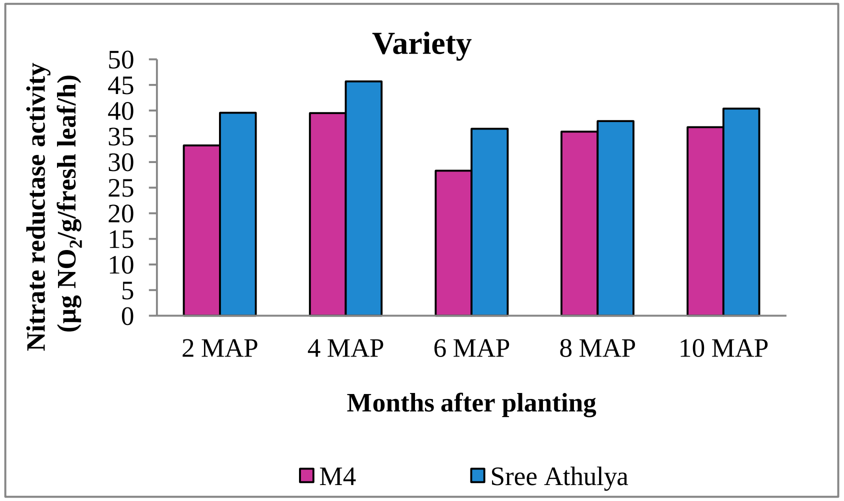
Fig. 14. Proline content of short and normal-duration cassava varieties as influenced by variety and month of planting

a. Short-duration





b. Normal-duration



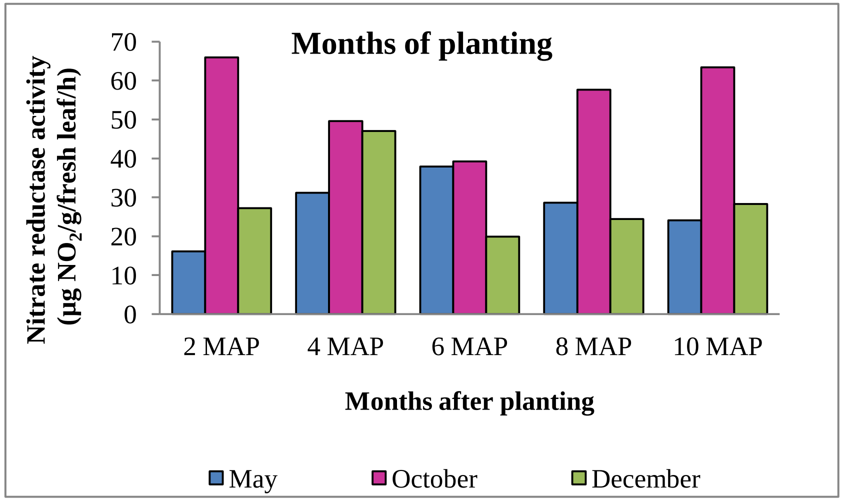


Fig. 15. Nitrate reductase activity of short and normal-duration cassava varieties as influenced by variety and month of planting

major enzyme in nitric oxide synthesis in plants (Gupta *et al.*, 2011). According to Garcia and Lamattina (2001), nitric oxide is a key component to regulate stomatal closure and has other signalling roles in drought response. Considering the month of planting, significantly higher NRase activity was observed for October planting for both short and normal-duration varieties for all the planting seasons. However, a general decline in NRase activity under low rainfall could not be observed, which is contradictory to reports that nitrate reductase activity was affected by dehydration (Ahmed *et al.*, 2000).

The leaf sugar content was found to be significantly less during December, especially during later stages of growth. This is in accordance with the study conducted by Kim *et al*. (2000), who reported that drought stress resulted in low carbohydrate metabolism and less leaf sucrose level, affecting the export mechanism. Considering varieties, Sree Athulya was observed to have higher leaf sugar content than M_4. Among short-duration varieties significantly higher leaf sugar content was observed when planted in May and October.

Relative leaf water content can be considered as an indicator of the water balance status of a plant since it quantifies the water in a tissue relative to the absolute quantity of water which the plant would need to achieve complete saturation. No significant relation of relative water content could be observed for both short and normal-duration varieties. Relative leaf water content was found to be more for May planting and lowest for December planting. Imposition of drought on cassava plants resulted in decrease in relative leaf water content. This is in accordance to the study conducted by Aina *et al*. (2007).

Among the three planting seasons, high photosynthetic rate were observed for May and October planted varieties while the same trend was followed for short-duration varieties with regard to the stomatal conductance. In normal-duration varieties it was seen to be higher in December planted crops. This may be due to the favourable weather conditions with ample rainfall availability and reduced evapotranspiration during the period of crop growth. Plants when exposed to mild to moderate water stress are reported to show low photosynthetic rate and stomatal conductance (Yokota *et al.,* 2002). Reduction in net photosynthetic rate was observed for all varieties for December planting compared to other seasons. This is mainly because under drought stress all varieties exhibit a reduction in their photosynthetic activity irrespective of their genetic characteristics. This is in line with the study conducted by Mafakheri *et al.* (2010). Cornic and Massaci (2006) reported that decline in the photosynthetic rate under drought stress conditions could be ascribed either to a decrease in stomatal conductance or due to non-stomatal limitations.

During crop growing period, net assimilation rate (NAR), crop growth rate (CGR), relative growth rate (RGR) and leaf area index (LAI) was observed. NAR was not significantly affected in short-duration varieties, whereas M_4 showed a significantly high NAR during the initial stage of establishment at 2 MAP. Among months of planting, significantly high NAR was for October planting for initial period of crop growth; however, NAR was high for December planting towards the later stages for both the varieties. Reduced NAR for May and October planting towards the later stages may be because of leaf loss under moisture stress condition. Similar results were reported by Giyhunguri and Ekanayake (2007). Net assimilation rate was found to follow an irregular pattern and decreased with age, which concurred with the study of Akparobi *et al.* (1998). In our study, highest NAR could have been expected during rainy period, when rapid growth was taking place, rather than during drought. Since this was not the case, these results had the overall implication that NAR was not a good indicator of productivity of cassava or a good screening criterion as opined by Githunguri *et al.* (2000).

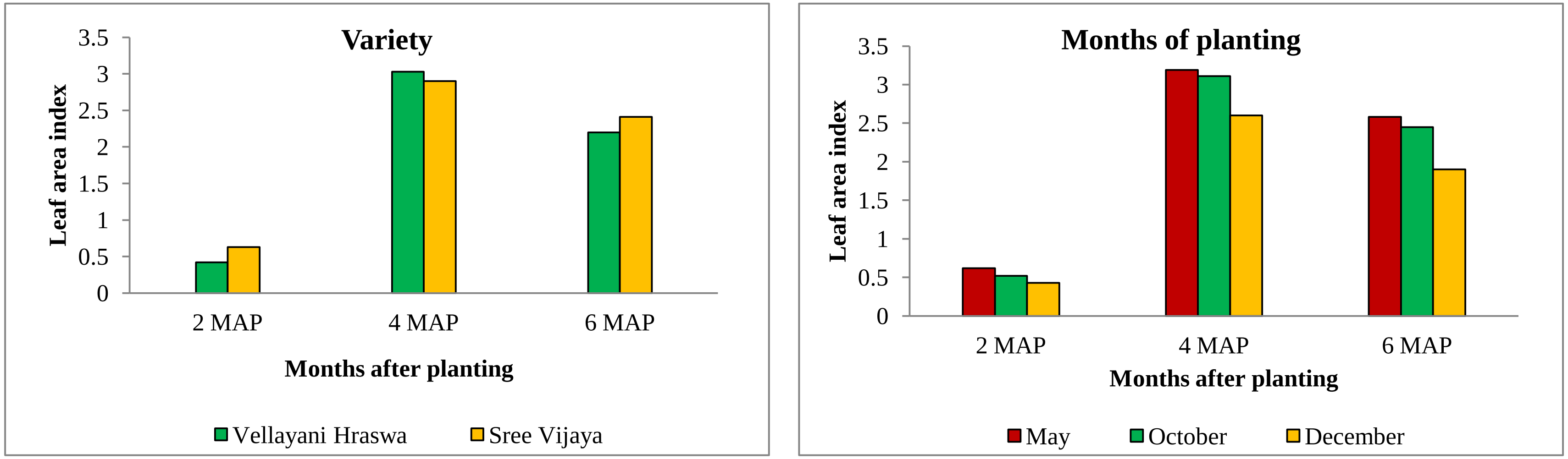
Among normal-duration varieties, Sree Athulya recorded significantly higher CGR during initial stages of crop growth. This may be because of the ability of high yielding varieties to maintain more leaf area with higher rate of photosynthesis even at initial stages of growth (Nigam *et al.*, 1988). In the present study increase in CGR was observed at later stages for crops planted during December planting season, which is contradictory to the studies by Okogbenin *et al.* (2013). So it could be suggested that factors other than moisture might also have influenced the plant CGR. This is in accordance with the study conducted by Giyhunguri and Ekanayake (2007).

Relative growth rate of cassava was found to decrease with age and was found positively associated with yield of tuberous roots. Among varieties, RGR was significantly higher for Sree Athulya than M_4. This may be due to the response of varieties to varying environmental conditions as suggested by Nwosu and Onofeghara (1992). An increase in RGR was observed for May planting for both the durations and lowest was observed for December planting. This may be because of the fact that RGR of cassava decreased under higher and longer moisture stress (Githunguri *et al.*, 2007).

It was found that the LAI was low during initial period of growth for both short and normal-duration varieties (Fig.16). Greatest LAI in case of normal-duration varieties was observed at 6 MAP for all the planting seasons, while in short-duration varieties, LAI was highest at 4 MAP. Considering the three plantings, LAI for the crop was highest during May planting and was lowest for December planted cassava varieties. This indicated the negative effect of moisture stress. The overall reduction in optimum LAI during December planting was 36.40 % for Vellayani Hraswa and 24.80 per cent for Sree Athulya respectively, when compared to May. Leaf number, LAI and canopy area have been found to be positively related to the amount of rainfall, but negatively correlated with evaporation and solar radiation in cassava (Lenis *et al.*, 2006). The development of LAI also depends on several factors such as leaf formation, leaf longevity and leaf size.

Seasonal comparison of different cassava varieties to understand the relation of starch and sugar contents (total and reducing) was conducted (Fig.17). It was found out that starch content in Sree Athulya variety was significantly higher for all the three plantings compared to other varieties. Among the three seasons, crops planted in May had high starch content in tuber. Sree Athulya planted during May showed higher starch accumulation as compared to October and December planting. Starch and sugar contents are governed by both internal and external factors such as cassava variety, initial water stress and conditions in the immediate month of harvest (Sriroth *et al.*, 1999**)**. Starch and sugars are two types of carbohydrates found in food. Sugar is the monomer unit of complex carbohydrate whereas starch is a polysaccharide which contains longer carbohydrate chains of glucose. Sucrose, glucose and fructose are all

a. Short-duration



b. Normal-duration

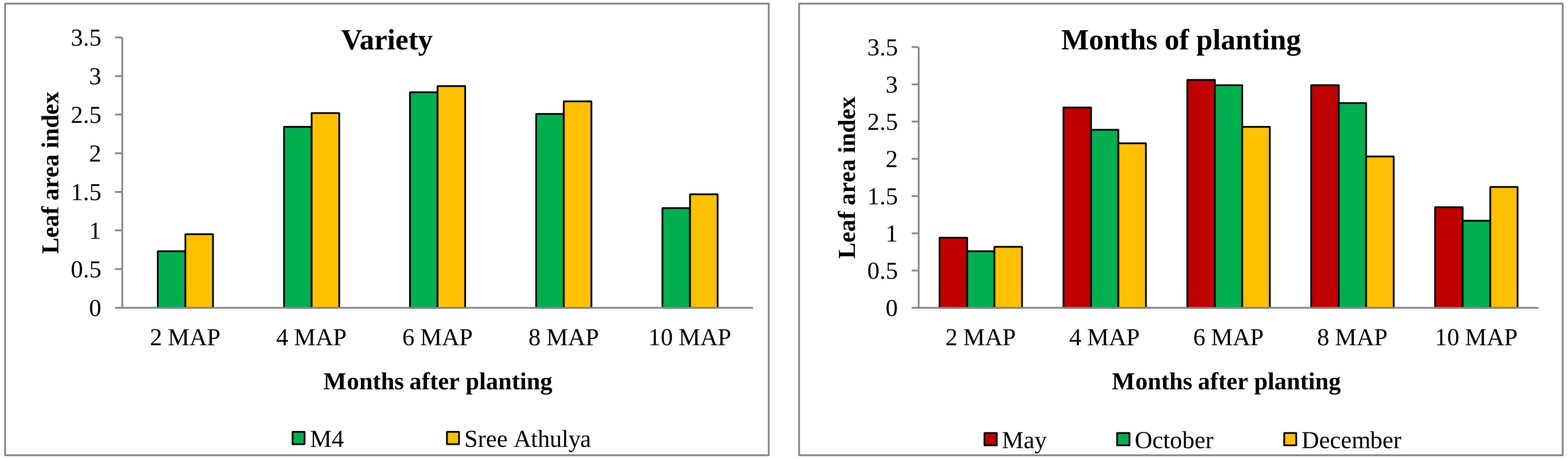


Fig.16. Leaf area index of short and normal-duration cassava varieties as influenced by variety and month of planting

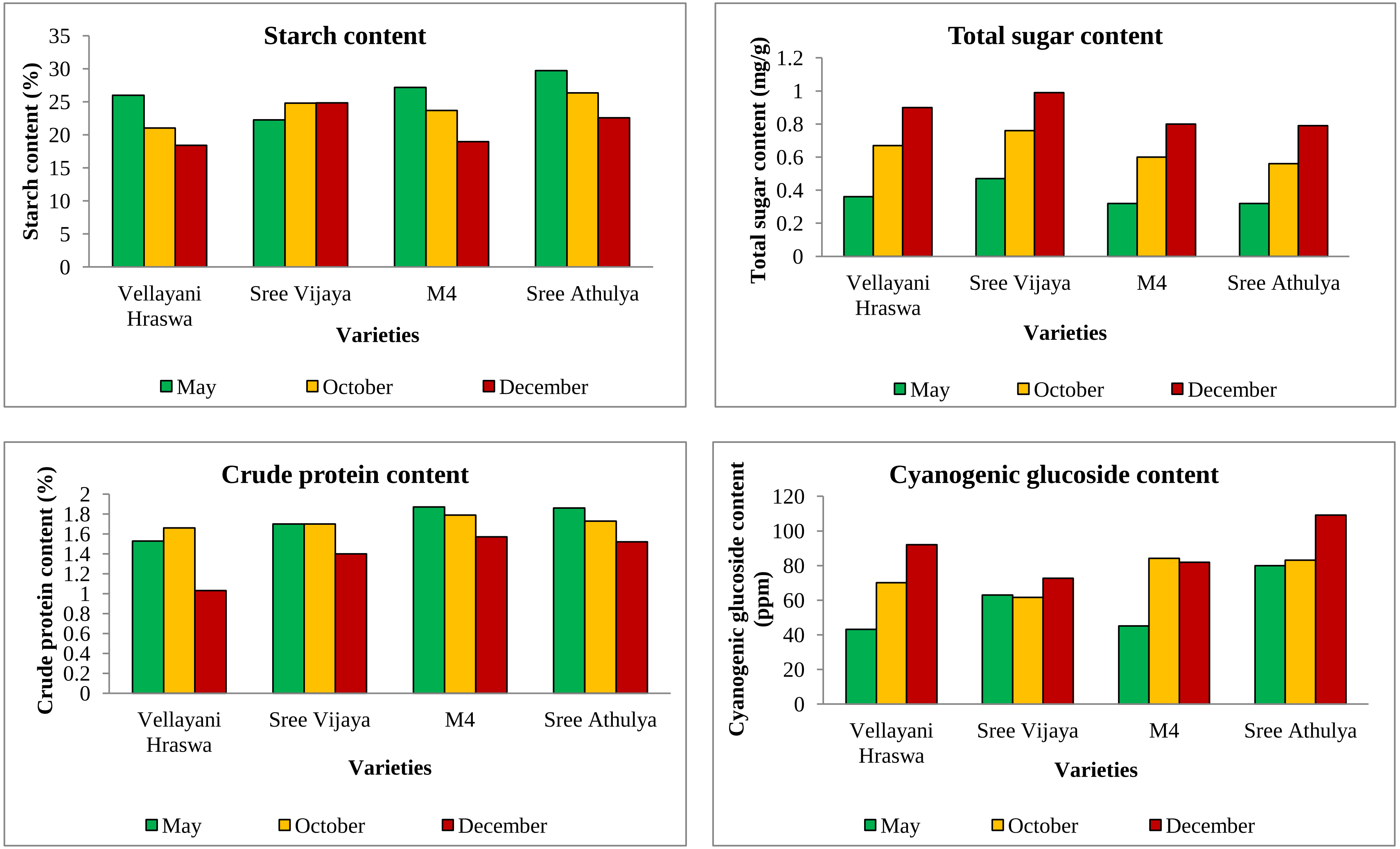


Fig. 17. Tuber quality parameters of short and normal-duration cassava varieties as influenced by variety and month of planting

the substrates for starch biosynthesis. There was a decline in starch content among varieties throughout the stress period although it was more pronounced among the susceptible ones *viz.*, Vellayani Hraswa and M_4. This was similar to the findings of Nuwamanya *et al.* (2014).The reduction in total starch during December planting can also be attributed as a plant protective mechanism through remobilization of stored resources in the plant to cater for survival during moisture stress (Ahmadi and Baker, 2001).

Though significantly higher starch content was present, sugar content was found to be less for the variety Sree Athulya. The variety Sree Vijaya recorded significantly higher sugar content than the other three varieties. A negative correlation between starch and sugar content depending on environmental condition was observed. According to Songhai (1994) and Lu (2005), the relationship between starch and total soluble sugar content of cassava is complicated and not well understood. A better sink-source relationship might have favoured the high starch variety to have more sugar transformation into starch. The decrease in reducing sugar in varieties may possibly result in decrease in metabolic activity and thereby help conserve energy and resource under moisture stress. Both total sugar and reducing sugar in all cassava varieties were found to be highest in the crops planted in December.

Comparison between the varieties revealed differences in drought tolerance. Sree Athulya exhibited highest yield per plant during all the growth seasons. But there was about 24 per cent reduction in starch content in December compared to May planting. During drought period, plants entered a dormant state which was interrupted by continuation of growth, stimulated by onset of rain. This new growth would draw on starch reserves for nutritional support and this was expressed by lower root starch content (Petchalanuwat, 1999). Defloor *et al*. (1998) reported that crops planted after the rainy season could have a starch content equivalent to crops planted during the rainy season. In the present experiment the extent of reduction in starch content in December planting as compared to May planting ranged from 18.43 % to 25.97 %. Reduction in starch content was observed with the progression of stress while an increase in reducing sugar content was recorded.

The percentage protein content in the four different varieties planted in three different plantings is depicted in Fig.17. Vellayani Hraswa recorded lower protein content (1.53 and 1.03 per cent) for May and December planting respectively. Lower crude protein content observed could be the result of one or more effects of drought stress on nitrogen mobility, uptake and assimilation (Zewdie *et al.*, 2008). Significantly higher crude protein content was recorded in M_4 (1.75 %) and Sree Athulya (1.71 %). The variation recorded was not abnormal and could be concluded as varietal characteristic of the crop. Significantly higher crude protein content was recorded for May and October plantings, which were on par and the lowest value was for December planting (Fig. 18). The exact relation of protein and starch content of cassava under water stress is unknown and is yet to be explored.

From the assessment of cyanogenic glucoside content of different varieties during varying plantings, it was noticed that significantly higher HCN was recorded for Sree Athulya, which was significantly higher than all other varieties. This high cyanogenic content in varieties could be attributed to seasonal variation, with highest content produced during dry season (Fig. 17). This is in accordance with the findings of Cigleneki *et al.* (2011) and Mlingi *et al.* (2011). Cyanogenic glucoside content and bitterness of varieties were found to progressively increase from May to October to December planting season. The per cent increase in cyanogenic glucoside content for December planting was 53.84 compared to May planting. From this study, Sree Athulya can be considered as a high yielding variety, but bitterness in the variety makes it inedible. Sree Athulya possessed bitterness through all the planting seasons. The natural bitterness in a variety may be due to the inherent trait involving a specific gene (Gleadow and Woodrow, 2000; Kizito *et al.*, 2007).

Cyanogenic glucoside content has a positive correlation with total and reducing sugar since cyanogenic glucosides such as linamarin are formed by the association of cyanohydrins, stabilized by the attachment of sugars with free hydrogen cyanide and is reported as the level of releasable hydrogen cayanide (Agbor-Egbe and Lape-Mbome, 2006).

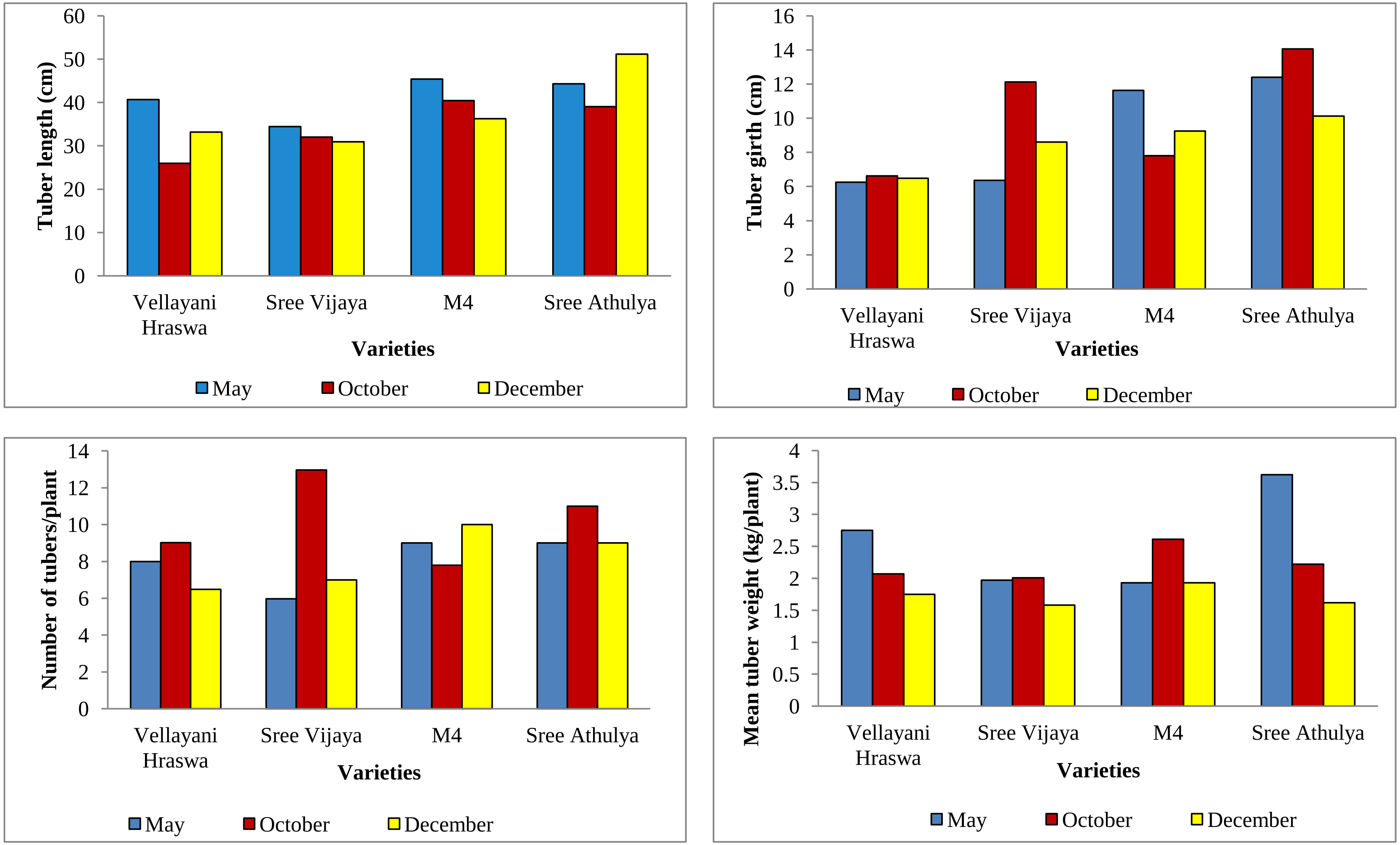


Fig. 18. Yield attributes of short and normal-duration cassava varieties as influenced by variety and month of planting

Considering the yield attributes of cassava, significantly greater tuber length, tuber girth, and mean tuber weight were observed when planted in May (Fig 18). Normal-duration variety Sree Athulya recorded significantly higher tuber length, tubergirth, number of tubers per plant and mean tuber weight per plant, which added to significantly higher yield per plant by the variety.

Among the varieties, Sree Athulya recorded significantly higher yields followed by M_4 and Sree Vijaya for all plantings. Vellayani Hraswa recorded significantly lower yield. The yield increase in the two 10 month duration varieties as compared to the shorter duration varieties might have been due to the availability of rainfall throughout the planting season, and longer durations. Tuber bulking in cassava is a continuous process (Ramanujam, 1990) and longer duration of crop under favourable environmental conditions leads to more tuber yield. Sree Athulya exhibited significantly higher yield per plant than M_4. Lesser amount of assimilate deposition required for storage root formation in a taller variety like Sree Athulya under water stress may be a reason for more yield per plant for this variety (El-Sharkawy and Tafur, 2010). Better leaf retention may also be one of the key factors for high yield as reported in several studies (El-Sharkawy, 2004; Lenis *et al.,* 2006). The variation in yield was related to the precipitation distribution within season, with dry and wet spells being key determinants of crop yield.

For all the varieties and seasons, higher yield, tuber length and girth, number of tubers and mean yield per plant were recorded for the normal-duration varieties. A dominant influence on root yield by water stress was evident at all harvest in all the four varieties. Root yield of cassava from the crop with initial water stress, *i.e.,* in December planting, was found to be lowest (Fig. 19). Lower root yield and starch content in crops planted after the rainy period have been reported by Sriroth *et al.* (2001).

Sensory evaluation for cassava varieties was carried out for various characters *viz.*, appearance, colour, flavour, texture, taste and overall acceptability. Overall acceptability was for variety Sree Vijaya compared to all other varieties in all the planting seasons. Vellayani Hraswa was also a favourite among the judges for October planting season along with Sree Vijaya. Qualitative performance of Sree Vijaya was good compared to other varieties, irrespective of seasonal conditions.

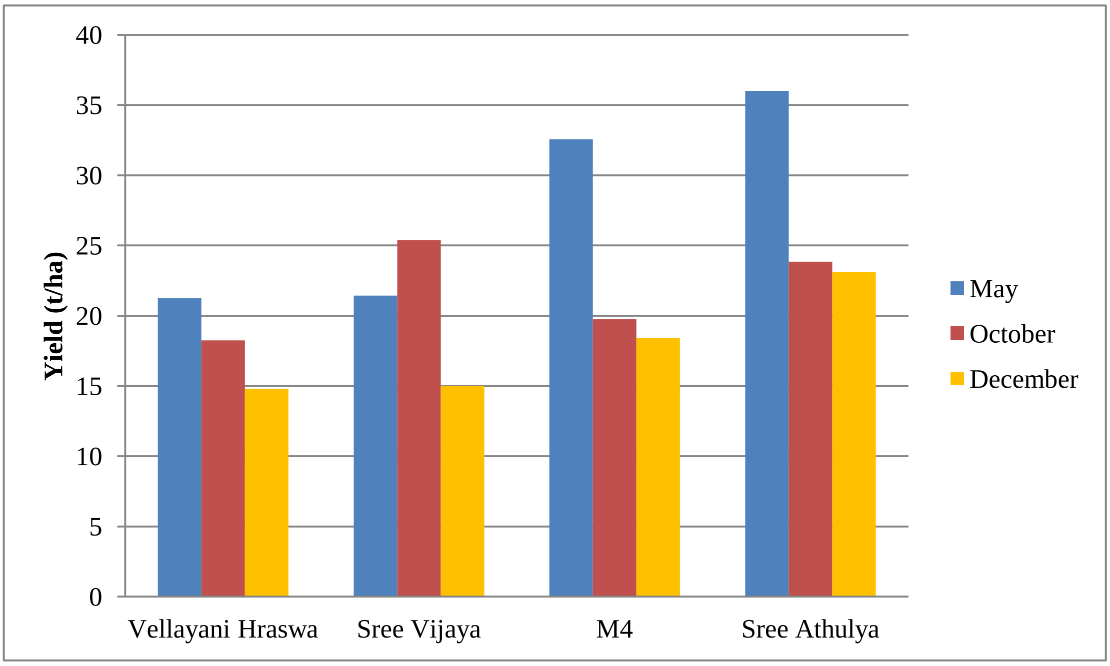


Fig. 19. Yield of short and normal-duration cassava varieties as influenced by variety and month of planting

Harvest index was significantly lower for long-duration varieties when planted during October and December. This may be due to an increase in biomass production due to the rapid regeneration of leaves soon after the receipt of rainfall (El-Sharkawy and Cock, 1987)

Soil moisture content (SMC) in general was higher during initial stages for May plantings, compared to December. Gradual decline in SMC was only noted at 105 days after planting. This may be an added advantage in this season leading to high yields. A similar observation was made during October planting, with varying trend in SMC. The varying SMC may be attributed to the mutual effect of soil water loss through evapo-transpiration and gain of water through precipitation. For December planting, a decreasing trend for SMC was recorded during the initial period. This may be due to high evaporation caused by high wind and temperature. The degree of soil moisture distribution varied with season and vegetation. This is consistent with the findings of Qiu *et al.* (2001).

Sree Vijaya was the variety which responded well to the available soil moisture content during May and October planting. However, Sree Athulya was the better performer during December planting season. This may be due to significantly higher root length during dry condition.

Following the trend of yields in the different seasons, cultivation of varieties during the traditional planting seasons, where availability of rainfall was plenty, was found to be monetarily advantageous. Sree Athulya maintained a B: C ratio in the range of 3.6-2.3, for all the planting seasons and the ratio was higher during May and December planting seasons. For October planting season, short-duration variety Sree Vijaya was found to be more remunerative than other varieties. This may be due to the highest yield per plant obtained during the period.

c. Qualitative and quantitative scoring of cassava in different planting seasons

Qualitative and quantitative scoring of cassava was done based on yield and cyanogenic glucoside content of the varieties for all the planting seasons (Table 104). HCN content in cassava though primarily a genetically associated parameter, may show changes to a certain extent based on stress, as cassava is a crop raised usually under moderate stress conditions. As such the HCN content in the sequential cropping patterns of the four varieties under consideration was subjected to statistical analysis season-wise and finally rationalised based on the scoring pattern suggested by Arunachalam and Bandhyopadhyay (1984). The highest rank score which speaks of the lowest content of HCN was regarded as the best. The above exercise was also carried out for the yield parameter, with the least yield with the smallest score. Finally a simultaneous scoring assessment was made based on the most critical parameters, *viz.*, HCN and yield. The results placed Sree Vijaya as the most promising variety followed by Sree Athulya. Even though Sree Athulya is a drought tolerant variety with highest yield, qualitatively it can be regarded as the second ordered variety since it cannot be used for edible purpose.

Table 103. Qualitative and quantitative scoring of cassava varieties during three planting seasons

Treatments	Cyanogenic glucoside content				Yield per hectare			
	May	Oct.	Dec.	Rank	May	Oct.	Dec.	Rank
T_1-Vellayani Hraswa	3	2.5	1	2	2	3	2	4
T_2-Sree Vijaya	2	3	2	1	2	1	2	2
T_3-M_4	3	1	1.5	3	1	2.5	2	3
T_4-Sree Athulya	1	1.5	1	4	1	1.5	1	1

d. Crop- weather relations

d. 1. Short-duration varieties

Correlation analysis of weather parameters with tuber yield in short duration cassava varieties brought out the significant relation between the two (Tables 68 and 69). The period up to crop establishment *i.e.,* 2 MAP required higher rainfall, while a lower maximum and minimum temperature was advantageous. Adejuwon and Ogundiminegha (2019) also reported these parameters to be most important. A higher mean relative humidity and lower mean evaporation, wind speed and mean sunshine hours was also seen to be desirable. This relation was found to persist in the case of maximum and minimum temperatures up to 6 MAP, while in the case of other parameters, the relation was not significant. The positive effect of rainfall was therefore striking just after planting, stressing the necessity of sufficient moisture at this period, and the better performance of the crop when planted during the south-west and north-east monsoon seasons (*i.e.,* May and October). Temperature being linked to rainfall were also more favourable during the two seasons, with lower maximum and minimum temperature prevailing. Any temperature extreme condition experienced during the two seasons might have compensated by spells of wet weather resulting in higher yield, as noted by Kahsay and Hansen (2016).

d. 2. Normal-duration varieties

In normal-duration varieties, the positive relation of rainfall with tuber yield persisted up to 6 MAP, which could be explained by longer vegetative phase of these varieties. The trend with temperatures was also similar with higher yields correlated with lower maximum and minimum temperature. Again higher relative humidity and lower mean evaporation, wind speed and mean sunshine hours were seen to be desirable, and typical of the two monsoon seasons. However, at maturity and harvest stages, a drier weather condition was seen to promote tuber yields as evident from the negative correlation with rainfall and mean relative humidity and positive correlation with low rainfall and high mean evaporation, wind speed and mean sunshine hours. This again is typical of the prevailing weather conditions if the cassava crop is planted in the most ideal month *i.e.,* May.

5.2. Effect of various chemical treatments in cassava varieties for drought mitigation

The effect of various chemical treatments on cassava varieties under drought was studied for the years 2015-16 and 2016-17 and the results are discussed below.

a. Weather conditions

The weather conditions during the period of study are presented in Figs.2a and 2b. The driest months for 2015-16 cropping period were January, February and March, with monthly precipitations of 23.80, 11.40 and 9.80 mm respectively. Total precipitation during the crop period was 514.10 mm, with mean evapo-transpiration of 29.10 mm and wind speed of 103. 61 km/h.

In 2016-17, the cropping period experienced extreme dry condition and monthly rainfall of 136.30 mm and no rainfall during January and February, which covered a major part of the crops critical growing period. Mean evapo-transpiration and wind speed recorded during the period were 28.00 mm and 89.10 km/h respectively. Even though cassava is drought tolerant, higher yield can be achieved with larger moisture cycle during its growth period. This is in line with the findings of Duque (2012).

a. Growth and development

General growth of cassava during the crop growing period was low for the second season (2016-17) compared to first season (2015-16), due to the failure of the north-east monsoon during the period. All biometric characters such as plant height, number of leaves, number of leaf scars, stem width, root length and diameter were significantly influenced by various chemical treatments, especially at 4 MAP. Progressive increase in plant height, stem girth, root length and root diameter was recorded on pooling the data of both years.

Positive effect of combined application of chemicals was observed with regard to plant height at all stages of observation (Fig.20). The treatment of water spray alone resulted in lowest plant height at all stages. This shows that under rainfed situation, supplementary foliar feeding of nutrients in combination helps in growth of the plant as also observed by Laane (2018) and Waraich *et al.* (2011). The combined application of KCl, silicic acid and $CaCl_2$ along with POP (T_8) resulted in superior plant height at later stages of measurement. At 4 MAP, this treatment was significantly superior to all other treatments. When number of leaves per plant was considered, water spray alone gave significantly lower number of leaves per plant compared to all other treatments at 2 MAP only. At other stages, most of the treatments were on par, and there was no desirable influence of nutrient application on leaf number (Fig. 21)

Commensurate with the leaf number, number of leaf scars was also higher. However, combined application of all chemicals along with POP (T_8) could considerably lower the leaf fall. Significantly higher number of leaf scars, indicating greater leaf fall, was seen in the treatment water spray, indicating the positive effect of nutrient application on leaf retention (Fig.22).

The pooled analysis of the data on stem girth, root length and root diameter revealed the positive effect of chemical treatments (Figs. 23 and 24). All these parameters were seen to be significantly lower in general, in the control treatments, *i.e.*, POP alone, POP + water spray and water spray alone. Adaptation of cassava to moisture stress was indicated by the high values for these plant characters as also observed by Helal *et al.* (2013).

Shoot fresh weight was seen to be significantly higher in the treatment POP + $CaCl_2$ at 4 and 6 MAP. The same treatment recorded highest root fresh weight at 6 MAP. All the chemical treatments recorded higher shoot and root fresh weight than the control treatments (POP + water spray and water spray alone) at 6 MAP (Figs. 25 and 26). Total dry matter production per plant was very low in all the treatments due to the debilitating effect of drought in the second year of experimentation. Even then, the positive effect of chemical treatments compared to control was evident (Fig. 27).

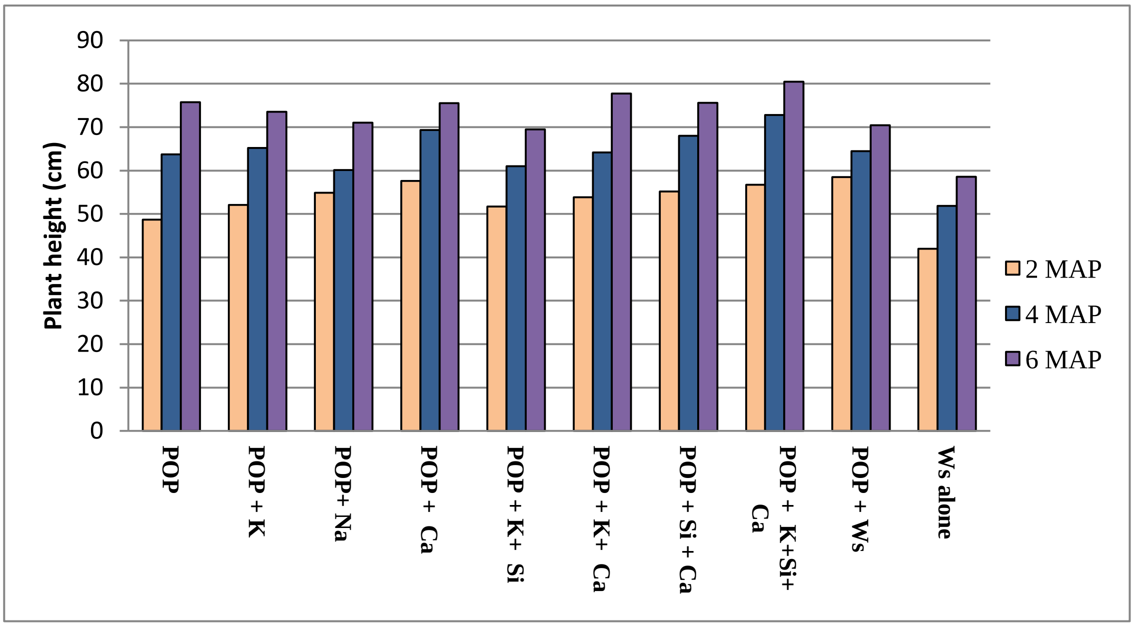


Fig. 20. Effect of treatments on plant height of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

The beneficial effect of combined application of KCl, silicic acid and $CaCl_2$ along with POP on chlorophyll content, photosynthetic activity and stomatal conductance was observed in cassava. Increased Chl a and Chl b contents were observed with this treatment. Favourable influences of mineral nutrients on these physiological parameters have been reported by Waraich *et al.* (2011). Potassium nutrition under drought stress is required for maintenance of photosynthetic carbon dioxide (Bowler *et al.*, 1992; Foyer *et al.*, 1998), osmotic potential and turgor of cells (Lindhauer, 1995) and regulation of stomatal functioning (Kant and Kafkafi, 2002).

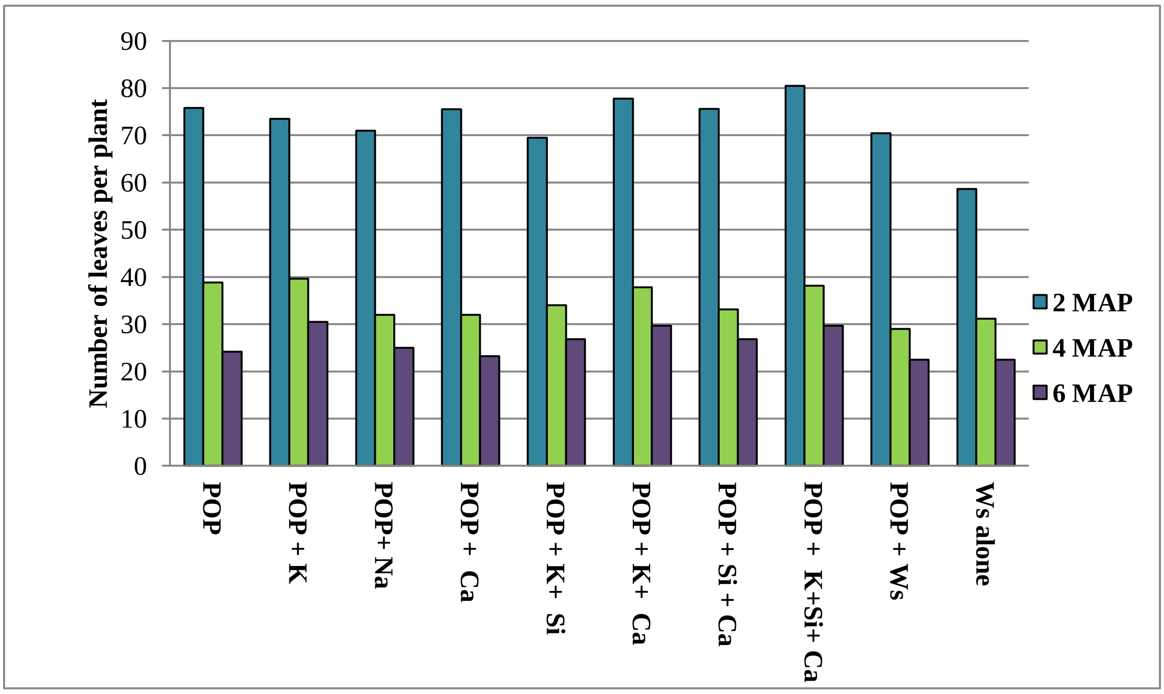


Fig.21. Effect of treatments on number of leaves per plant of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

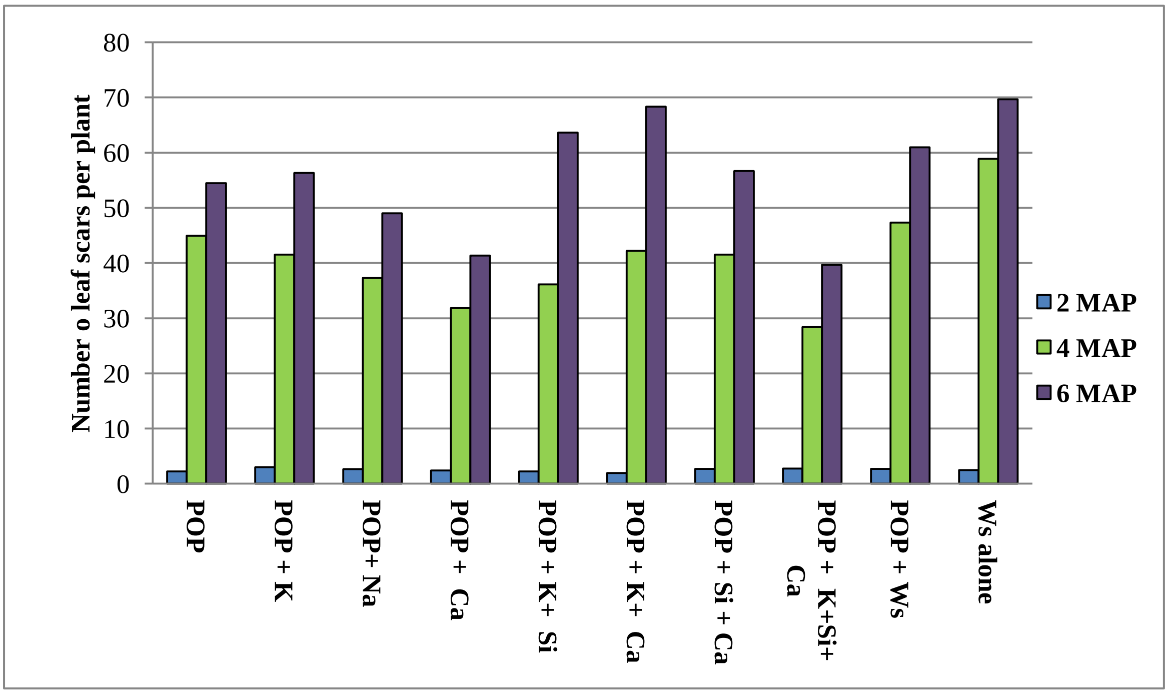


Fig. 22 . Effect of treatments on no. of leaf scars per plant of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

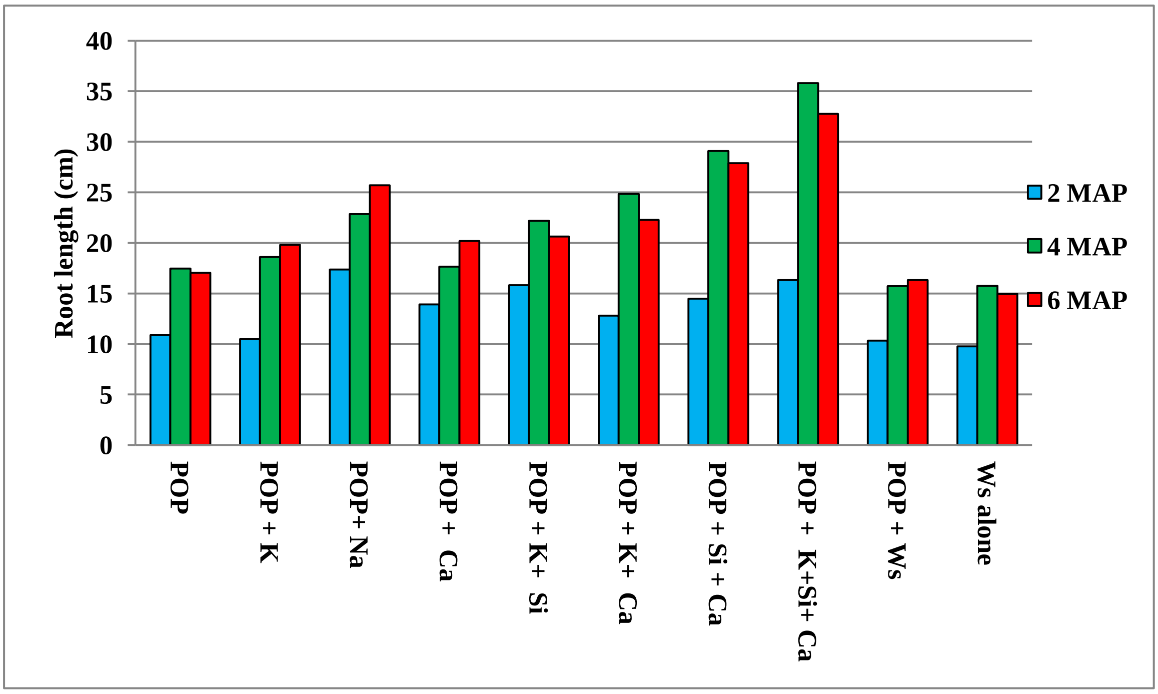


Fig. 23. Effect of treatments on root length of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

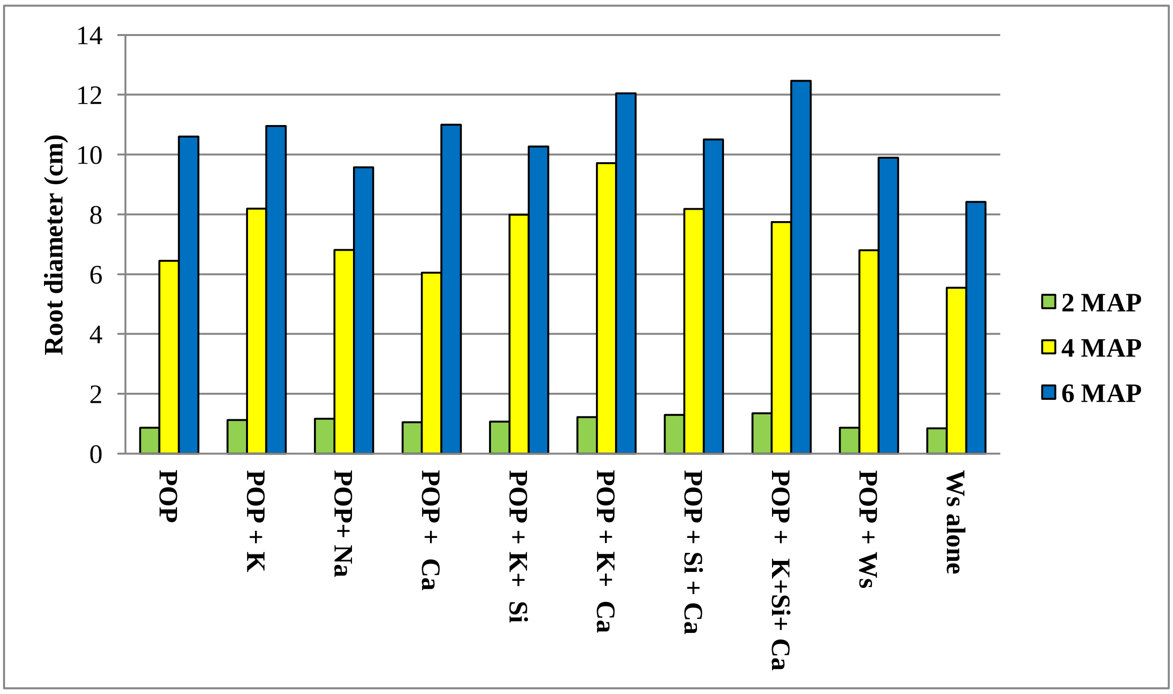


Fig. 24. Effect of treatments on root diameter of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

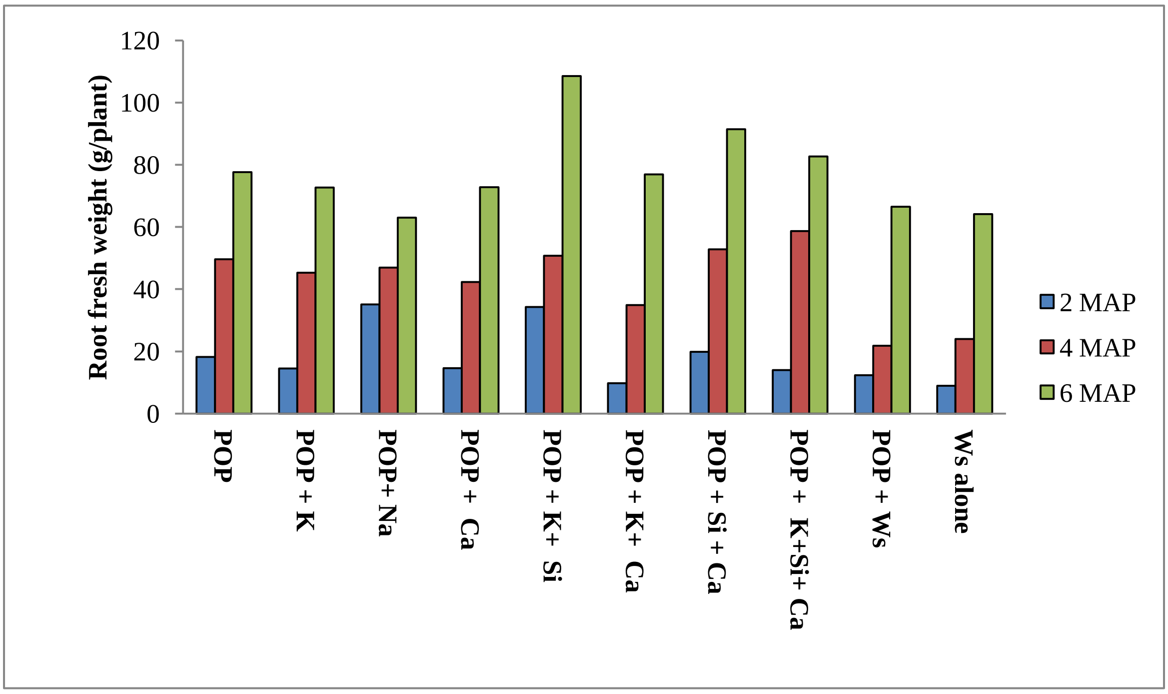


Fig. 25. Effect of treatments on root fresh weight of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

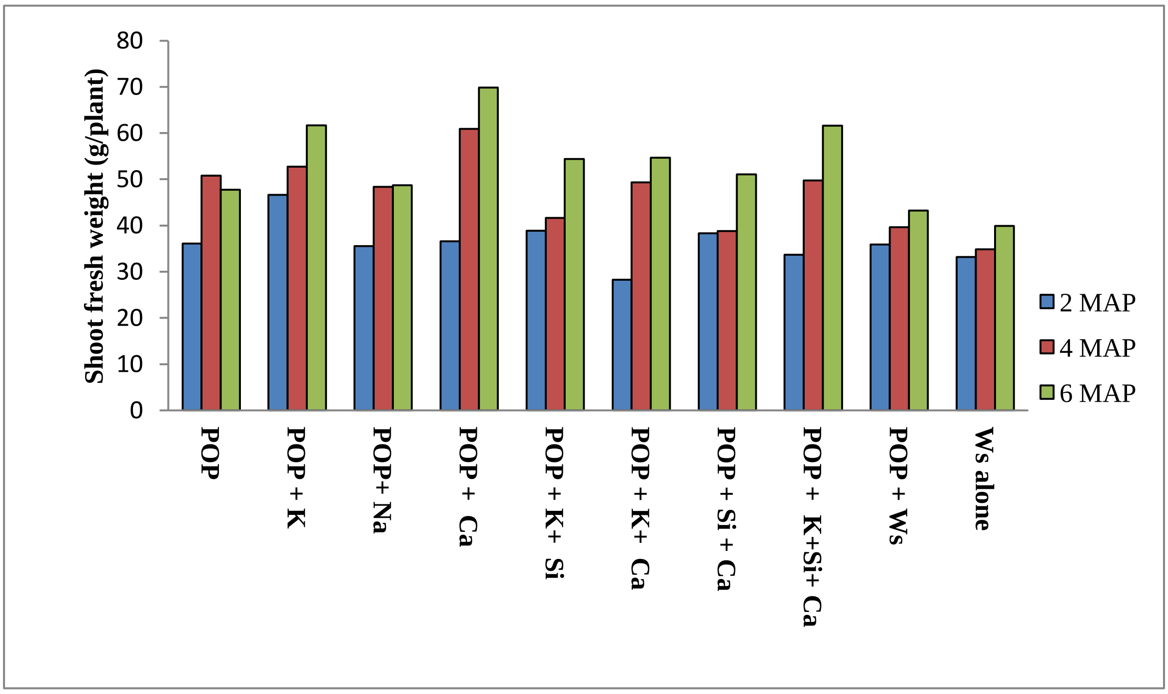


Fig. 26. Effect of treatments on shoot fresh weight of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

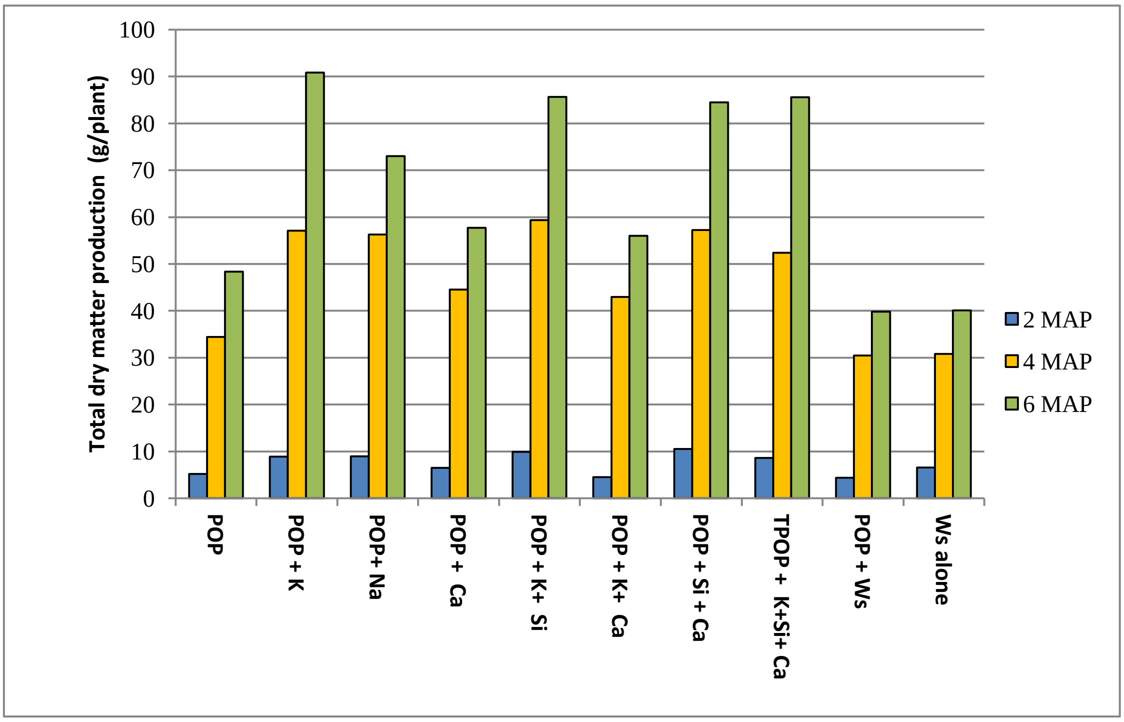


Fig. 27. Effect of treatments on total dry matter production of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

The protective role of K in plants suffering from drought stress by maintenance of a high pH in stroma and against the photo- oxidative damage to chloroplast was also reported by Cakmak (1997). The effect of silicon in reducing ROS generation and reducing photo-oxidative damage and maintaining integrity of chloroplast membrane was studied by Zhu *et al.* (2004), and calcium is known to have a positive effect on drought stress (Palta, 2000). High photosynthetic activity might have aided in the production of sucrose in the leaves, which was required for photosynthetic product transportation and distribution from leaves to the pool end. This was in accordance with the findings of El-Sharkawy *et al.* (1990).

Under drought situation it was also noticed that chlorophyll a was greater than chlorophyll b at 2 and 4 months after planting. Shamshi (2010) reported similar effect in wheat. Ramanujanm (1990) studied the effect of moisture stress on net photosynthetic rate in cassava and reported 24-56 per cent reduction for the same. Reductions in stomatal conductance serve as a first line of defence, by protecting the leaf from tissue desiccation (Vico *et al.,* 2013), and lower values of stomatal conductance were observed in the crop. This is in conformity with the findings of Laffray and Louguet (1990).

Significantly higher proline content was observed in the treatment POP alone, followed by the treatments water spray alone and POP + water spray (Fig.28). This could be due to the accumulation of free proline in leaf tissue in response to water stress, and is in agreement with the findings of Hanson *et al.* (1979), who observed a positive correlation between proline accumulation and drought injury in barley. The results bring out the relation between chemical application and lowered proline production, thereby indicting reduction in the effect of moisture stress.

Nitrate reductase activity was seen to be significantly lower in the control treatments where KCl, silicic acid and $CaCl_2$ were not applied. This is in agreement with the findings of Silveira *et al*. (2001) (Fig.29).

The ability to maintain high water content in leaves in spite of moisture stress is indicative of drought tolerance capability of cassava. This was further promoted by application of nutrients. Combined application of KCl, silicic acid and $CaCl_2$ along with POP resulted in high relative water content. Application of KCl with POP at 2 and 4 months after planting and of $CaCl_2$ along with POP at 6 months after planting also resulted in significantly higher relative leaf water content.

The photosynthesising ability of a plant is a direct function of the leaf area. The positive impact of chemical application on leaf area is clearly brought out, with higher values of leaf area index for all treatments as compared to POP alone, POP + water spray, or water spray alone. The data indicate a more favourable effect due to application of KCl and sodium silicate. Increased leaf area index in treatments with chemical application were accompanied by higher values of net assimilation rate, crop growth rate and relative growth rate. A positive relation between CGR and LAI has also been observed by Opas-Boonseng (1988) (Figs. 30 and 31). Though chemical treatments helped to increase LAI, the leaf area was below optimum due to drought stress and consequent effect on leaf production. Under drought stress, leaf growth is

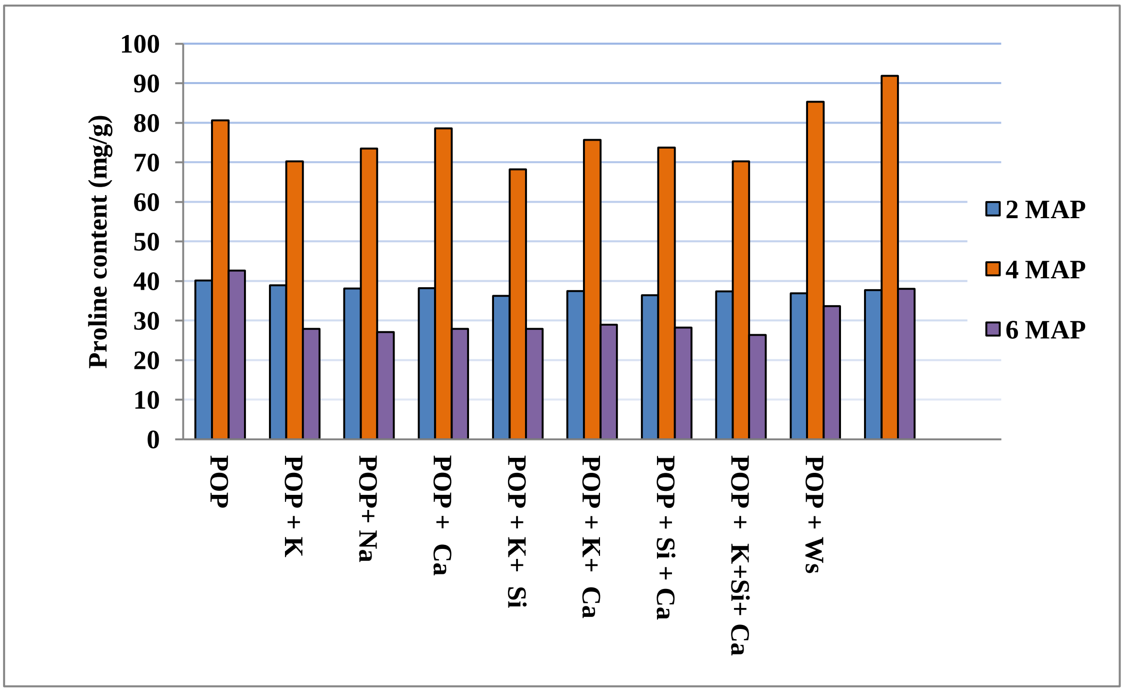


Fig. 28. Effect of treatments on proline content of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

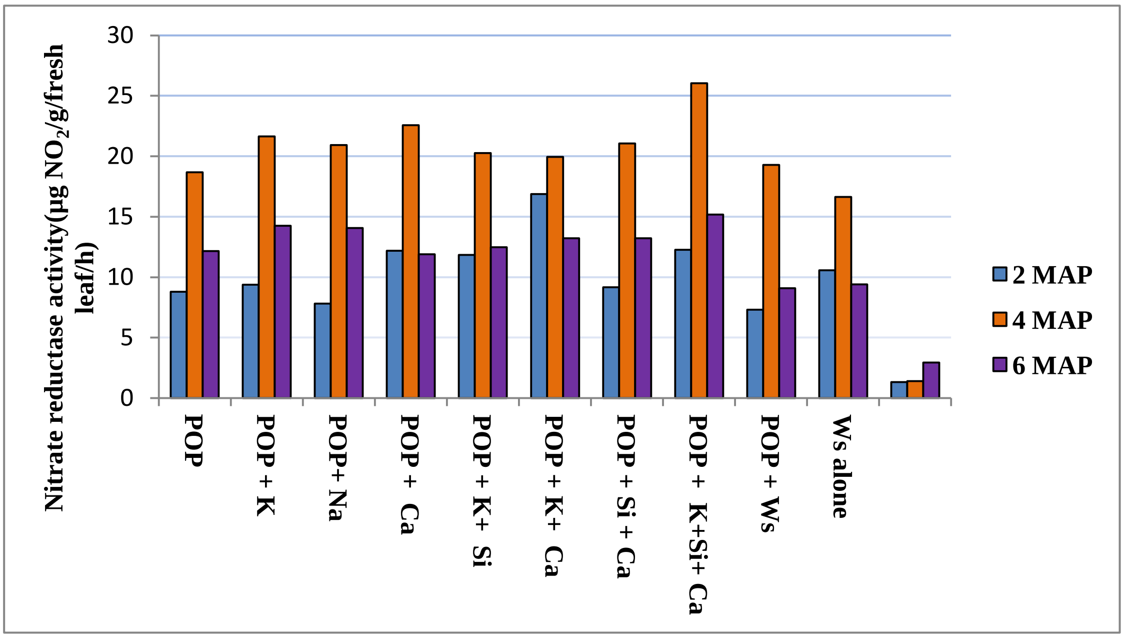


Fig. 29. Effect of treatments on nitrate reductase activity of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

Generally the starch content of the crop was low even though various chemical treatments had significant influence on the same. This could be linked to the significantly reduced and photosynthates partitioning is altered to support root growth (Crawford, 1989; Setter, 1990).

environmental conditions prevalent during the period of plant growth. In both years, significant influence on starch content was recorded for the treatments POP + KCl + $CaCl_2$, POP + KCl + silicic acid + $CaCl_2$ and POP + silicic acid + $CaCl_2$. A decrease in tuber sugar content was recorded in the second year, due to increased stress intensity and the decrease was found to be significantly higher for control (water spray alone). This was in accordance with the findings of Chaves and Oliveira (2004), (Fig.32).

Information on the influence of chemical on improving starch content in cassava is meagre. In general, starch quality is related to rainfall sufficiency, which ultimately influences soil temperature and nutrient availability (Santisopasri, 2001).

Cyanogenic glucoside content was found to increase under water stress situation as explained by Morante *et al.* (2016). This may be the reason for significant increase in HCN content, even under chemical treatments, compared to first season. HCN content was significantly influenced by different chemical treatments. (Fig. 33). Low HCN content was recorded for POP + KCl + silicic acid+$CaCl_2$ and POP + silicic acid + $CaCl_{2.}$ Under water stress situation, HCN content can be controlled by the option of treating with chemical elements (Burns *et al.*, 2010).

Yield and yield attributes were significantly influenced by chemical treatments. The pooled analysis for two years showed a significantly higher values for tuber length, tuber girth, number of tubers per plant and mean tuber weight for the treatment combining all chemical treatments along with POP (T_8), resulting in highest yield of 12.09 tonnes/ha (Fig. 34)

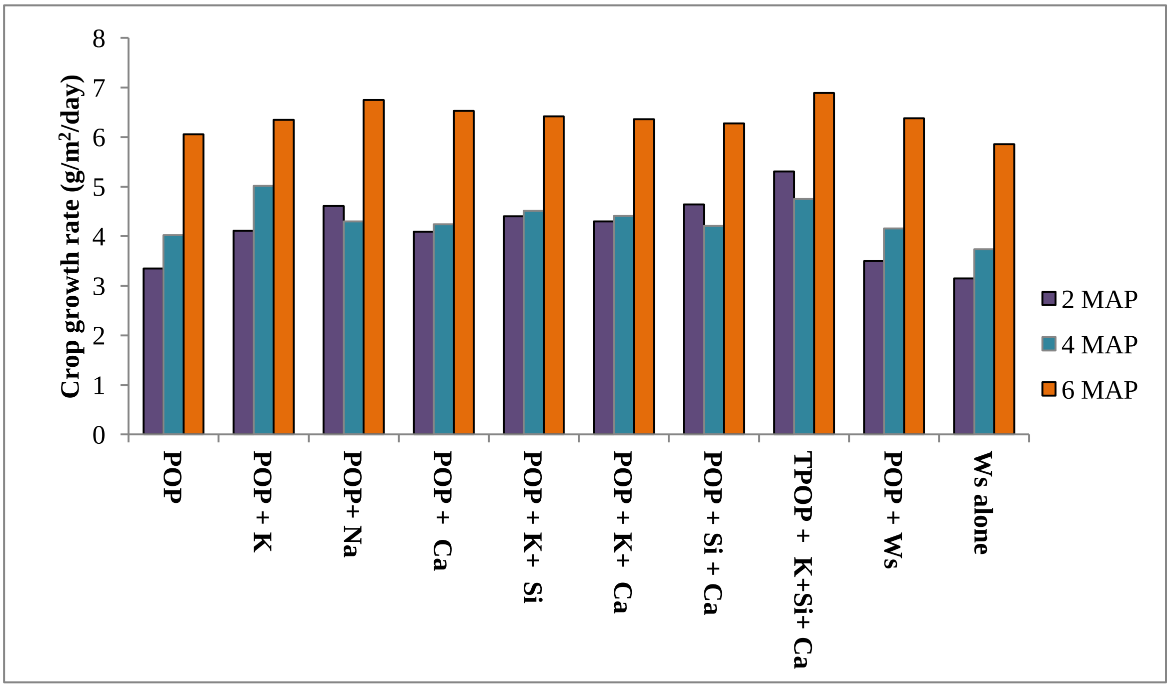


Fig.30. Effect of treatments on crop growth rate of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

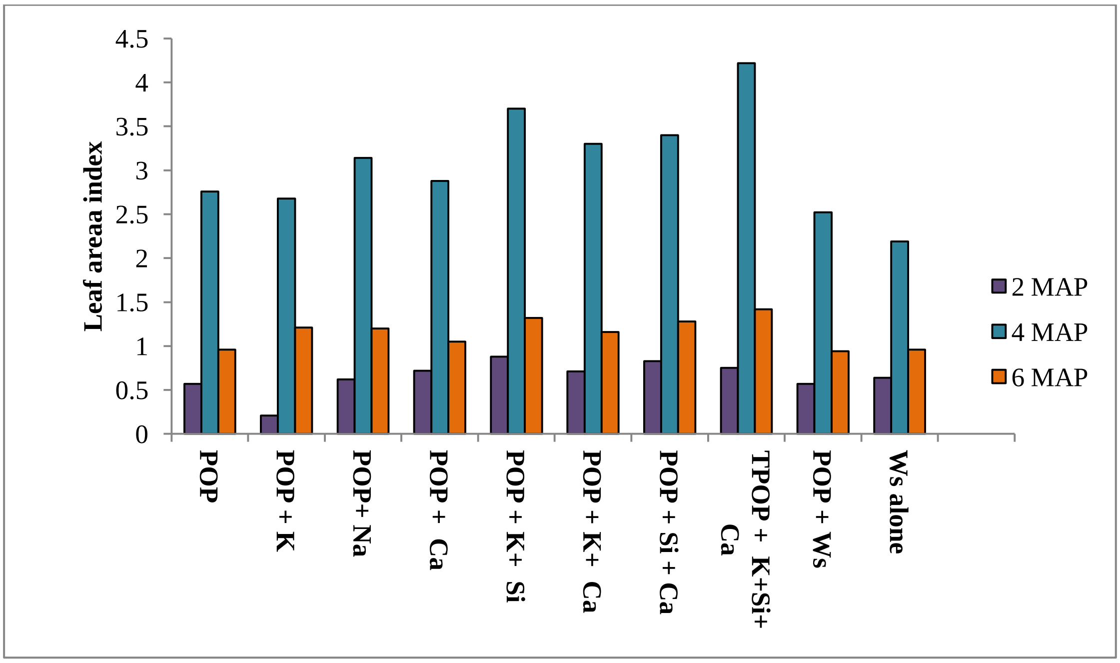


Fig.31. Effect of treatments on leaf area index of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

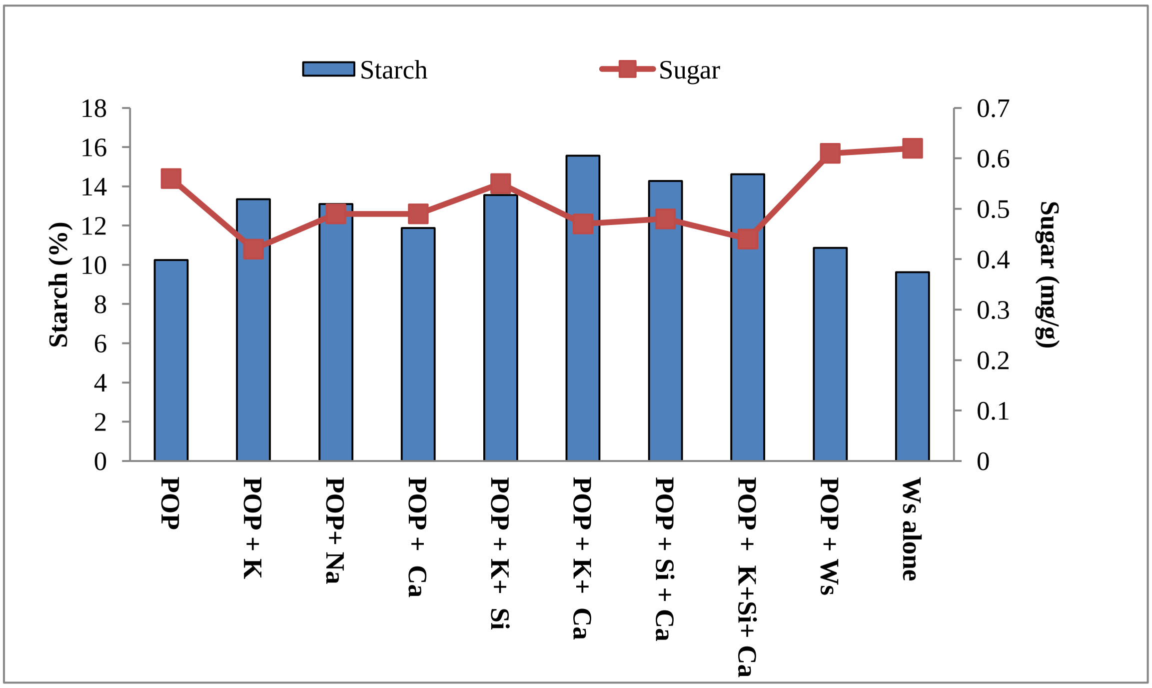


Fig. 32. Effect of treatments on total starch and sugar content of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

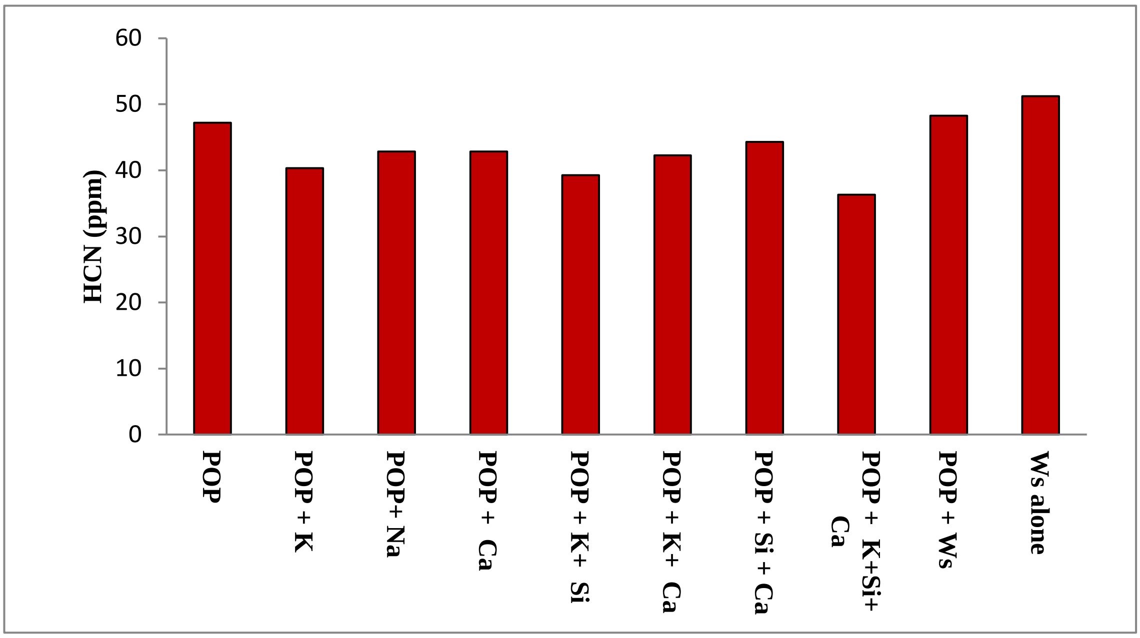


Fig. 33. Effect of treatments on cyanogenic glucoside content of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

The favourable interaction of the chemical combination in improving growth, physiological and biochemical parameters resulted in higher yield. It may have helped the crop to improve the photosynthetic activity, reduce senescence and improve leaf productivity and stomatal conductance as suggested by Bowler *et al*. (1992) and Waraich *et al.* (2011). The positive effect of chemical treatments alone, and in combination, in improving various yield attributes as well as yield as compared to control treatment was clear.

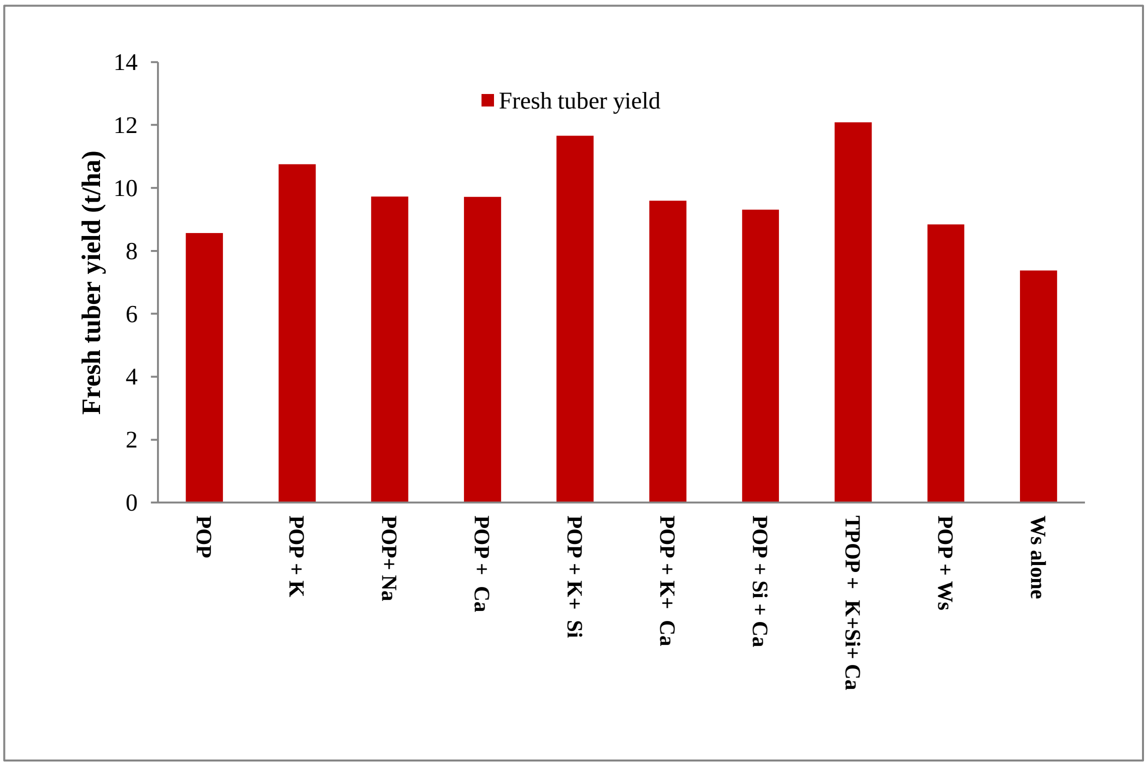


Fig. 34 . Effect of treatments on fresh tuber yield of Vellayani Hraswa (pooled means for 2015-16 and 2016-17)

Significant influence of treatments on total nutrient uptake by tubers was observed. Tuber N and K uptake was highest for POP+ silicic acid + KCl+ $CaCl_2$ in 2015-16, whereas most chemical treatments resulted in significantly higher tuber P. This may be due to the favourable influence of these chemicals in promoting root growth (Waraich, 2011) and increasing shoot biomass and yield as observed by Jin and Enomoto (2009). Moreover direct application of nutrients on leaves might also have resulted in rapid absorption of nutrients compared to soil application under drought situation (Rajitha *et al.*, 2018).

In keeping with higher yield obtained with the treatment combining all chemicals with POP, highest leaf and stem N and P, and highest leaf, stem and tuber K were recorded in this treatment. Significantly higher values of uptake of primary nutrients were also observed in chemical treatments as compared to the control treatments, indicating the positive effect of these treatments (Fig. 35).

A similar trend was seen with regard to secondary nutrient uptake, with significantly higher total Ca, Mg and S being taken up in the treatment combining application of KCl, silicic acid and $CaCl_2$ along with POP (Fig. 36). Low uptake of these nutrients in the treatments POP alone, POP + water spray and water spray alone could be explained by variations induced by less rainfall, high evaporation and low soil moisture content, in line with the findings of El-Sharkawy *et al.* (1992a) and Van Duivenbooden *et al.* (1999).

Economics of crop production calculated in the two years revealed that with comparatively better moisture availability in 2015-16, application of the nutrients K, Ca, Si alone or in combination along with POP could increase the B:C ratio. Combination of all three nutrients along with recommended doses of N, P and K gave the highest B:C ratio. When moisture was severely limiting as was the case in 2016-17, nutrient application effects were not worthwhile. But from an academic point of view, it is significant to note that compared to POP alone, POP in combination with water spray or water spray alone, higher B:C ratios were obtained when K, Si or Ca were applied alone or in combination a long with POP.

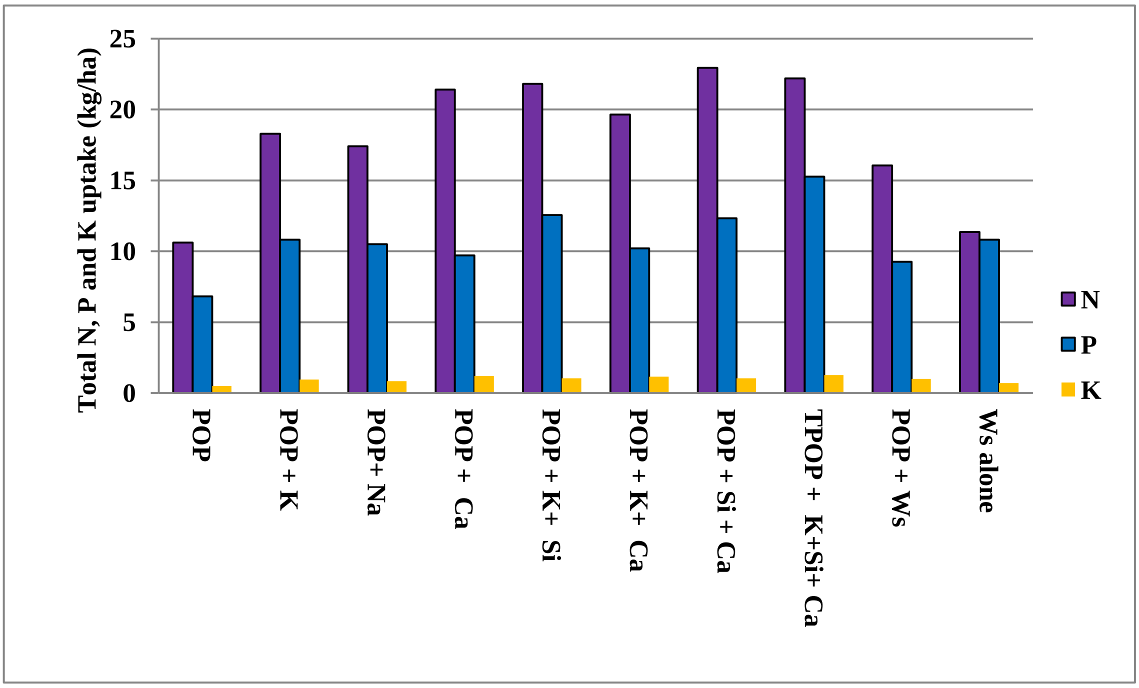


Fig. 35. Effect of treatments on total N, P, K uptake of Vellayani Hraswa (pooled means for 2015-16 and 2016-17

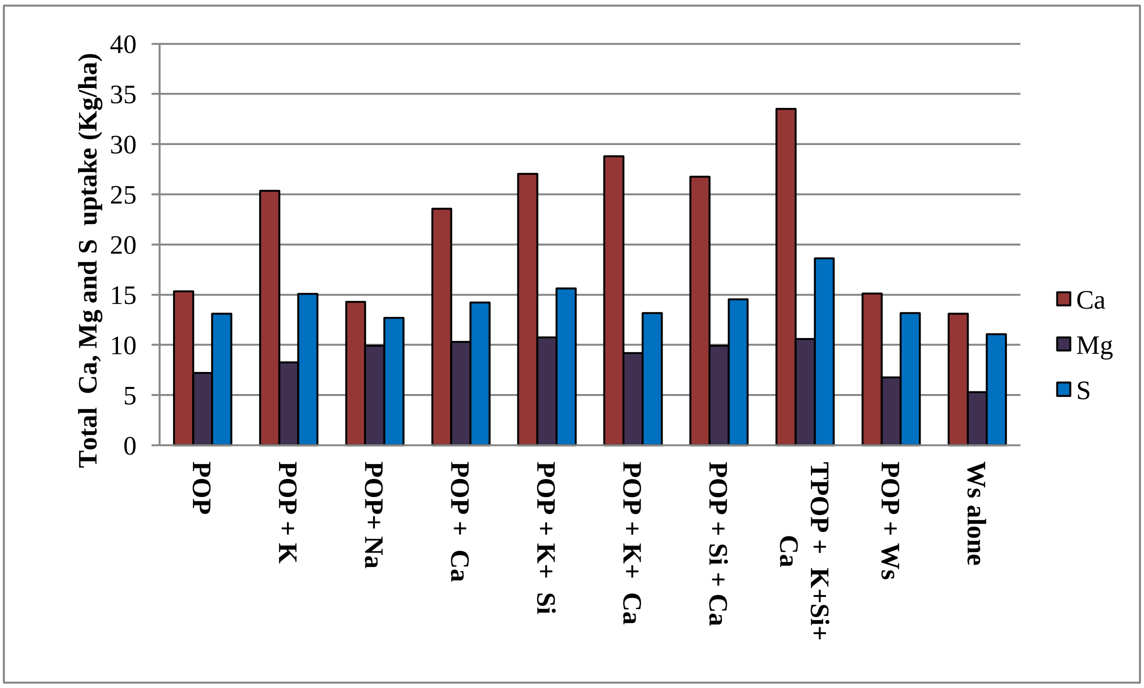


Fig. 36. Effect of treatments on total Ca, Mg, S uptake of Vellayani Hraswa (pooled means for 2015-16 and 2016-17

Summary

6. Summary

Investigations were undertaken as two separate experiments at the Agronomy farm, College of Horticulture, Vellanikkara, during 2015-16 and 2016-17. In experiment I, the response of four cassava varieties of varying durations were planted in three planting seasons *viz.*, May, October and December. In experiment II, the effect of foliar application of potassium, silicon and calcium along with major nutrients on short-duration variety Vellayani Hraswa grown under drought stress was studied for two years, *viz.*, 2015-16 and 2016-17. The salient findings of the above studies are summarized below.

6.1 Experiment I. Crop-weather relations in cassava under drought condition

Four varieties of varying duration *viz.*, Vellayani Hraswa and Sree Vijaya (short-duration) and M_4 and Sree Athulya (normal-duration), were planted in three different seasons and grown under rainfed situation.

- May planted crop received a total rainfall of 2450.37 mm, whereas October and December planted crops received rainfall of 1829.00 mm and 1744.00 mm respectively. The three crops were thus subjected to varied environmental conditions, in terms of varying temperature, precipitation and solar radiation during the period of study.

- In general, the growth of cassava varieties was considerably greater for May and October planted varieties, whereas growth of December planted varieties was comparatively less.

- Progressive increase in plant height was recorded for all varieties during the three planting seasons. May planted cassava varieties recorded greatest plant height among the seasons. Considering the varieties, Sree Athulya, a normal-duration variety, and Sree Vijaya a short-duration variety, were seen to have significantly greater plant height and stem girth.

- More number of leaves was recorded for short-duration varieties Sree Vijaya and Vellayani Hraswa at 4 and 6 MAP. In normal-duration varieties, M_4 was seen to produce higher number of leaves than Sree Athulya throughout the growing period. Low number of leaves was recorded for December planting season compared to other seasons.

- Considering the effect of variety on number of leaf scars per plant, significantly higher number of leaf scars was recorded for short-duration variety Vellayani Hraswa at all the growth stages and December planted crop had significantly higher number of leaf scars per plant during initial stage *i.e.,* upto 2 MAP for short-duration varieties. However towards the later stages, May and October planted crops had significantly higher number of leaf scars for both short and normal-duration varieties.

- Root length was significantly higher for M_4 among normal-duration varieties and Sree Vijaya among short-duration varieties for May planting. Root diameter was found to be greater for May planting and among varieties, Sree Vijaya of short-duration varieties and Sree Athulya of normal-duration varieties had significantly greater root diameter.

- Root fresh weight was found to be significantly higher for Sree Athulya upto 6 MAP, but Sree Vijaya and Vellayani Hraswa did not differ significantly in root fresh weight at all stages. Varieties had significantly higher root fresh weight when planted during May, and lowest weights when planted during December.

- Total dry matter production was found to be higher for Sree Athulya among normal-duration varieties for all the planting seasons. Between short-duration varieties, Sree Vijaya was found to be superior to Vellayani Hraswa. Considering the month of planting dry matter production was significantly higher for May planting for short-duration varieties, while for normal-duration varieties, May planting was superior upto 6 MAP, after which May and October planting were on par.

- Among the three planting seasons, higher photosynthetic rates were observed for May and October planted varieties, and the same trend was followed for short-duration varieties with regards to the stomatal conductance. In normal-duration varieties it was seen to be higher in December planted crops.

- Short-duration variety Vellayani Hraswa was observed to have significantly higher proline content when planted during October and December, and variety M_4 was found to have more proline content compared to Sree Athulya among normal-duration varieties at 2 and 6 MAP. Considering the month of planting, October planted crop had higher proline content in normal-duration varieties in the initial stages, while the values were higher in crops planted in December.

- Leaf nitrate reductase activity was found to be decreased under water stress. Among varieties, Sree Athulya recorded higher NRase activity

- Starch content in Sree Athulya variety was significantly higher for all the three plantings compared to other varieties. Among the three seasons, crops planted in May had highest starch content in tuber. Sree Athulya planted during May showed highest starch accumulation as compared to

October and December planting. Sugar content was found to be less for Sree Athulya, whereas the variety Sree Vijaya recorded significantly higher sugar content in all the three seasons.

- Significantly higher HCN was recorded for Sree Athulya, compared to other varieties. Cyanogenic glucoside content and bitteness of varieties were found to progressively increase from May to October to December planting seasons.

- Significantly greater tuber length, tuber girth, and mean tuber weight were observed when planted in May. Normal-duration variety Sree Athulya recorded significantly higher tuber length, tuber girth, number of tubers per plant and mean tuber weight per plant, which contributed to significantly higher yield per plant by the variety. Among the varieties, Sree Athulya recorded significantly higher yields followed by M_4 and Sree Vijaya irrespective of the date of planting. Vellayani Hraswa recorded significantly lower yield.

- Overall acceptability of Sree Vijaya for sensory qualities was higher compared to other varieties, irrespective of seasonal conditions.

- The degree of soil moisture distribution varied with season and among varieties, Sree Vijaya responded well to the available soil moisture content planted in May and October. However, Sree Athulya performed better when planted in December planting season.

- Cultivation of varieties during the traditional planting seasons, where availability of rainfall was plenty was found to be monetarily advantageous, with Sree Athulya having highest B: C ratio when planted in May and December. However in October planted crops, Sree Vijaya was found to be more remunerative than the other varieties.

- Overall, quantitatively and qualitatively, Sree Vijaya can be considered as the best variety, with Sree Athulya variety ranked next.

- Crop-weather studies revealed that a positive correlation existed between minimum temperature and rainfall at initial period of growth and yield of short- duration varieties.

- Rainfall and yield were positively correlated for normal-duration varieties up to 6 months after planting

- Higher relative humidity at early stage of plant growth favoured yields for both short and normal–duration crops.

6.2. Effect of various chemical treatments in cassava varieties for drought mitigation

Field experiments were conducted with 10 treatments in short duration variety Vellayani Hraswa to study the effect of foliar application of potassium, silicon and calcium along with NPK as per the recommendation of POP during 2015-16 and 2016-17. The data for the two seasons were pooled and analysed.

- Total precipitation during 2015-16 was recorded to be 514.10 mm. 2016-17 cropping season experienced extreme dry condition with total recipt of rainfall being only 136.30 mm during the entire cropping period.

- Crop growth in general was low for 2016-17 compared to 2015-16 due to adverse climatic conditions.

- Progressive increase in plant height, stem girth, root length and diameter were recorded during both seasons.

- Combined application of chemicals had a positive effect on plants with regard to plant height and number of leaves at all stages of observation.

- Combined application of KCl + silicic acid + calcium along with POP resulted in superior plant height at all stages of measurement. With regard to the number of leaves, higher leaf number was observed in all treatments at all stages, compared to water spray alone (T_{10}) and POP + water spray (T_9) in which leaf number was lowest.

- Number of leaf scars per plant was considerably lower with combined application of chemicals along with POP at 4 and 6 MAP.

- Combined application of KCl + silicic acid + $CaCl_2$ in addition to POP (T_8) was seen to significantly increase root length and root diameter.

- Along with POP, POP + silicic acid (T_3) promoted root fresh weight in 2015-16.

- In 2016-17, highest dry matter production was obtained with POP + KCl + silicic acid + $CaCl_2$.

- There was beneficial effect of combined application of KCl, silicic acid and $CaCl_2$ along with POP on chlorophyll content, photosynthetic activity, stomatal conductance and relative leaf water content.

- There was increase in proline content and decrease in NRase activity in control. The treatment POP + KCl + silicic acid + $CaCl_2$ had positive influence on crop growth rate, relative growth rate and LAI.

- Pooled analysis showed a general reduction in starch content due to moisture stress. However POP + KCl + silicic acid + $CaCl_2$, and POP + silicic acid+ $CaCl_2$, POP + KCl + $CaCl_2$ and POP + KCl + silicic acid showed significant positive influence on starch content during both years. Significantly higher HCN content was recorded for POP + water spray and water spray alone.

- Treatment combination, POP + KCl + silicic acid+ $CaCl_2$ recorded significantly higher tuber girth, number of tubers, fresh tuber yield per plant and yield per ha.

- POP + treatment also recorded higher fresh tuber yield along with POP + KCl + silicic acid. Sixty three per cent increase in tuber yield was observed when all chemicals were applied in combination compared to the control.

- Total N and K uptake was significantly higher for treatment POP + KCl + silicic acid + $CaCl_2$ (T_8). Total P uptake in cassava was significantly higher for treatments POP + KCl + silicic acid + $CaCl_2$ (T_8), POP + KCl + silicic acid (T_5), POP + silicic acid + $CaCl_2$ (T_7), POP + $CaCl_2$ (T_4) and POP + silicic acid (T_3).

- Ca, Mg and S uptake by the leaf was highest for the treatment POP + KCl + silicic acid + $CaCl_2$

- Combination of all three nutrients along with recommended doses of N, P and K resulted in highest B:C ratio. In 2016-17, when moisture was severely limiting, nutrient application was not worthwhile. Compared to POP alone, POP in combination with water spray or water spray alone, higher B:C ratios were obtained when K, Si or Ca were applied alone or in combination with POP during 2016-17.

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Appendix 1.a.Weather data for cropping period (May 2015-March 2016)

Months	Max.temp.	Min. Temp.	Mean RH	Rainfall	Rainy days	Mean evap.	Total SShrs	Mean SShs	Wind speed
May	32.9	24.7	80	259	12	3.1	156.6	5	6.4
June	31	23.9	85	629.8	23	2.6	54.6	1.8	6.2
July	30.03	23.5	85	510.1	23	2.8	118.5	3.8	6.8
Aug	31	23.7	83	320.8	17	2.9	180.6	5.8	3
Sep	31.9	23.7	81	242.2	12	3	167.7	5.6	1.4
Oct	32.5	24.1	79	203.8	15	2.7	174.1	5.6	4.1
Nov	31.6	23.8	75	151.2	8	2.8	137.4	4.6	11.2
Dec	32.3	23.3	65	88.3	3	4	214.8	6.9	24.8
Jan	33.2	23	56	23.8	1	5.1	266.2	8.6	31.9
Feb	35.3	23.5	57	11.4	1	5.1	237.2	8.2	11.7
March	36.3	25.2	67	9.8	1	4.7	247.5	8	9.2

Appendix 1.b. Weather data for cropping period (October 2015-August 2016)

Months	Max.temp.	Min. Temp.	Mean RH	Rainfall	Rainy days	Mean evap.	Total SShrs	Mean SShs	Wind speed
Oct	32.5	24.1	79	203.8	15	2.7	174.1	5.6	4.1
Nov	31.6	23.8	75	151.2	8	2.8	137.4	4.6	11.2
Dec	32.3	23.3	65	88.3	3	4	214.8	6.9	24.8
Jan	33.2	23	56	23.8	1	5.1	266.2	8.6	31.9
Feb	35.3	23.5	57	11.4	1	5.1	237.2	8.2	11.7
March	36.3	25.2	67	9.8	1	4.7	247.5	8	9.2
April	35.8	26.2	69	25.8	2	4.7	238.2	7.9	10.7
May	34	24.2	78	270.7	9	3.8	182.2	5.9	6.9
June	29.8	21.7	89	654.7	22	2.1	49.3	1.6	4.9
July	29.9	21.6	85	390.4	19	2.5	71.2	2.3	7.7
Aug	30.4	23.2	83	183.5	19	2.9	152.4	4.9	7.2

Appendix 1.c. Weather data for cropping period (December 2015-May 2016)

Months	**Max.temp.**	**Min. Temp.**	**Mean Rh**	**Rainfall**	**Rainy days**	**Mean evap.**	**Total SShrs**	**Mean SShs**	**Wind speed**
Dec	32.3	23.3	65	88.3	3	4	214.8	6.9	24.8
Jan	33.2	23	56	23.8	1	5.1	266.2	8.6	31.9
Feb	35.3	23.5	57	11.4	1	5.1	237.2	8.2	11.7
March	36.3	25.2	67	9.8	1	4.7	247.5	8	9.2
April	35.8	26.2	69	25.8	2	4.7	238.2	7.9	10.7
May	34	24.2	78	270.7	9	3.8	182.2	5.9	6.9
June	29.8	21.7	89	654.7	22	2.1	49.3	1.6	4.9
July	29.9	21.6	85	390.4	19	2.5	71.2	2.3	7.7
Aug	30.4	23.2	83	183.5	19	2.9	152.4	4.9	7.2
April	35.8	26.2	69	25.8	2	4.7	238.2	7.9	10.7
May	34	24.2	78	270.7	9	3.8	182.2	5.9	6.9

Appendix 2a. Weather data for first crop of second experiment (October 2015-16)

Months	Max.temp.	Min. Temp.	Mean RH	Rainfall	Rainy days	Mean evap.	Total SShrs	Mean SShs	Wind speed
Oct	32.5	24.1	79	203.8	15	2.7	174.1	5.6	4.1
Nov	31.6	23.8	75	151.2	8	2.8	137.4	4.6	11.2
Dec	32.3	23.3	65	88.3	3	4	214.8	6.9	24.8
Jan	33.2	23	56	23.8	1	5.1	266.2	8.6	31.9
Feb	35.3	23.5	57	11.4	1	5.1	237.2	8.2	11.7
March	36.3	25.2	67	9.8	1	4.7	247.5	8	9.2
April	35.8	26.2	69	25.8	2	4.7	238.2	7.9	10.7

Appendix 2b. Weather data for second crop of second experiment (October 2016-17)

Months	Max.temp.	Min. Temp.	Mean Rh	Rainfall	Rainy days	Mean evap.	Total SShrs	Mean SShs	Wind speed
Oct	31.5	22.7	81	37.3	4	2.8	170.3	5.5	5
Nov	32.9	22.2	69	13.8	1	3	174.7	5.8	7.9
Dec	32.4	22.3	69	52.9	3	3.3	197.6	6.5	12.1
Jan	34.1	22.9	53	0	0	4.7	235.2	7.6	26.5
Feb	36	23.2	51	0	0	5.7	243	8.7	19.9
March	36.1	24.7	67	13.2	1	4.5	229.9	7.4	7.5
April	35.7	26	70	19.1	1	4	194.4	6.5	10.2

Appendix 3. Input cost and market price of produce

Particulars	Amount
Land Preparation	
Tractor charges	Rs. 550/hr
Labour charges	
Men	Rs. 550/day
Women	Rs. 450/day
Cost of input	
Setts	Rs. 5/m
Farm yard manure	Rs. 3/kg
Urea	Rs. 6/kg
Rajphos	Rs.11/kg
MOP	Rs.18/kg
KCl	Rs. 220/500g
$CaCl_2$	Rs.312/500g
Silicic acid	Rs. 448/500g
Chlorpyrifos	Rs.100/250g
Oxyfluorfen	Rs. 590/250 ml
Produce	
Cost of tubers	Rs. 15/kg

CROP-WEATHER-NUTRIENT RELATIONS IN CASSAVA UNDER DROUGHT STRESS

By

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(2014-21-103)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

DOCTOR OF PHILOSOPHY IN AGRICULTURE

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KERALA, INDIA

2020

Abstract

Due to global warming the risk of environmental stresses, especially of prolonged drought, are expected to increase in the coming years. Cassava (*Manihot esculenta* Crantz.) is a typical tropical plant with its distribution confined almost entirely to the tropical zone. The crop is sensitive to soil water deficit during the first three months after planting, and water stress during the later stages of crop growth causes reduced yield and quality of tubers. In case supplemental irrigation is not possible, some nutrients are found to play important roles in imparting drought resistance to the crop. With this background, the present investigation entitled “Crop-weather-nutrient relation in cassava under drought stress” was undertaken.

Two separate experiments were conducted in the Agronomy farm of College of Horticulture Vellanikkara (10^{o} 31’ N latitude and 76^{o} 13’E longitude) in Thrissur District of Kerala. In experiment I, conducted in 2015-16, the response of four cassava varieties of varying durations *viz.*.Vellayani Hraswa and Sree Vijaya of short duration and M_4 and Sree Athulya of long duration, planted in May, October and December to variations in environmental conditions. In experiment II, the effect of foliar application of potassium, silicon and calcium along with major nutrients on short duration variety Vellayani Hraswa grown under drought stress was investigated in two years, *viz.*, 2015-16 and 2016-17. The experiments were laid out in randomized block design, with net plot size of 5.4 m x 5.4 m and three replications. The crops were raised as per the package of practice recommendation of Kerala Agricultural University (KAU, 2011).

In experiment I, the crops were grown under rainfed condition and were thus subjected to varying temperature, precipitation and solar radiation during the period of study. May planted crops received a total rainfall of 2450.37 mm, whereas October and December planted crops received rainfall amount of 2013.4 mm and 1781.7mm respectively.

Considering the general growth habit, May and October planted crops recorded considerable greater growth compared to the December planted one. Progressive increase in plant height was observed during all the three planting seasons, with May planted varieties outperforming the other two plantings. Among the varieties, Sree Athulya a normal-duration variety and Sree Vijaya a short-duration variety were significantly taller. Leaf retention and number of leaves fallen were less for Sree Athulya planted in December planting season compared to other seasons. Among normal-duration varieties, M_4 was seen to produce greater number of leaves than Sree Athulya throughout the growing period, whereas short-duration

varieties Sree Vijaya and Vellayani Hraswa recorded more number of leaves only towards later stages. Values of physiological parameters were higher in May and October planted crops with high stomatal conductance and photosynthetic activity. Sree Athulya variety recorded higher crop growth rate for all the plantings. Cyanogenic glucoside content and bitterness of varieties were found to progressively increase in tubers from May to October to December plantings. For all seasons, higher yield, tuber length and girth, number of tubers and mean yield per plant were in May. Normal-duration variety Sree Athulya recorded significantly higher tuber length, tuber girth, number of tubers per plant and mean tuber weight per plant, which added to significantly greater yield per plant by the variety. Among the varieties, Sree Athulya recorded significantly higher yields followed by M_4 and Sree Vijaya for all seasons, while Vellayani Hraswa recorded significantly lower yield.

Sree Athulya recorded higher B:C ratio of 3.67 and 2.37 when planted in May and December plantings respectively. However, short duration variety Sree Vijaya was more profitable when planted in October.

Correlation between yield and weather parameters suggested that yield influencing weather parameters at early crop establishment period were maximum temperature, minimum temperature, rainfall and relative humidity. Reduced maximum and minimum temperature, high rainfall and high relative humidity were seen to be desirable.

The results placed Sree Vijaya and M_4 as the most promising varieties for moisture stressed conditions followed by Sree Athulya. Even though Sree Athulya was drought tolerant and produced highest yield, qualitatively it could be regarded as only the second ordered variety since it cannot be used for edible purpose.

In experiment II, field experiments were conducted with 10 treatments. The treatments consisted of the recommended package of practices (POP) for nutrients, POP along with KCl, $CaCl_2$ and silicic acid separately and in combinations. Controls included POP with water spray and water spray alone. The total precipitation during 2015-16 was recorded to be 514.1mm. The 2016-17 cropping season experienced extreme dry condition with monthly rainfall of only 136.3 mm during the entire cropping period.

Pooled analysis of data showed that combined application of nutrients as per package of practices along with KCl + $CaCl_2$ + silicic acid (T_8) had significant positive impact on plant height, leaf retention, root length, stomatal conductance, photosynthetic activity and relative leaf water content. Significantly higher HCN content in tubers was recorded in 2016-17 compared to 2015-16.

The above treatment combination also resulted in significantly higher tuber girth, number of tubers, mean tuber weight and yield per hectare in 2015-16. Generally, yield of crop was comparatively low during 2016-17 cropping period due to insufficient rain. However, POP+ KCl + $CaCl_2$ along with POP + KCl + silicic acid and POP + KCl + silicic acid + $CaCl_2$ recorded higher fresh tuber yield. Tuber girth was highest in the treatment POP + KCl + silicic acid + $CaCl_2$.

Combination of all three nutrients along with recommended doses of N, P and K resulted in significant increase in the total uptake of primary and secondary nutrients compared to control. However nutrient uptake was limited in 2016-17.

In general, foliar application of chemical treatments along with recommended package of practices were found to have a significant positive influence on cassava even under low rainfall conditions.