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Photosynthesis, Dry Matter Production and Partitioning in Cassava (*Manihot esculenta* Crantz) Under Partial Shade of a Coconut Plantation

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Abstract

Photosynthetic rate of cassava (*Manihot esculenta* Crantz) varieties showed variation under partial shade of a coconut plantation at Coconut Research Station, Bhubaneswar, Odisha, India. The varieties, Sree Jaya, Sree Prakash, Sree Vijaya and H-165 had greater photosynthetic rate during the early crop growth period of 2 and 4 months after planting (MAP), which decreased later. Decrease in intercellular CO_2 concentrations was observed during the later crop growth period in the above varieties. The intercellular CO_2 concentrations had influenced the photosynthetic rate. Transpiration rate was observed to be maximum at 4 and 6 MAP when the crop was in the active growth period. Photosynthetic rate, intercellular CO_2 concentrations and transpiration rate decreased with decrease in stomatal conductance. Among the varieties, Sree Jaya and H-165 showed higher dry matter production and partitioning to the tubers. Higher dry matter accumulation in shoot than in the tuber was observed in the varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham. The photosynthetic rate exhibited strong and positive correlation with tuber bulking rate. Higher tuber yield was observed in Sree Jaya and H-165 due to more number of tubers per plant and tuber girth apart from greater biomass accumulation under partial shade.

Key words: Cassava, photosynthetic rate, transpiration rate, stomatal conductance, yield

Introduction

Cassava (*Manihot esculenta* Crantz) is grown for its starchy roots. It provides 50% of the calorie need of 420 million people in 27 countries (Hahn, 1979). It is a subsistence crop as well as staple food, serves as animal feed and an industrial raw material supporting starch based industries. In India it is mostly grown in Southern Peninsular region covering Kerala, Tamil Nadu and Andhra Pradesh. It is gaining importance as an industrial crop in the West, East and North-eastern states of India. Cassava has the potential to produce maximum dry matter (250 x 10^3 cal ha^{-1} day^{-1}) and has the ability to adapt to a wide range of climate and soil (Nedunchezhiyan and Mohanty, 2005). It is an ideal intercrop in the coconut plantations of South India (Nayar and Suja, 2004), Sri Lanka and Philippines (Liyanage and Dassanayake, 1993).

Photosynthetic performance of higher plants could be used for prediction of the plant productivity (Leegood and Walker, 1985; Paul and Foyer, 2001). Seed number in most of the cereal crops is a function of the rate of photosynthesis during yield forming critical period (Egli and Yu, 1991). High photosynthetic rate increases seed number per plant in maize, sunflower and soybean (Vega et al., 2001). Difference in photosynthetic rate agreed well with the difference in the growth parameter as well as dry matter production in potato (Fujita et al., 2004). However, Usuda (2003) could not find clear-cut relationship between the rate of photosynthesis and biomass of plants. In intercropping situation, shading effect of one crop on the other has been reported widely. Low availability of photosynthetically active radiation (PAR) reduces photosynthesis of the bottom storey crop. Rate of photosynthesis has direct bearing on dry matter production. In maize + sweet potato intercropping system, shade of maize plants caused poor development of root system in sweet potato (Amede and Nigatu, 2001). Jena and Misera (1988) also reported similar findings in pigeonpea + rice intercropping. Though reduced photosynthetic rate and other physiological yield attributing characteristics at low light intensity has been widely reported in various field crops, few studies have been conducted in cassava to elucidate dry matter production and partitioning under partial shaded conditions. Hence, the objective of the present investigation was to characterize photosynthesis and dry matter production and partitioning in cassava varieties under partial shade as existing in a coconut plantation.

Materials and Methods

A field experiment was conducted for three consecutive years from 2003-2004 to 2005-2006 at Coconut Research Station, Shakigopal, Bhubaneswar, India, under rainfed conditions. Nine cassava varieties (H-165, Meg-36, Sree Prakash, Sree Jaya, Sree Vijaya, H-226, Sree Visakham, H-97 and M-4) were tested in Randomized Block Design with three replications. The coconut palms were spaced at 7.5 x 7.5 m (178 plants ha^{-1}) and the age of the trees was 30 to 33 years.

The soil of the experimental site was sandy loam with pH 7.2. The initial soil nutrient status was as follows: available N 296 kg ha^{-1}, available P 18.8 kg $ha^{-1}$and available K 162 kg ha^{-1}. The average annual rainfall was 1450 mm, while 75% of this was received between June and September in all the years of study. The average maximum temperature varied between 29.0 and 39.0ºC, whereas the average minimum temperature varied between 15.0 and 27.0ºC. The maximum rainfall was received during July and August. Mostly, dry weather prevailed during November to April in all the years of study. The mean relative humidity during the wet and dry seasons were >80% and <70% respectively (Fig.1). The average PAR reaching the ground surface was 700 - 900 µmol m^{-2} s^{-1} (50-60% of the total). The gross plot size was 7.2 x 7.2 m. Each treatment consisted of one coconut palm and 55 cassava plants (9790 plants ha^{-1}). Leaving 7.29 m^2 area around the basin of the coconut palm, 15-20 cm long cassava setts were planted on top of the mounds around the coconut palm at 90 x 90 cm spacing during June every year. The cassava varieties were planted in the same fixed plots for three years. FYM @ 12.5 t ha^{-1} and NPK @ 75:50:75 kg ha^{-1} were applied to cassava. Full P was applied along with FYM before planting. N and K were applied in two equal splits at the time of planting and 60 days after planting. The recommended nutrient dose of 0.5 kg N, 0.32 kg P and 1.2 kg K was applied per palm in two equal split doses. First dose was applied in the month of June and the second dose was applied in the month of September. Cassava was harvested 10 months after planting.

A portable open gas exchange measuring system (LCA-4, ADC, Herts, UK) was used for rapid simultaneous determination of photosynthetic rate, stomatal conductance, internal CO_2 concentration and transpiration rate. All leaf gas exchange measurements were made between 10.00 – 12.00 h (IST) on sunny and cloud free days throughout the experimental period. For measuring photosynthetic characters, portable leaf chamber (model PLC-4 B, ADC, Herts, UK) was clipped onto the leaf, without disturbing the position of leaf. Atmospheric air drawn from 3 m height through telescopic mast was flown through the leaf chamber in order to avoid fluctuations in CO_2 concentration of the ambient air, which would otherwise arise due to the addition of respired CO_2 by the researcher (s) at the time of measurement. When readings became stable after clipping the chamber on the selected leaf then the read outs were recorded. Measurements were taken from the 3rd and 5th fully open leaf from the top from representative plants in each treatment at 2, 4, 6 and 8 months after planting (MAP). At harvest, observation was not recorded as the plants retained very few leaves. Pattern of dry matter production and partitioning was studied at 2, 4, 6, 8 and 10 MAP (harvest) by standard procedures.

Results and Discussion

Photosynthesis

Photosynthetic rate measured in the youngest fully expanded leaves (3rd and 5th) of cassava showed variation among the varieties under partial shaded conditions during the crop growth period (Table 1). The varieties, Sree Jaya, Sree Prakash, Sree Vijaya and H-165 showed greater photosynthetic rate during the early crop growth period of 2 and 4 MAP, which decreased during the later part of the crop growth period. However, the varieties, M-4, Meg-36, H-226 and H-97 showed higher rates at mid growth phase (6 MAP). A perusal of data on intercellular CO_2 concentrations presented in Table 2 revealed that the intercellular CO_2 concentration in Sree Jaya, Sree Prakash, Sree Vijaya and H-165 was lower at later stage of the crop growth compared to other varieties. In general, more intercellular CO_2 concentrations were noticed in all the varieties studied at early stages. Stomatal conductance also showed similar trends as that of photosynthetic rate and intercellular CO_2 concentrations. The varieties, Sree Jaya, Sree Prakash, Sree Vijaya and H-165 had higher stomatal conductance during the early crop growth period which decreased with the age (Table 3).

Rate of photosynthesis determines the rate of dry matter accumulation in the various plant parts. Under partial shade as existing in a coconut plantation, where PAR of 700 – 900 µmol m^{-2} s^{-1} (50 - 60% of the total PAR) reached the ground surface, the photosynthetic rate of cassava varied between 7 and 15 CO_2 µmol m^{-2} s^{-1}. However the varieties exhibited considerable differences at various growth periods. The varieties, Sree Jaya, Sree Prakash, Sree Vijaya and H-165 maintained higher photosynthetic rate during the early crop growth period due to higher intercellular CO_2 concentrations. The intercellular CO_2 concentration in Sree Jaya, Sree Prakash, Sree Vijaya and H-165 was low at later period

Table 1. Photosynthetic rate of cassava varieties at various stages (mean of 3 years)

Variety	Photosynthetic rate (CO_2 µmol m^{-2} s^{-1})			
	2 MAP	4 MAP	6 MAP	8 MAP
H-165	12.61 ± 0.91	11.99 ± 1.12	11.20 ± 1.05	8.23 ± 0.86
Sree Prakash	11.94 ± 0.84	12.76 ± 1.09	10.28 ± 1.16	7.01 ± 0.68
Sree Jaya	13.31 ± 1.12	11.78 ± 1.06	10.88 ± 1.28	8.63 ± 1.07
Sree Vijaya	12.58 ± 1.23	11.85 ± 1.17	10.91 ± 1.12	7.67 ± 0.94
Sree Visakham	10.87 ± 1.08	12.14 ± 1.08	11.32 ± 1.31	10.76 ± 0.96
H-97	11.45 ± 0.99	12.72 ± 1.17	13.81 ± 1.22	11.75 ± 1.07
H-226	10.58 ± 0.77	10.73 ± 1.01	14.99 ± 0.96	11.42 ± 1.25
Meg-36	11.36 ± 1.08	10.31 ± 0.92	16.06 ± 0.99	10.94 ± 0.95
M-4	11.00 ± 1.41	11.06 ± 0.99	15.06 ± 1.28	12.98 ± 1.08

± Standard deviation

Table 2. Internal CO_2 concentration of cassava varieties at various stages (mean of 3 years)

Variety	Internal CO_2 concentration (µmol mol^{-1})			
	2 MAP	4 MAP	6 MAP	8 MAP
H-165	283.4 ± 14.2	260.1 ± 23.1	288.4 ± 33.6	183.3 ± 22.3
Sree Prakash	303.5 ± 17.1	264.9 ± 23.5	260.6 ± 24.3	193.4 ± 12.6
Sree Jaya	300.8 ±13.8	260.9 ± 18.9	257.8 ± 28.9	193.2 ± 32.8
Sree Vijaya	298.1 ± 18.5	261.0 ± 14.1	276.1 ± 33.4	182.9 ± 28.3
Sree Visakham	284.4 ± 14.6	264.4 ± 22.8	292.2 ± 23.7	229.1 ± 22.9
H-97	290.0 ± 13.6	269.5 ± 20.3	272.2 ± 22.6	217.4 ± 23.0
H-226	301.9 ± 19.7	256.8 ± 16.1	234.3 ± 33.3	254.4 ± 22.8
Meg-36	302.2 ± 13.9	248.2 ± 14.0	230.7 ± 13.8	222.1 ± 20.7
M-4	306.2 ± 20.1	262.2 ± 24.1	234.7 ± 23.7	235.5 ± 18.2

± Standard deviation

Table 3. Stomatal conductance of cassava varieties at various stages (mean of 3 years)

Variety	Stomatal conductance (mol m^{-2} s^{-1})			
	2 MAP	4 MAP	6 MAP	8 MAP
H-165	16.21 ± 1.42	16.29 ± 1.26	13.87 ± 1.16	11.18 ± 1.04
Sree Prakash	18.07 ± 1.61	22.67 ± 1.49	13.72 ± 1.16	11.80 ± 1.00
Sree Jaya	17.01 ± 1.22	15.61 ± 1.22	12.25 ± 1.27	15.86 ± 1.49
Sree Vijaya	16.00 ± 1.37	14.77 ± 1.06	14.40 ± 1.68	12.91 ± 1.12
Sree Visakham	21.89 ± 0.98	23.00 ± 1.59	22.24 ± 1.72	17.95 ± 1.37
H-97	21.67 ± 1.35	22.12 ± 1.53	23.11 ± 1.44	18.71 ± 1.42
H-226	22.51 ± 1.22	23.87 ± 1.41	23.62 ± 1.67	19.29 ± 1.39
Meg-36	20.17 ± 0.97	23.88 ± 1.47	23.28 ± 1.52	18.81 ± 1.53
M-4	20.49 ± 1.14	23.74 ± 1.23	23.96 ± 1.88	18.83 ± 1.46

± Standard deviation

of crop growth, which might be one of the reasons for lower photosynthesis. Thus, the intercellular CO_2 concentrations were found to influence the photosynthetic rate. Stomatal conductance and stomatal resistance also influences photosynthesis as the stomatal movements regulate intercellular CO_2 concentrations (Kubota et al., 1994). The varieties, Sree Jaya, Sree Prakash, Sree Vijaya and H-165 maintained lower stomatal conductance than the other varieties at later stages. However, irrespective of varieties, low stomatal conductance was observed at later stages of the crop growth (Table 3). This was due to prevalence of dry weather at later stages of the crop growth (Fig. 1).

Though transpiration rate has direct relation with the stomatal conductance, at early stage (2 MAP), lower transpiration rate was observed in all the varieties (Table 4). The maximum transpiration rate was observed at 4 and 6 MAP. The varieties M-4, Meg-36, H-226, H-97 and Sree Visakham had greater transpiration rate compared to Sree Jaya, Sree Prakash, Sree Vijaya and H-165 at later period (8 MAP). Decrease in stomatal conductance was reported in cassava leaves under water deficit stress (WDS) conditions (Cayon et al., 1997; Ravi and Saravanan, 2001). The lower stomatal conductance under water deficit stress conditions indicated partial closure of stomata. Higher stomatal conductance leads to higher photosynthetic and transpiration rates (Ravi and Saravanan, 2001). Eckstein and Robinson (1995) observed a highly significant correlation between photosynthetic rate and stomatal conductance. The maximum transpiration rate was observed between 4 and 6 MAP in all the varieties due to active crop growth.

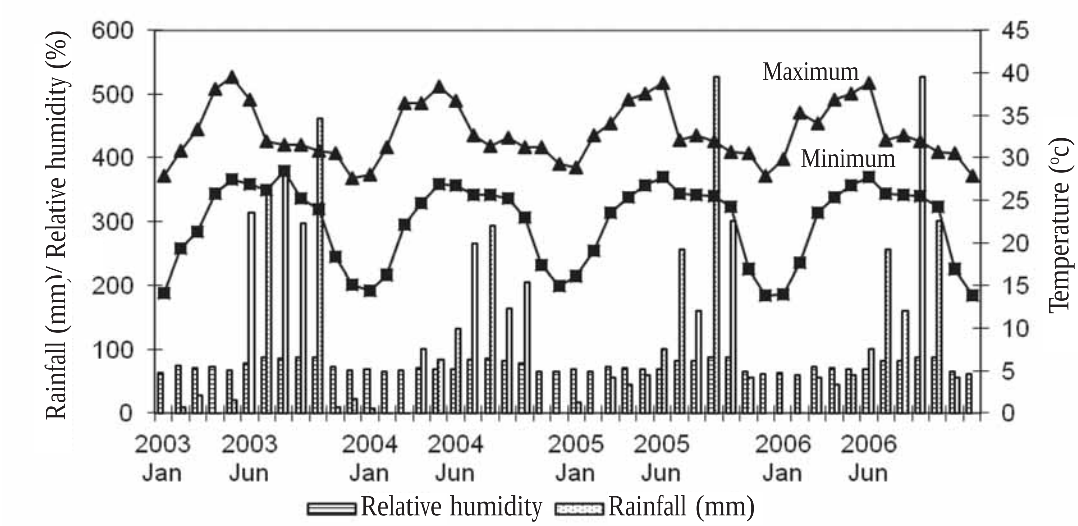

Fig.1. Weather parameters during the crop growth period (2003-2006)

Table 4. Transpiration rate of cassava varieties at various stages (mean of 3 years)

Variety	Transpiration rate (mol m^{-2} s^{-1})			
	2 MAP	4 MAP	6 MAP	8 MAP
H-165	0.90 ± 0.02	1.76 ± 0.16	1.41 ± 0.09	0.90 ± 0.07
Sree Prakash	1.06 ± 0.06	1.66 ± 0.05	1.35 ± 0.12	0.74 ± 0.03
Sree Jaya	0.94 ± 0.04	1.76 ± 0.12	1.36 ± 0.09	0.80 ± 0.06
Sree Vijaya	0.93 ± 0.08	1.84 ± 0.17	1.36 ± 0.15	0.72 ± 0.09
Sree Visakham	0.97 ± 0.07	1.58 ± 0.06	1.35 ± 0.14	1.00 ± 0.08
H-97	0.92 ± 0.04	1.41 ± 0.09	1.40 ± 0.16	1.19 ± 0.11
H-226	0.87 ± 0.06	1.66 ± 0.15	1.45 ± 0.09	1.02 ± 0.06
Meg-36	0.74 ± 0.09	1.62 ± 0.09	1.41 ± 0.08	1.14 ± 0.09
M-4	0.67 ± 0.08	1.53 ± 0.08	1.33 ± 0.12	1.16 ± 0.11

± Standard deviation

During this period leaf area development was maximum (Table 6) and the soil rhizosphere was congenial for crop growth due to monsoon rains (Fig. 1). Higher stomatal conductance even in the dry period (later stages) in the varieties M-4, Meg-36, H-226, H-97 and Sree Visakham maintained higher intercellular CO_2 concentrations, which caused higher photosynthetic rate along with higher transpiration rate. This might be due to the genetic character of these varieties.

Growth and dry matter production

The growth response of cassava varieties indicated that plant height (Table 5) and number of leaves per plant differed significantly (Table 6). Except at 2 MAP, the variety M-4 was taller throughout the crop growth followed by the varieties H-97 and Sree Visakham. The varieties, Sree Prakash, H-165, Sree Jaya and Sree Vijaya were short statured. The varieties, M-4, Meg-36, H-226, H-97 and Sree Visakham retained more number of leaves between 4 and 10 MAP. In general, leaf production increased drastically up to 6 MAP and thereafter declined due to water deficit stress (Fig. 1). Under water deficit stress conditions, the foliage weight of cassava decreased drastically (Ravi and Saravanan, 2001).

The rate of dry matter production increased up to 6 MAP and then remained static in all the varieties (Fig. 2). The varieties, Sree Jaya, Sree Vijaya and H-165 produced higher rate of dry matter during the initial six months than the varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham. But after six months, the rate of dry matter accumulation was greater in the varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham compared to Sree Jaya, Sree Vijaya and H-165, though the rate of increase was little. This showed that the varieties, Sree Jaya, Sree Vijaya and H-165 produced maximum dry matter at early crop growth period. Short duration varieties have greater early biomass production rate (Sreekumari and Abraham, 1991; Suja et al., 2010). The short duration varieties utilized the prevailing favourable agro-climatic conditions efficiently to produce higher biomass (Nedunchezhiyan and Naskar, 2004; Suja et al., 2011). The total biomass accumulation per plant varied between 115.7 and 148.9 g at 2 MAP, 333.8 and 449.8 g at 4 MAP, 571.3 and 750.6 g at 6 MAP, 660.9 and 832.4 g at 8 MAP and between 732.0 and 871.1 g at 10 MAP among the varieties. The dry matter accumulation of all the varieties increased with the crop age.

Table 5. Plant height of cassava varieties at various stages (mean of 3 years)

Variety	Plant height (cm)				
	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP
H-165	33	129	175	180	182
Sree Prakash	30	142	157	165	175
Sree Jaya	28	136	160	176	182
Sree Vijaya	26	155	167	179	185
Sree Visakham	28	162	196	210	237
H-97	36	125	206	228	247
H-226	31	135	158	180	197
Meg-36	36	154	175	196	212
M-4	25	185	220	244	265
CD (0.05)	4	11	14	21	18

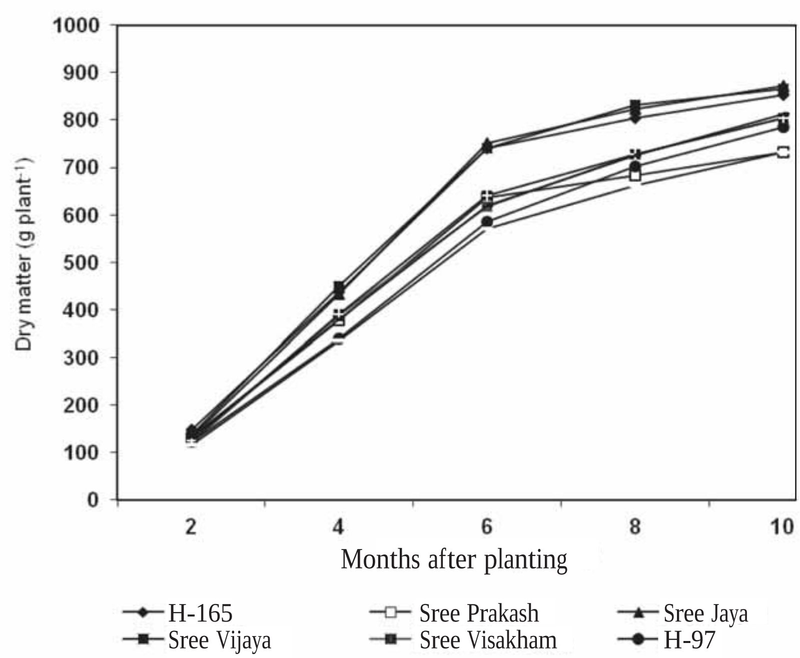

Fig. 2. Phasic pattern of total dry matter production in cassava varieties

However the rate of total dry matter accumulation between 8 and 10 MAP was minimum. The variety, H-165 accumulated maximum dry matter of 148.9 g plant^{-1} at 2 MAP, while the variety, Sree Vijaya, being the second highest, accumulated 136.8 g plant^{-1}. At 4 MAP, Sree Vijaya produced maximum dry matter of 449.8 g plant^{-1}, while the variety, H-165 produced 436.5 g plant^{-1}. At 6 MAP, Sree Jaya and Sree Vijaya produced higher dry matter of 750.6 and 740.8 g plant^{-1}, respectively. At 8 MAP, Sree Vijaya produced highest dry matter (832.4 g plant^{-1}) followed by Sree Jaya, which produced 822.8 g plant^{-1}. At harvest (10 MAP), the maximum total dry matter production was observed in Sree Jaya (871.1 g plant^{-1}) followed by Sree Vijaya (866.7 g plant^{-1}) under partial shaded conditions of a coconut plantation (Fig. 2). This was due to maximum dry matter accumulation in tubers (Fig. 3) when weather conditions were favorable (Fig. 1). The variety, Sree Prakash produced the lowest biomass throughout the crop growth period (115.7, 333.8, 571.3, 660.9 and 732.0 g plant^{-1} at 2, 4, 6, 8, and 10 MAP, respectively). The long duration varieties have late and long period of bulking. In the present investigation, active bulking of Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham coincided with the dry period, hence biomass accumulation was reduced. Sreekumari and Abraham (1991) and Roberts-Nkrumah et al. (1995) observed distinct genotypic variations in total dry matter production under shade in cassava and sweet potato, respectively.

Table 6. Leaf production of cassava varieties at various stages (mean of 3 years)

Variety	Number of leaves retained per plant				
	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP
H-165	23	60	86	62	45
Sree Prakash	15	57	80	55	35
Sree Jaya	10	46	84	58	51
Sree Vijaya	11	76	86	56	52
Sree Visakham	14	60	92	96	60
H-97	16	56	94	88	57
H-226	11	69	90	83	54
Meg-36	13	72	96	80	46
M-4	10	62	94	92	54
CD (0.05)	2	6	8	7	6

The distribution of dry matter was maximum in the stem (>60%) at 2 MAP (Fig. 3). However, at later crop growth period with the increase in tuber dry matter accumulation, the stem dry matter accumulation was found to be 50%. The leaf dry matter accumulation ranged between 10 and 15% during the first 6 MAP and later decreased to less than 10%. The dry matter accumulation in leaves was lower than in stems and tubers throughout the crop growth period (Fig. 3). In varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham, dry matter accumulation in stem was observed to be higher throughout the crop growth period (Fig. 3), whereas in varieties Sree Jaya, Sree Vijaya and H-165, dry matter accumulation was observed to be greater in tubers, except at 2 MAP. At harvest, higher shoot dry biomass than tuber dry biomass was observed in the varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham, whereas higher tuber dry biomass than shoot biomass was found in Sree Jaya, Sree Vijaya and H-165. The highest shoot dry

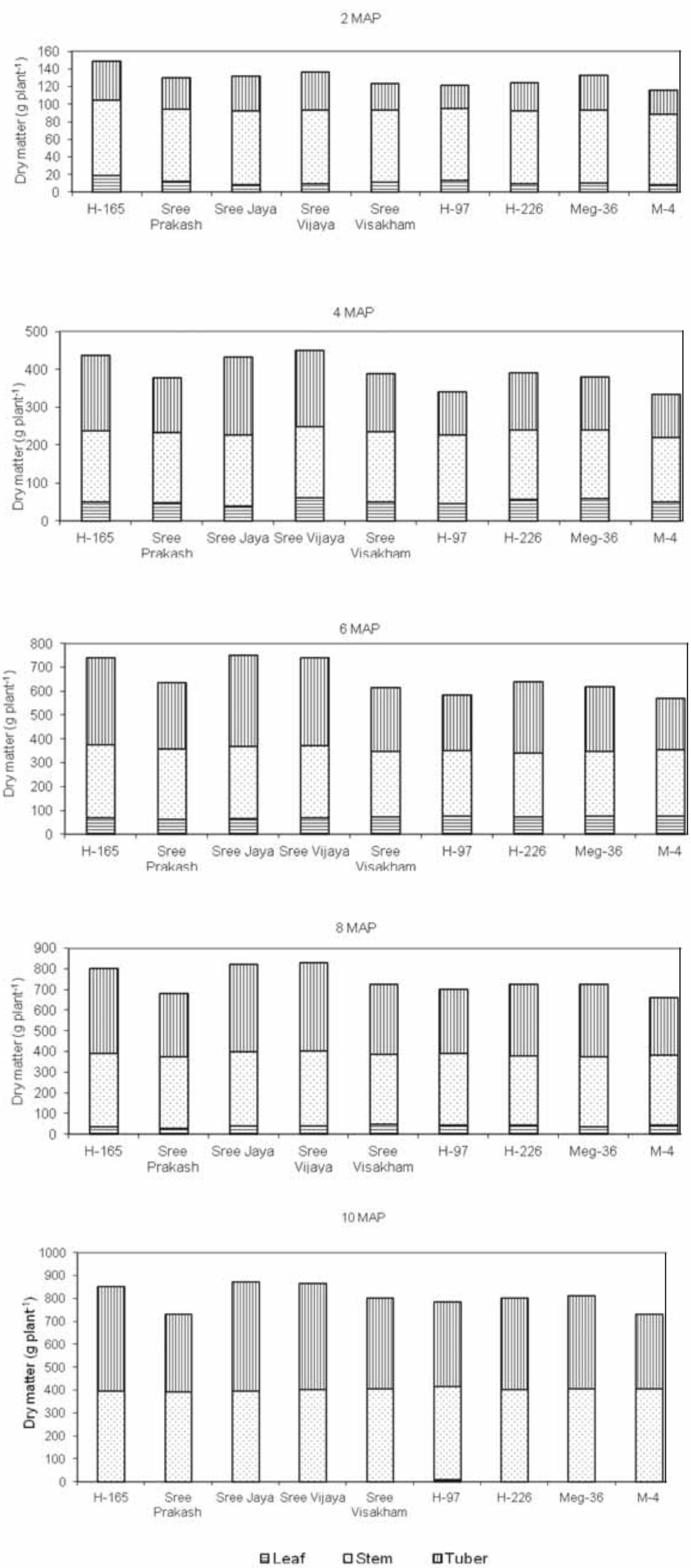

Fig. 3. Dry matter distribution pattern in cassava varieties during crop growth period

matter (53.2%) was noticed in H-97, whereas the highest tuber dry matter (54.5%) was observed in Sree Jaya. Early tuber bulking and high dry matter partitioning efficiency leads to greater dry matter accumulation in tubers irrespective of foliage development. However, in spite of greater shoot dry weight in the varieties, Sree Prakash, M-4, Meg-36, H-226, H-97 and Sree Visakham, lower biomass was accumulated in tubers due to poor partitioning efficiency and late bulking which coincided with dry period. Tuber yield was reported to have no significant correlation with leaf area (Ramanujam, 1990). Greater production of foliage has been reported not to imply a greater root yield (Ramanujam, 1990; De Tafur et al., 1997). Reduction in leaf production during dry period was a major limiting factor in attaining maximum yield as the dry period coincided with the tuber-bulking phase. The present study also revealed that the degree of leaf shedding and tuber bulking phase varied among cassava varieties.

Tuber yield

Significant variation in yield attributes and yield was observed among the varieties tested (Table 7). The variety, Sree Jaya produced significantly greater number of tubers per plant. This was followed by the varieties, H-165 and Sree Vijaya. The variety, M-4 produced the lowest number of tubers per plant. The varieties, Sree Visakham, H-97 and H-226 produced greater number of tubers per plant than M-4. The longest tubers were observed in the varieties, H-97 and Sree Visakham. The variety, H-165 produced small, globular tubers. The variety, H-165 and Sree Jaya produced tubers with maximum girth. The tuber girth of M-4, H-97 and Sree Visakham was lowest and almost the same. The variety, Sree Jaya produced maximum tuber yield at harvest followed by H-165. The variety, Sree Jaya produced 36.3, 21.2,

Table 7. Yield attributes and yield of cassava varieties intercropped in coconut garden (mean of 3 years)

Variety	No. of tubers per plant	Tuber length (cm)	Tuber girth (cm)	Tuber yield	
				g plant^{-1}	t ha^{-1}
H-165	6	21.7	10.8	1405	13.76
Sree Prakash	6	23.1	10.1	1250	12.24
Sree Jaya	7	22.6	10.6	1418	13.88
Sree Vijaya	6	22.8	10.6	1350	34.27
Sree Visakham	6	23.7	9.7	1170	11.45
H-97	6	23.9	9.7	1190	11.65
H-226	6	23.6	9.9	1275	12.48
Meg-36	6	23.4	10.2	1340	13.12
M-4	5	23.6	9.2	1040	10.19
CD (0.05)	0.4	1.8	0.6	104	1.018

19.2, 13.4 and 11.2% higher yield than the varieties, M-4, Sree Visakham, H-97, Sree Prakash and H-226, respectively. The variety, H-165 produced 35.1, 20.1, 18.1, 12.4 and 9.3% higher yield than the variety M-4, H-1687, H-97, Sree Prakash and H-226, respectively. M-4 produced the lowest yield per plant. The tuber yields of H-97 and Sree Visakham were greater than M-4. Higher yield in Sree Jaya and H-165 might be due to more number of tubers per plant and mean tuber girth (Table 7). Tuber yield was strongly and positively correlated with the number of tubers per plant (Suthanthirapandian et al., 1994) and tuber girth (Rekha et al., 1991). The varieties having early tuber bulking produced greater yield (Nedunchezhiyan and Naskar, 2004; Suja et al., 2010). Rekha et al. (1991) reported that tuber length was not significantly correlated with yield. The variety, M-4 produced the lowest tuber yield due to lower yield attributing factors.

Increase in dry matter partitioning to tubers is presumably attributed to increase in photosynthetic rate (Oswald et al., 1994; 1996). Under shaded conditions, varieties with greater tuber production (sink capacity) and lesser shoot growth showed lesser reduction in tuber yield, whereas varieties with greater shoot growth relative to their tuber production showed greater reduction in tuber yield (Oswald et al., 1994). Because varieties with greater tuber production and lesser shoot growth develop a rather small shoot system, yield increase in low irradiance can only be achieved by an improved photosynthetic rate per unit leaf area. The photosynthetic rate exhibited strong and positive correlation with tuber bulking rate. The photosynthetic rate at 2 MAP was significantly correlated ($P = 0.01$) with tuber bulking rate at 2, 4 and 6 MAP, whereas photosynthetic rate at 4 and 8 MAP was significantly correlated ($P = 0.05$) with tuber bulking rate at 4 and 8 MAP, respectively (Table 8).

The onset of tuber bulking varied among the varieties studied. A steep fall in tuber bulking rate coincided with leaf shedding. The comparatively high leaf retention

Table 8. Correlation coefficients (r values) between photosynthetic rate and tuber bulking rate

Photosynthetic rate (CO_2 µmol m^{-2} s^{-1})	Tuber bulking rate (g day^{-1} plant^{-1}, dry weight basis)				
	2 MAP	4 MAP	6 MAP	8 MAP	10 MAP
2 MAP	0.7595**	0.7985**	0.9130**	-0.4839	-0.4222
4 MAP		0.6579*	0.5559	-0.3083	-0.1899
6 MAP			0.5013	-0.2350	-0.0677
8 MAP				0.6534*	0.7422**

* Significant at $P = 0.05$; ** Significant at $P = 0.01$

capacity might have increased the photosynthetic efficiency thereby enabling tuber bulking at an early period (Sreekumari and Abraham, 2001). The rate of tuber bulking varied with varieties (Sreekumari and Abraham, 1991), environment and plant growth period (Bhagsari and Harmon, 1982).

Conclusion

The present study revealed that the varieties, Sree Jaya and H-165 can be recommended as intercrops under partial shade of coconut gardens in sub humid eastern India due to their greater production potential.

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