Dry matter production and accumulation in arrowroot (*Maranta arundinacea* L.) when intercropped with coconut

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A field experiment was conducted during the *monsoon* seasons of 1995–96 and 1996–97 to assess the effect of different agronomic practices on dry matter (DM) production and accumulation and yield of arrowroot (*Maranta arundinacea* L.) when grown as an intercrop in a coconut garden. Dry matter production, accumulation, and fresh rhizome yield did not differ significantly at 15–20 g or 25–30 g sizes. The total DM production per plant was significantly higher at 111 000 ha^{-1} but the fresh rhizome yield was on par at 166 000 ha^{-1}. Among organic manures, the total DM production was higher under farmyard manure (FYM) + NPK which resulted in higher fresh rhizome yield. Vermicompost at both the levels also recorded significantly higher yield compared with FYM and composted coir pith applied alone, and NPK alone. Dry matter production and yield were significantly lower under the control treatment.

Keywords: Coconut; Arrowroot; Intercropping; Farmyard manure; Vermicompost; Composted coir pith

In India, increasing the area under cultivation is difficult and intensive cultivation of crops and raising the productivity per unit area are the only means of increasing food production. Because of the long gestation period of coconut, inter- and (or) mixed-cropping is economically feasible. Studies on land and solar energy utilisation in intensive coconut production revealed its ability to harness unutilised space, solar energy, and other resources. Studies conducted at the Central Plantation Crops Research Institute (CPCRI), Kerala, India, and elsewhere, have shown the suitability and economic viability of growing various mixed crops in a coconut garden.

As a result of increased health consciousness of people in general, and the carcinogenic hazards of synthetic drugs, there is an enhanced demand for the products of medicinal plants. However, as their availability from natural resources is limited, there is need for these crops in existing cropping systems with the appropriate agro-techniques. Of the different medicinal crops, arrowroot (*Maranta arundinacea* L.) grows well under shade. It is an erect, perennial herb belonging to the family Marantaceae. It is indigenous to Tropical America and widely distributed throughout the tropical countries like India, Sri Lanka, Indonesia, Philippines, Australia, and the West Indies. The economic part is the rhizome, which is used for the production of starch.

Research conducted on agro-techniques for the sustainable production of this crop is scanty, hence, a study was conducted to determine the influence of agronomic practices on dry matter (DM) production and accumulation in the different parts of arrowroot and its economic yield.

Materials and Methods

The field experiment was conducted during the *monsoon* seasons of 1995–96 and 1996–97 at CPCRI, Kasaragod, Kerala, India, which is situated at 12°30′ N latitude and 75°00′ E longitude at an elevation of 10.7 m above mean sea level.

An average annual rainfall of 3401 mm is received at CPCRI, Kasaragod. Of the total rainfall, 75% is received during the months of June to August. The maximum temperature ranges between 28.8°C and 32.4°C and minimum temperature between 19.4°C and 24.2°C. The relative humidity ranges between 81 and 94%. Maximum evaporation is recorded during the months of March and May. Maximum daily bright sunshine hours are recorded during September and May.

The soil of the experimental site was a red sandy loam with coarse sand varying from 75.6–77.6%, fine sand 4.0–4.6%, silt 3.0–3.8%, and clay 14.8–16.6%. The field capacity

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values of the soil for the 0–25 cm and 25–50 cm depths were 7.40 and 8.95%, respectively. The permanent wilting per cent values were 4.2 and 4.4, respectively, for the two depths. The bulk density of the soil in the 0–25 and 25–50 cm depths were 1.55 and 1.45 g mL^{-1}, respectively. The porosity of the soil was 41.5 to 45.3%. The soil was slightly acidic (pH, 5.0–5.2) with an electrical conductivity of 0.04 dS m^{-1} at 25°C. The soil was low in available N, available K, and high in available P. The organic C content of the soil was low (0.21% at the 0–25 cm depth and 0.18% at the 25–50 cm depth) with a cation exchange capacity (CEC) of 3.5 cmol (P^+) kg^{-1} soil.

Experimental procedures

The experiment was laid out in a split-plot design, replicated thrice. Main plot treatments were (a) size of planting materials: S_1 (15–20 g) and S_2 (25–30 g) and (b) plant population levels: 111 000 ha^{-1} (30 cm × 30 cm) and 166 000 ha^{-1} (30 cm × 20 cm). The sub-plot treatments were: F_1, farmyard manure (FYM) at 26 t ha^{-1}; F_2, FYM at 34 t ha^{-1}; F_3, composted coir pith (CCP) at 32 t ha^{-1}; F_4, CCP at 42 t ha^{-1}; F_5, vermicompost (VC) at 22 t ha^{-1}; F_6, VC at 30 t ha^{-1}; F_7, recommended organic manure (FYM at 20 t ha^{-1}) + NPK (75:50:50 kg ha^{-1}); F_8, recommended NPK alone (75:50:50 kg ha^{-1}); and F_9, control.

The sub-plot size was 30 m × 1.8 m (gross plot) and 2.4 m × 1.2 m (net plot). In 1995–96, the crop was planted during the second week of June and during 1996–97, it was planted during the third week of May. The respective harvesting dates were the second week of April and the fourth week of March.

Growth analysis and chlorophyll and carotenoid estimation

The crop growth rate (CGR) was calculated according to Watson (1952):

$$CGR = (W_2 - W_1)/(t_2 - t_1) \times 1/P$$

where CGR = mean crop growth rate (g cm^{-2} day^{-1}); W_1, W_2 = dry matter production (g) at time t_1 and t_2, respectively; and P = ground area covered by the plant (cm^2).

The absolute growth rate (AGR) was calculated according to West *et al.* (1920):

$$AGR = (W_2 - W_1)/(t_2 - t_1)$$

where AGR = mean absolute growth rate (g $plant^{-1}$ day^{-1}) and W_1 and W_2 = dry matter production (g) at time t_1 and t_2, respectively.

The harvest index (HI) was calculated as the ratio of the economic yield to the biological yield.

$$HI = \text{economic yield/biological yield}$$

The chlorophyll and carotenoid estimation were done according to Arnon (1949):

Acetone extraction method:

Chlorophyll a (mg g^{-1} fresh cut) = 12.7 A663 − 2.69 A645/a × 1000 × W × V.

Chlorophyll b (mg g^{-1} fresh cut) = 22.9 A645 − 4.68 A663/a × 1000 × W × V.

where W = fresh weight of discs (g);
V = volume made up;
A663 = absorbance at 633 nm;
A645 = Absorbance at 645 nm; and
a = constant = 1.

Carotenoid (mg g^{-1} fresh cut) = $D \times V \times F \times 10/25$

where D = absorbance at 450 nm;
V = volume of the original extract (mL); and
F = dilution factor.

The plant samples were collected randomly at different growth stages, separated into leaves, roots, and rhizomes, and dried in an oven at 70°C, and the DM recorded. The data recorded on various characteristics were subjected to Fisher's method of analysis of variance and interpretation of data as given by Gomez and Gomez (1984). The level of significance used in the F and t test was P = 0.05. Critical Difference (CD) values were calculated whenever the F test was significant. The data were pooled over the two years and analysed.

Results and Discussion

Chlorophyll and carotenoid contents

Chlorophyll a and b and carotenoid contents of leaves were estimated at 175 days after planting (DAP) and are presented in Table 1. The size of planting material and plant population levels had no effect on chlorophyll a and b and carotenoid contents. Among the organic manures, the content of chlorophyll a was significantly higher in F_7 and F_8 (2.100 and 2.113 mg g^{-1} fresh leaf, respectively) followed by FYM and VC. Composted coir pith at both levels had significantly less chlorophyll a (0.980 and 0.943 mg g^{-1} fresh leaf) and was on par with the control (1.020 mg g^{-1} fresh leaf). Treatment F_7 had significantly higher chlorophyll b (0.863 mg g^{-1} fresh leaf) followed by F_8, VC, and FYM, the latter two being on par with each other, but were significantly higher than CCP. The carotenoid content was significantly higher in treatment F_8 (0.134 mg g^{-1} fresh leaf) followed by F_7 and VC. Treatments FYM, VC, and F_7 also had significantly higher carotenoid contents compared with CCP at both the levels. The higher chlorophyll a and b and carotenoid contents were mainly attributed to higher uptake of nutrients under these treatments resulting in synthesis of chlorophyll a and b and carotenoid at higher levels.

Dry matter production and its distribution in different parts

Total DM produced per plant did not differ significantly at all the observed growth stages due to sizes of planting material (Table 1), since the growth characters and chlorophyll content did not differ significantly among the sizes. The DM distribution in the stem, leaf, root, and rhizome also did not differ significantly due to sizes of the planting material (Figure 1). Dalion *et al.* (1988) reported that the DM accumulation and distribution in corms, leaves, and petioles were similar at the same growth stages for 10–20 g, 50–60 g, and 100–120 g sett sizes in taro.

At 111 000 plants ha^{-1} population, the DM produced per plant from 120 DAP until the crop was harvested was significantly higher compared with 166 000 plants ha^{-1} population (Table 1). At lower plant populations, the individual plants were able to exploit the higher quantum of resources available for each plant as reflected in the higher AGR (Table 2), and thus, produced higher DM. Generally, increase in plant density reduces the AGR, net assimilation rate (NAR), and RGR. Enyi (1973) showed that in research conducted in cassava, the DM was higher at the lower population level.

The DM increased significantly with the combined application of FYM + NPK from 120 DAP until the harvest of the crop (Table 1) compared with the other treatments. The CCP at both levels had significantly lower DM compared with other organic manures, but recorded significantly higher DM compared with the control (20.31 g per plant). At 120 DAP, the per cent DM distribution in the stem was higher (34 to 39.1%) than the leaf (21.7 to 34.0%), root (7.9 to 17.9 g per plant), and rhizome (18.3 to 27.6%). The DM produced in the leaf was less in F_3 (25.4%) and the control (21.7%) treatments compared with the other treatments.

At 240 DAP, among organic manures, F_7 had significantly higher DM (125.69 g per plant) compared with other treatments. Treatment F_6 also had significantly higher DM (118.39 g per plant) compared with F_5 (116.72 g per plant). FYM at both the levels (112.73

Table 1 Chlorophyll (Chl) and carotenoid (Carot.) contents (mg g^{-1} fresh leaf), total dry matter (DM) production (g $plant^{-1}$), fresh rhizome yield (t ha^{-1}), and harvest index (HI) as influenced by different treatments in arrowroot[1]

	Chl a	Chl b	Carot.	Total DM			Fresh rhizome yield	HI
Treatments	175 DAP	175 DAP	175 DAP	120 DAP	240 DAP	At harvest	At harvest	At harvest
Sizes of planting material								
S_1: 15–20 g	1.591	0.562	0.099	41.87	94.10	112.34	12.5	0.428
S_2: 25–30 g	1.650	0.560	0.098	42.23	93.68	112.38	12.5	0.427
F test	ns	ns	ns	ns	ns	ns	ns	ns
SEM (±)	0.03	0.002	0.0004	0.09	0.05	0.10	0.40	0.001
$CD_{0.05}$	—	—	—	—	—	—	—	—
Plant population levels								
P_1: 111 000 ha^{-1}	1.661	0.564	0.094	42.39	95.89	114.99	12.5	0.428
P_2: 166 000 ha^{-1}	1.580	0.563	0.095	41.69	91.88	109.74	12.7	0.421
F test	ns	ns	ns	ns	ns	ns	ns	ns
SEM (±)	0.03	0.002	0.0004	0.09	0.05	0.10	0.04	0.001
$CD_{0.05}$	—	—	—	0.31	0.16	0.33	—	0.004
Organic manures and levels								
F_1: FYM[2] @ 26 t ha^{-1}	1.841	0.592	0.102	47.88	112.73	133.58	14.2	0.455
F_2: FYM @ 34 t ha^{-1}	1.892	0.601	0.106	47.70	113.03	133.83	14.3	0.456
F_3: CCP[3] @ 32 t ha^{-1}	0.980	0.302	0.051	26.06	58.77	66.18	10.0	0.342
F_4: CCP @ 42 t ha^{-1}	0.943	0.309	0.053	26.70	59.24	64.83	9.8	0.335
F_5: VC[4] @ 22 t ha^{-1}	1.765	0.631	0.096	51.53	116.72	140.74	14.7	0.451
F_6: VC @ 30 t ha^{-1}	1.906	0.628	0.112	53.53	118.39	140.49	14.9	0.451
F_7: FYM (20 t ha^{-1}) + NPK (75:50:50 kg ha^{-1})	2.100	0.863	0.120	65.12	125.69	167.93	17.1	0.451
F_8: NPK (75:50:50 kg ha^{-1})	2.113	0.814	0.134	39.38	97.58	111.47	12.5	0.391
F_9: Control	1.020	0.312	0.060	20.39	42.98	50.18	6.2	0.362
F test	*	*	*	*	*	*	*	*
SEM (±)	0.053	0.004	0.001	0.18	0.14	0.19	0.08	0.002
$CD_{0.05}$	0.151	0.012	0.002	0.51	0.40	0.53	0.20	0.005

[1]Pooled data; [2]FYM, Farmyard manure; [3]CCP, Composted coir pith; [4]VC, Vermicompost
DAP, Days after planting; ns, Non-significant

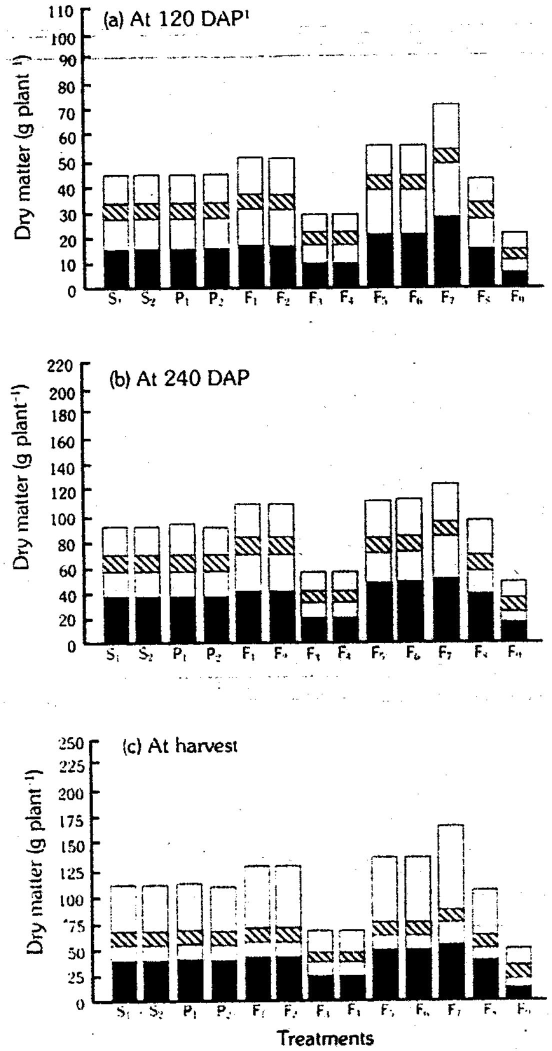

Figure 1 Dry matter accumulation and distribution in different parts of arrowroot at different stages

[1]Days after planting

S_1, 15–20 g; S_2, 25–30 g; P_1, 111 000 plants ha^{-1}; P_2, 166 000 plants ha^{-1}; F_1, Farmyard manure (FYM) @ 26 t ha^{-1}; F_2, FYM @ 34 t ha^{-1}; F_3, Composted coir pith (CCP) @ 32 t ha^{-1}; F_4, CCP @ 42 t ha^{-1}; F_5, Vermicompost (VC) @ 22 t ha^{-1}; F_6, VC @ 30 t ha^{-1}; F_7, FYM (20 t ha^{-1}) + NPK (75:50:50 kg ha^{-1}); F_8, NPK alone (75:50:50 kg ha^{-1}); and F_9, Control

■, Stem; ☰, Leaf; ▨, Root; □, Rhizome

and 113.03 g per plant), and CCP at both the levels (58.79 and 59.24 g per plant). The per cent distribution of DM in the stem was higher (33.2 to 42.2%) compared with the leaf (15.9 to 23.5%), root (9.8 to 20.5%), and rhizome (25.5 to 30.3%). The per cent DM in the leaf was lower in the control compared with other treatments since the chlorophyll content was less in these treatments. Organic manures had higher leaf DM (21.7 to 23.5%) compared with NPK alone (19.5%).

The interaction effects of P × F were significant with respect to DM content (Table 3) at 240 DAP. Treatment F_7 and P_1 level of population had significantly higher DM (127.4 g per plant) compared with other combinations. Treatment CCP at both levels with P_1 and P_2 level of population had significantly lower DM compared with other organic manures.

At harvest, among organic manures, the combination of FYM + NPK had significantly higher DM (167.93 g per plant) compared with other manures. The DM produced under VC at both levels was on par with each other (140.74 and 140.49 g per plant) but differed significantly over FYM at both levels (133.58 and 133.83 g per plant), CCP at both levels (66.18 and 64.83 g per plant), and NPK alone (11.47 g per plant). The control had significantly lower DM (50.18 g per plant). The per cent DM distribution in the rhizome was less in CCP treatments (33.5 to 34.2%) and the control (36.3%) compared with FYM, VC, and FYM + NPK treatments (45 to 45.6%) and NPK alone (39.2%).

The interaction effects of P × F were significant at harvest also (Table 4). The P_1 level of population using F_7 had significantly higher DM (172.5 g per plant) compared with other combinations, F_6 with P_1 level of population also had significantly higher DM (139.5 g per plant) compared with FYM at both levels (135.5 and 135.4 g per plant), CCP at both levels (65.7 and 64.4 g per plant), and NPK alone (121.8 g per plant).

In general, the DM distribution was higher in the stem followed by rhizome, leaf, and root from 120 DAP until 240 DAP, whereas at harvest, it was higher in the rhizome followed by stem, leaf, and root (Figure 1).

Among organic manures, FYM + NPK combination, FYM, and VC at both levels had significantly higher total DM compared with CCP at both the levels and NPK alone. The DM accumulation in stems, leaves, and rhizomes under these treatments was higher compared with CCP at both levels and control (Figure 1). This was mainly attributed to the production of greater number of leaves, having maximum breadth and length, and maintenance of higher chlorophyll a and b and carotenoid contents resulting in higher photosynthetic rate. This was reflected in the higher AGR and CGR under these treatments (Table 2). At harvest also, the DM distribution was higher in rhizomes under FYM + NPK, FYM, VC at both levels, and NPK alone compared with CCP at both the levels and the control. This was attributed to efficient translocation of DM into rhizomes under these treatments. Ramesan (1991) also reported the higher DM production of arrowroot at NPK dose of 150:75:150 kg ha^{-1} compared with lower levels. When turmeric was grown as an intercrop in coconut, increase in N application resulted in higher biomass production (Satheesan, 1984). Sannamarappa (1983) reported that intercropping of turmeric in arecanut with 40% of the recommended population and

Table 2 Absolute growth rate (AGR; g plant^{-1} day^{-1}) and crop growth rate (CGR; g m^{-2} day^{-1}) as influenced by different treatments in arrowroot[1]

Treatments	AGR		CGR	
	120–180 DAP	240–Harvest	120–180 DAP	240–Harvest
Sizes of planting material				
S_1: 15–20 g	0.397	0.308	5.462	4.241
S_2: 25–30 g	0.398	0.310	5.497	4.342
F test	ns	ns	ns	ns
SEM (±)	0.002	0.002	0.034	0.031
$CD_{0.05}$	—	—	—	—
Plant population levels				
P_1: 111 000 ha^{-1}	0.411	0.328	4.569	3.641
P_2: 166 000 ha^{-1}	0.383	0.296	6.391	4.943
F test	*	*	*	*
SEM (±)	0.002	0.002	0.034	0.031
$CD_{0.05}$	0.007	0.007	0.118	0.107
Organic manures and levels				
F_1: FYM[2] @ 26 t ha^{-1}	0.517	0.353	7.112	4.924
F_2: FYM @ 34 t ha^{-1}	0.508	0.352	7.004	4.891
F_3: CCP[3] @ 32 t ha^{-1}	0.211	0.105	2.920	1.452
F_4: CCP @ 42 t ha^{-1}	0.188	0.094	2.632	1.388
F_5: VC[4] @ 22 t ha^{-1}	0.464	0.358	6.380	4.848
F_6: VC @ 0 t ha^{-1}	0.494	0.337	6.815	4.553
F_7: FYM (20 t ha^{-1}) + NPK (75:50:50 kg ha^{-1})	0.506	0.716	6.997	9.848
F_8: NPK (75:50:50 kg ha^{-1})	0.488	0.328	6.754	4.437
F_9: Control	0.197	0.166	2.705	2.285
F test	*	*	*	*
SEM (±)	0.004	0.003	0.062	0.048
$CD_{0.05}$	0.012	0.009	0.176	0.135

[1]Pooled data; [2]FYM. Farmyard manure; [3]CCP. Composted coir pith; [4]VC. Vermicompost
DAP: Days after planting; ns: Non-significant

a fertilizer schedule of 70:60:120 kg NPK ha^{-1} produced higher DM.

Fresh rhizome yield (t ha^{-1})

The fresh rhizome yield did not differ significantly due to sizes of planting material and plant population levels (Table 1). This was attributed to non-significant difference in growth parameters and yield components under both sizes of planting material. Among the plant population levels, AGR during 180–240 DAP was statistically on par at both the population levels. The number of rhizomes produced per plant with 111 000 ha^{-1} was significantly superior (7.7), compared with 166 000 plants ha^{-1} (7.0) resulting in higher yield. The lower plant population density had significantly higher HI (0.428) compared with higher plant density (0.426). This was because higher plant density generally decreases the proportion of total DM diverted into the rhizomes, which was reflected in the higher rhizome DM at lower planting density (Figure 1). This finding is in conformity with the results of Enyi (1973) and Ramakrishnan Nayar and Sadanandan (1990) in cassava crop. Rajagopalan *et al.* (1992) also reported the maximum fresh rhizome yield of arrowroot at 30 cm × 30 cm spacing when grown as an intercrop in coconut garden. Cock *et al.* (1977) reported the higher yield of cassava with closer spacing. Ramakrishnan Nayar and Sadanandan (1990) reported the maximum yield of cassava at 90 cm × 90 cm spacing compared with 60 cm × 60 cm and 120 cm × 120 cm spacings.

Among organic manures, combination of FYM + NPK recorded significantly higher yield (17.1 t ha^{-1}) compared with the other treatments. Vermicompost at both levels also recorded significantly higher yield (14.7 and 14.9

Table 3 Interaction effects of P × F on total dry matter of arrowroot at 240 days after planting[1]

Treatments	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9
P_1	114.9	114.6	60.6	61.8	114.1	116.6	127.4	99.6	52.2
P_2	111.5	111.7	57.5	57.4	113.8	115.6	125.6	98.5	42.8

[1]Pooled data
$CD_{0.05}$ for *F* at the same levels of *P* = 0.58
$CD_{0.05}$ for *P* at the same or different levels of *F* = 0.57

Table 4 Interaction effects of P × F on total dry matter of arrowroot at harvest[1]

Treatments	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9
P_1	135.5	135.4	65.7	64.4	138.4	139.5	172.5	121.8	52.6
P_2	133.2	132.9	63.6	64.7	132.5	133.0	166.4	115.6	52.3

[1]Pooled data
$CD_{0.05}$ for *F* at the same levels of *P* = 0.75
$CD_{0.05}$ for *P* at the same or different levels of *F* = 0.78

t ha^{-1}) compared with FYM (14.2 and 14.3 t ha^{-1}), NPK alone (12.5 t ha^{-1}), and CCP (10.0 and 9.8 t ha^{-1}). Inorganic fertilizer (NPK alone) recorded significantly higher yield (12.5 t ha^{-1}) compared with CCP at both the levels (10.0 and 9.8 t ha^{-1}). The control recorded significantly lower yield (6.2 t ha^{-1}). The per cent reduction in yield under different treatments compared with FYM + NPK was 16.4 and 17.0% with FYM, 41.5 and 42.7% with CCP, 12.9 and 14.0% with VC, and 26.9% with NPK alone. The superior yield with FYM + NPK was mainly due to the combined effect of organic and chemical fertilizers on growth characters, yield components, chlorophyll a and b contents, and higher AGR and CGR coupled with higher nutrient uptake. Farmyard manure and VC applied alone at the two levels also favoured the growth of the crop which resulted in higher yield. The leaf area and leaf area duration (LAD) were maintained for a longer period under these treatments. This was mainly attributed to higher DM production and better partitioning into rhizomes as reflected in higher DM in rhizomes. The HI which indicates the efficiency of accumulation of photosynthates in the economic parts, observed under FYM at both the levels (0.455 and 0.456), VC at both levels (0.451 each), and FYM + NPK (0.451) was significantly higher compared with CCP at both levels (0.342 and 0.335) and NPK alone (0.392) (Table 1). The per cent reduction in yield was 63.7% compared with the control since the DM production and its partitioning in rhizomes was lower, resulting in lower HI. Ramesan (1991) reported that application of 150:75:150 kg NPK resulted in higher yield of arrowroot compared with lower doses. Increase in yield due to combined application, FYM, and inorganic fertilizer, has been reported in ginger (Pawar and Patil, 1987). Application of FYM alone resulting in higher yield of amorphophallus (Patel and Mehta, 1987) and turmeric (Balashanmugam *et al.*, 1989) has been documented. Vermicompost application alone or in combination increased the yield of turmeric (Vadiraj *et al.*, 1996). The overall better growth and yield under FYM and VC treatments also attributed to a higher microbial population and dehydrogenase activity which might have influenced nutrient uptake, chlorophyll synthesis, plant growth, and yield. Further, these microbes promoted soil aggregation and thus indirectly influenced the root environment and plant growth.

Conclusion

The investigation has clearly shown that growing arrowroot as an intercrop in coconut garden, using rhizomes of 15–20 g size with a spacing of 30 cm × 30 cm (111 000 population ha^{-1}) is recommended. Application of FYM (20 t ha^{-1}) + NPK (75:50:50 kg ha^{-1}) of FYM alone at 26 t ha^{-1} or VC at 22 t ha^{-1} was found to be remunerative with respect to obtaining maximum fresh rhizome yield.

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