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Research Article

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Root morphology and root characters of different cocoa (*Theobroma cacao* L) types at 100 and 50 percent field capacity under water deficit condition

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ABSTRACT

The main aim of this study was to screen the root morphology and root characters of different cocoa types at 100 and 50 percent field capacity under water deficit condition at seedling stage. A survey was conducted at Idukki region of Kerala, India and twenty seven plus trees were identified. These twenty seven plus trees were screened for water stress tolerance under glasshouse condition by gravimetric method. With respect to the performance of plus trees, root length under 50% field capacity got increased to 21.15 cm as against 20.51 cm in 100 per cent field capacity. Fresh root weight and dry root weight substantially got increased under water stress. The average root girth of 27 plus trees got increased in stressed condition from 3.70 cm to 3.88 cm. The root volume also followed the same trend (47.28 as against 45.96). The percent of nitrogen is 1.37 in 50 per cent field capacity as against 1.63 in 100 per cent field capacity. The percentage of phosphorous decreased to 0.16 under 50 per cent field capacity as against 0.37 in 100 per cent field capacity. Similarly the percentage of potassium also showed a decreasing trend (1.27 % under 100 % field capacity to 1.06 % under 50 % field capacity). In the present investigation, underwater stress condition the root length, number of roots, fresh weight of root and dry weight of root tends to increase compared to the 100 per cent field capacity, indicating the morphological adaptations of roots to survive under water stress condition. Furthermore, under water stress condition, root nutrients tend to get depleted.

KEYWORDS: Plus trees, water stress, field capacity

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INTRODUCTION

Cocoa (*Theobroma cacao* L) is a most important beverage plantation crop widely grown in tropical regions in the world. Cocoa comes under Malvaceae family. Cocoa, being one of the essential raw material in the production of chocolates, cocoa mass, cocoa butter and other confectioneries, there is a growing demand in the international market. Cocoa is highly sensitive to drought, which is a majorly present in cocoa growing areas due to inconsistent rainfall patterns [1]. Under water deficit condition the root nitrogen, phosphorus and potassium is decreased when compared to normal water condition. This will affect the growth of cocoa plants [2].

This study is mainly worked on to screen the different cocoa types based on root morphology and root characters at 100 and 50 percent field capacity under water deficit condition at seedling stage.

MATERIALS AND METHODS

Plus trees were collected from different regions of Idukki district, Kerala State, India (Kumily, Thopramkudi, Murikkassery and Rajapuram) during August 2016. Totally twenty seven plus trees were selected. These were further sown in cocoa nursery maintained by Mondelez India Food Pvt Ltd., at Anamalai, Pollachi to evaluate the seedling performance. The 100 percent and 50 percent field capacity is fixed by gravimetric method drought imposition. Statistical design is Factorial Completely Randomized Design with two replication.

The root morphology and root characters like root length, number of roots, fresh root weight, dry root weight, root girth, root volume, root nitrogen, root phosphorus and root potassium was recorded. Length and girth of the root of each plus tree were measured using a thread and scale and expressed in centimeter.

Table 1: Effect of irrigation regime on root length (cm) of cocoa plus trees

S.No	Plus trees	Root length (cm)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	14.50	18.05	16.27
2	Tc (Thopramkudi) 2	18.45	19.65	19.05
3	Tc (Thopramkudi) 3	16.50	19.70	18.10
4	Tc (Thopramkudi) 4	17.40	18.60	18.00
5	Tc (Thopramkudi) 5	20.30	20.65	20.47
6	Tc (Thopramkudi) 6	20.45	22.40	21.42
7	Tc (Thopramkudi) 7	22.60	25.45	24.02
8	Tc (Thopramkudi) 8	18.80	23.30	21.05
9	Tc (Thopramkudi) 9	25.35	27.40	26.37
10	Tc (Thopramkudi) 10	16.55	17.55	17.05
11	Tc (Thopramkudi) 11	21.15	21.75	21.45
12	Tc (Thopramkudi) 12	18.05	17.50	17.77
13	Tc (Thopramkudi) 13	16.30	20.40	18.35
14	Tc (Thopramkudi) 14	20.25	21.55h	20.90
15	Tc (Murikassery) 15	22.50	20.50	21.50
16	Tc (Murikassery) 16	19.75	17.40	18.57
17	Tc (Murikassery) 17	29.55	25.40	27.47
18	Tc (Murikassery) 18	21.40	22.25	21.82
19	Tc (Murikassery) 19	24.75	25.40	25.07
20	Tc (Murikassery) 20	21.50	23.65	22.57
21	Tc (Rajapuram) 21	24.50	18.80	21.65
22	Tc (Rajapuram) 22	19.60	22.70	21.15
23	Tc (Rajapuram) 23	23.45	21.65	22.55
24	Tc (Rajapuram) 24	21.35	19.60	20.47
25	Tc (Rajapuram) 25	17.60	18.40	18.00
26	Tc (Rajapuram) 26	17.65	17.75	17.70
27	Tc (Rajapuram) 27	23.75	23.80	23.77
Mean		20.51	21.15	20.83
		P	I	P x I
SE (d)		0.28	0.07	0.40
CD (P=0.05)		0.57**	0.15**	0.80**

NS- Non Significant, *Significant, **Highly Significant

Table 2: Effect of irrigation regime on number of roots of cocoa plus trees

S.No	Plus trees	Number of roots		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	10.00	12.50	11.25
2	Tc (Thopramkudi) 2	23.00	33.50	28.25
3	Tc (Thopramkudi) 3	25.50	27.00	26.25
4	Tc (Thopramkudi) 4	23.50	40.50	32.00
5	Tc (Thopramkudi) 5	22.00	33.50	27.75
6	Tc (Thopramkudi) 6	23.00	25.00	24.00
7	Tc (Thopramkudi) 7	30.00	32.50	31.25
8	Tc (Thopramkudi) 8	26.50	28.50	27.50
9	Tc (Thopramkudi) 9	23.00	26.50	24.75
10	Tc (Thopramkudi) 10	38.00	31.50	34.75
11	Tc (Thopramkudi) 11	26.50	36.00	31.25
12	Tc (Thopramkudi) 12	35.50	27.50	31.50
13	Tc (Thopramkudi) 13	25.00	28.00	26.50
14	Tc (Thopramkudi) 14	33.50	36.50	35.00
15	Tc (Murikassery) 15	30.50	28.50	29.50
16	Tc (Murikassery) 16	33.00	42.00	37.50
17	Tc (Murikassery) 17	25.00	28.50	26.75
18	Tc (Murikassery) 18	40.00	39.50	39.75
19	Tc (Murikassery) 19	35.00	46.50	40.75
20	Tc (Murikassery) 20	28.00	32.00	30.00
21	Tc (Rajapuram) 21	33.50	36.50	35.00
22	Tc (Rajapuram) 22	30.00	33.50	31.75
23	Tc (Rajapuram) 23	27.50	41.00	34.25
24	Tc (Rajapuram) 24	34.50	31.50	33.00
25	Tc (Rajapuram) 25	26.50	33.50	30.00
26	Tc (Rajapuram) 26	25.00	31.00	28.00
27	Tc (Rajapuram) 27	37.50	35.50	36.50
Mean		28.55	32.53	30.54
		P	I	P x I
SE (d)		1.01	0.27	1.43
CD (P=0.05)		2.03**	0.55**	2.88**

NS- Non Significant, *Significant, **Highly Significant

Root volume was estimated after immersion of roots in a known water volume and observing its displacement. Total nitrogen content in the root samples of each seedling was estimated by Microkjeldahl method [3] and expressed in percentage. The phosphorous in the triple acid extract of the given root sample of each seedlings was estimated by colorimetric method [4] and expressed in percentage. The potassium content of root samples of each seedlings were estimated from the triple acid extract by using a Flame Photometer [5] and the values were expressed in percentage.

RESULTS AND DISCUSSION

The root morphology and root characters like root length, number of roots, root girth, fresh root weight, dry root weight, root volume, root nitrogen, root phosphorus and root potassium are furnished in Tables 1-9. Among the twenty seven plus trees seedlings, Tc (Murikassery) 17 followed by Tc (Thopramkudi) 9 exhibited higher mean root length (27.47 cm and 26.37 cm respectively). In the case of treatments, plants imposed with 100 per cent field capacity registered lower root length (20.51 cm) than 50 per cent field capacity (21.15 cm). With respect to interaction effect of irrigation regime on plus trees, Tc (Murikassery) 17 folllowed by Tc (Thopramkudi) 9, recorded significantly higher root length (29.55 cm and 25.35 cm respectively) under 100 per cent field capacity while the lowest was recorded by Tc (Kumily) 1 (14.50cm). Under water stress condition, Tc (Thopramkudi) 9 and Tc (Thopramkudi) 7 registered significantly higher root length (27.40 cm and 25.45cm respectively) (Table 1).

The mean number of roots was maximum in Tc (Murikassery) 19 and Tc (Murikassery) 18 (40.75 and 39.75 respectively). Under water stress condition, the number of roots substantially got increased to 32.53 as against 28.55 under 100 per cent field capacity. At 100 per cent field capacity, Tc (Murikassery) 18 and Tc (Thopramkudi) 10 recorded the highest number of roots (40.00 and 38.00) when compared to seedlings from other plus trees. Performance of the plus trees under water deficit condition indicated that Tc (Murikassery) 19 and Tc (Murikassery) 16 were significantly superior as they had maximim number of roots (46.50 and 42.00 respectively) (Table 2).

Among the plus trees, maximum fresh root weight was recorded Tc (Murikassery) 19 followed by Tc (Thopramkudi) 6 (4.55 g and 4.40 g respectively) and Tc (Thoramkudi) 2 recorded the least fresh root weight (1.60 g). Regarding treatment effects, plants subjected to 50 per cent field capacity documented higher fresh root weight (3.21 g) than plants subjected to 100 per cent field capacity

Table 3: Effect of irrigation regime on fresh root weight (g) of cocoa plus trees

S.No	Plus trees	Fresh root weight (g)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	1.25	2.20	1.72
2	Tc (Thopramkudi) 2	1.15	2.05	1.60
3	Tc (Thopramkudi) 3	2.15	4.10	3.12
4	Tc (Thopramkudi) 4	2.05	3.20	2.65
5	Tc (Thopramkudi) 5	3.25	3.25	3.25
6	Tc (Thopramkudi) 6	3.90	4.90	4.40
7	Tc (Thopramkudi) 7	3.10	4.25	3.67
8	Tc (Thopramkudi) 8	2.15	2.35	2.25
9	Tc (Thopramkudi) 9	1.40	3.15	2.27
10	Tc (Thopramkudi) 10	1.45	3.20	2.32
11	Tc (Thopramkudi) 11	3.30	4.10	3.70
12	Tc (Thopramkudi) 12	2.30	3.05	2.67
13	Tc (Thopramkudi) 13	2.15	3.20	2.67
14	Tc (Thopramkudi) 14	2.25	2.75	2.50
15	Tc (Murikassery) 15	1.40	2.20	1.80
16	Tc (Murikassery) 16	3.30	4.10	3.70
17	Tc (Murikassery) 17	2.35	3.15	2.75
18	Tc (Murikassery) 18	2.30	4.10	3.20
19	Tc (Murikassery) 19	4.20	4.90	4.55
20	Tc (Murikassery) 20	1.45	2.30	1.87
21	Tc (Rajapuram) 21	2.35	4.05	3.20
22	Tc (Rajapuram) 22	3.25	4.05	3.65
23	Tc (Rajapuram) 23	1.45	2.20	1.82
24	Tc (Rajapuram) 24	3.25	3.30	3.27
25	Tc (Rajapuram) 25	3.15	2.35	2.75
26	Tc (Rajapuram) 26	1.45	2.20	1.82
27	Tc (Rajapuram) 27	2.30	2.20	2.25
Mean		2.37	3.21	2.79
		P	I	P **x** I
SE (d)		0.24	0.067	0.35
CD (P=0.05)		0.50**	0.13**	0.70**

NS- Non Significant, *Significant, **Highly Significant

Table 4: Effect of irrigation regime on dry root weight (g) of cocoa plus trees

S.No	Plus trees	Dry root weight (g)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	0.77	1.08	0.92
2	Tc (Thopramkudi) 2	0.61	1.12	0.86
3	Tc (Thopramkudi) 3	1.11	1.99	1.55
4	Tc (Thopramkudi) 4	1.08	1.51	1.29
5	Tc (Thopramkudi) 5	1.69	1.67	1.68
6	Tc (Thopramkudi) 6	1.94	2.47	2.20
7	Tc (Thopramkudi) 7	1.44	2.13	1.78
8	Tc (Thopramkudi) 8	1.06	1.02	1.04
9	Tc (Thopramkudi) 9	0.58	1.61	1.09
10	Tc (Thopramkudi) 10	0.65	1.53	1.09
11	Tc (Thopramkudi) 11	1.59	2.21	1.90
12	Tc (Thopramkudi) 12	1.06	1.47	1.26
13	Tc (Thopramkudi) 13	1.06	1.61	1.33
14	Tc (Thopramkudi) 14	1.23	1.47	1.35
15	Tc (Murikassery) 15	0.63	1.24	0.93
16	Tc (Murikassery) 16	1.38	2.15	1.76
17	Tc (Murikassery) 17	1.07	1.58	1.32
18	Tc (Murikassery) 18	1.05	2.10	1.57
19	Tc (Murikassery) 19	2.20	2.70	2.45
20	Tc (Murikassery) 20	0.75	1.24	1.00
21	Tc (Rajapuram) 21	1.17	2.23	1.70
22	Tc (Rajapuram) 22	1.61	2.09	1.85
23	Tc (Rajapuram) 23	0.60	1.30	0.95
24	Tc (Rajapuram) 24	1.60	1.70	1.65
25	Tc (Rajapuram) 25	1.60	1.16	1.38
26	Tc (Rajapuram) 26	1.11	1.16	1.14
27	Tc (Rajapuram) 27	1.09	1.09	1.09
Mean		1.17	1.65	1.41
		P	I	P **x** I
SE (d)		0.12	0.03	1.17
CD (P=0.05)		0.24**	0.06**	0.34**

NS- Non Significant, *Significant, **Highly Significant

(2.37 g). The interaction between the plus trees and irrigation regime showed Tc (Murikassery) 19 registered the highest fresh root weight (4.20 g) at 100 per cent field capacity and 4.90 g at 50 % field capacity. Hence under water stress condition, performance of Tc (Murikassery) 19 and Tc (Thopramkudi) 6 were on par with each other and recorded fresh root weight of 4.90 g (Table 3).

The maximum mean dry root weight was observed in Tc (Murikassery) 19 and Tc (Thopramkudi) 6 (2.45 g and 2.20 g respectively) while the least mean value was observed in Tc (Thopramkudi) 2 (0.86 g). Under water stress condition, the dry root weight substantially got increased to 1.65g as against 1.17 g under 100 per cent field capacity. At 100 per cent field capacity, Tc (Murikassery) 19 and Tc (Thopramkudi) 6 recorded the highest root weight (2.20 g and 1.94 g) compared to all the plus trees. Performance of the plus trees under water stress indicated that Tc (Murikassery) 19 and Tc (Thopramkudi) 6 were significantly superior as they had higher dry root weight of 2.70 g and 2.47 g respectively than any other plus trees (Table 4).

Among the plus trees, Tc (Murikassery) 19 and Tc (Thopramkudi) 4 showed maximum mean root girth (4.35 cm and 4.22 cm) and Tc (Thopramkudi) 6 and Tc (Murikassery) 20 recorded the least root girth (3.37 cm). With respect to treatment effects, plants subjected to 50 per cent field capacity documented higher root girth (3.88 cm) than the plants treated with 100 per cent field capacity plants (3.70 cm). The interaction between the factors such as plus trees and Irrigation regime showed, Tc (Thopramkudi) 7 and Tc (Murikassery) 19 registered higher root girth (4.35 cm) at 100 per cent field capacity level. But under water stress condition, Tc (Kumily) 1 and Tc (Murikassery) 19 performance were on par with each other (4.35 cm) (Table 5).

Among the plus trees, the mean maximum root volume was recorded in Tc (Thopramkudi) 3 and Tc (Thopramkudi) 6 (55.12 cm^3 and 54.00 cm^3 respectively) while the least was observed in Tc (Rajapuram) 27 (39.00 cm^3). In the case of treatments, plants imposed with 100 per cent field capacity irrigation regime registered lower root volume (45.96 cm^3) than 50 per cent field capacity (47.28 cm^3) (Table 6).

The highest mean nitrogen content was observed in Tc (Rajapuram) 26 (1.66 %) closely followed by Tc (Thopramkudi) 3 (1.64 %) while the least value was observed in Tc (Rajapuram) 23 and Tc (Rajapuram) 27 (1.35 %). Under water stress condition, the nitrogen content substantially got decreased to 1.37 % as against 1.63% under 100 per cent field capacity. Root nitrogen content at 100 % field capacity was on par with each other for the plus trees

Table 5: Effect of irrigation regime on root girth (cm) of cocoa plus trees

S.No	Plus trees	Root girth (cm)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	3.20	4.35	3.77
2	Tc (Thopramkudi) 2	3.40	4.25	3.82
3	Tc (Thopramkudi) 3	3.40	3.60	3.50
4	Tc (Thopramkudi) 4	4.30	4.15	4.22
5	Tc (Thopramkudi) 5	4.35	3.45	3.90
6	Tc (Thopramkudi) 6	3.15	3.60	3.37
7	Tc (Thopramkudi) 7	4.35	3.00	3.67
8	Tc (Thopramkudi) 8	3.75	3.80	3.77
9	Tc (Thopramkudi) 9	3.75	3.75	3.75
10	Tc (Thopramkudi) 10	3.55	3.85	3.70
11	Tc (Thopramkudi) 11	3.35	3.75	3.55
12	Tc (Thopramkudi) 12	3.55	4.20	3.87
13	Tc (Thopramkudi) 13	3.40	3.80	3.60
14	Tc (Thopramkudi) 14	4.15	4.50	4.32
15	Tc (Murikassery) 15	3.45	3.75	3.60
16	Tc (Murikassery) 16	3.65	3.85	3.75
17	Tc (Murikassery) 17	3.75	4.05	3.90
18	Tc (Murikassery) 18	4.00	4.22	4.11
19	Tc (Murikassery) 19	4.35	4.35	4.35
20	Tc (Murikassery) 20	3.25	3.50	3.37
21	Tc (Rajapuram) 21	3.80	3.85	3.82
22	Tc (Rajapuram) 22	3.75	4.15	3.95
23	Tc (Rajapuram) 23	3.60	4.10	3.85
24	Tc (Rajapuram) 24	3.50	4.20	3.85
25	Tc (Rajapuram) 25	3.50	3.60	3.55
26	Tc (Rajapuram) 26	4.25	3.50	3.87
27	Tc (Rajapuram) 27	3.60	3.65	3.62
Mean		3.70	3.88	3.79
		P	I	P x I
SE (d)		0.10	0.02	0.15
CD (P=0.05)		0.21**	0.05**	0.30**

NS- Non Significant, *Significant, **Highly Significant

Table 6: Effect of irrigation regime on root volume (cm^3) of cocoa plus trees

S.No	Plus trees	Root volume (cm^3)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	50.50	52.00	51.25
2	Tc (Thopramkudi) 2	51.50	52.05	51.77
3	Tc (Thopramkudi) 3	55.00	55.25	55.12
4	Tc (Thopramkudi) 4	50.00	52.50	51.25
5	Tc (Thopramkudi) 5	45.25	45.50	45.37
6	Tc (Thopramkudi) 6	52.00	56.00	54.00
7	Tc (Thopramkudi) 7	51.00	53.75	52.62
8	Tc (Thopramkudi) 8	40.75	41.25	41.00
9	Tc (Thopramkudi) 9	42.50	43.75	43.12
10	Tc (Thopramkudi) 10	47.00	50.50	48.75
11	Tc (Thopramkudi) 11	40.75	41.25	41.00
12	Tc (Thopramkudi) 12	41.75	41.75	41.75
13	Tc (Thopramkudi) 13	45.75	45.75	45.72
14	Tc (Thopramkudi) 14	47.20	48.75	47.97
15	Tc (Murikassery) 15	51.25	51.50	51.37
16	Tc (Murikassery) 16	44.50	46.75	45.62
17	Tc (Murikassery) 17	44.70	45.65	45.17
18	Tc (Murikassery) 18	51.25	53.50	52.37
19	Tc (Murikassery) 19	47.50	49.50	48.50
20	Tc (Murikassery) 20	49.50	50.50	50.00
21	Tc (Rajapuram) 21	45.50	46.50	46.00
22	Tc (Rajapuram) 22	40.50	41.25	40.87
23	Tc (Rajapuram) 23	43.50	47.50	45.50
24	Tc (Rajapuram) 24	39.75	42.75	41.25
25	Tc (Rajapuram) 25	41.25	40.25	40.75
26	Tc (Rajapuram) 26	41.75	41.72	41.73
27	Tc (Rajapuram) 27	38.75	39.25	39.00
Mean		45.96	47.28	46.62
		P	I	P x I
SE (d)		0.66	0.18	0.94
CD (P=0.05)		1.34**	0.36**	1.89 NS

NS- Non Significant, *Significant, **Highly Significant

Tc (Thopramkudi) 2 and Tc (Murikassery) 17 (1.78 % and 1.77 % respectively). Performance of the plus trees under water stress indicated that Tc (Rajapuram) 26 followed by Tc (Thopramkudi) 3 were significantly superior as they had higher nitrogen content of 1.65 % and 1.63 % respectively than any other plus trees (Table 7).

The highest mean phosphorous content was observed in Tc (Thopramkudi) 4 (0.45%) closely followed by Tc (Kumily) 1 (0.37 %) while the least value was observed in Tc (Thopramkudi) 5 (0.19 %). Under water stress condition, the phosphorous content substantially got decreased to 0.16 % as against 0.37 % under 100 per cent field capacity. Root phosphorous content at 100 % field capacity was maximum in Tc (Thopramkudi) 4 (0.75 %). Performance of the plus trees under water stress indicated that Tc (Rajapuram) 26 followed by Tc (Thopramkudi) 3 and Tc (Thopramkudi) 10 were significantly superior as they had higher phosphorous content of 0.31 %, 0.27 % and 0.25 % respectively than any other plus trees (Table 8).

Among the plus trees, Tc (Rajapuram) 26 and Tc (Thopramkudi) 6 showed more content of potassium (1.35 % and 1.29 % respectively) and Tc (Murikassery) 15 recorded the least (0.92 %).With respect to the treatment effects, plants subjected to 50 per cent field capacity documented lower root potassium (1.06 %) than 100 per cent field capacity plants (1.27 %). The interaction between the factors such as plus trees and Irrigation regime showed Tc (Rajapuram) 26 (1.37 %) closely followed by Tc (Thopramkudi) 9 and Tc (Murikassery) 20 (1.33 %) registered the highest root potassium at 100 per cent field capacity level and the root potassium was lower in Tc (Murikassery) 15 (1.14 %). But under water stress condition, Tc (Rajapuram) 26 and Tc (Thopramkudi) 6 relatively recorded the highest root potassium (1.34 % and 1.26 % respectively) (Table 9).

Drought condition would cause water deficit in shoots under conditions of limited soil water supply [2]. In present study, in contrast to the root length, shoot length tends to decrease under stress condition. Under drought condition, tolerance plants are higher biomass with high root length, lower leaf area and thicker leaves [6]. In the present study, root length tends to increase in stress condition when compared to the control. Drought sensitive plants showed the highest significant reductions in leaf N, P and K content, compared to control healthy plants [7]. Similar trend were observed in case of root N, P and K content.

CONCLUSION

Among the plus trees, Tc (Thopramkudi) 9 and Tc (Murikassery) 19 shows higher root length in stress condition. Tc (Murikassery)

Table 7: Effect of irrigation regime on root Nitrogen (%) of cocoa plus trees

S.No	Plus trees	Root nitrogen (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	1.62	1.48	1.55
2	Tc (Thopramkudi) 2	1.78	1.45	1.62
3	Tc (Thopramkudi) 3	1.65	1.63	1.64
4	Tc (Thopramkudi) 4	1.70	1.55	1.62
5	Tc (Thopramkudi) 5	1.65	1.40	1.52
6	Tc (Thopramkudi) 6	1.43	1.30	1.36
7	Tc (Thopramkudi) 7	1.46	1.30	1.38
8	Tc (Thopramkudi) 8	1.57	1.29	1.43
9	Tc (Thopramkudi) 9	1.74	1.37	1.56
10	Tc (Thopramkudi) 10	1.59	1.60	1.59
11	Tc (Thopramkudi) 11	1.70	1.33	1.51
12	Tc (Thopramkudi) 12	1.57	1.24	1.41
13	Tc (Thopramkudi) 13	1.70	1.34	1.52
14	Tc (Thopramkudi) 14	1.60	1.60	1.60
15	Tc (Murikassery) 15	1.73	1.31	1.52
16	Tc (Murikassery) 16	1.64	1.30	1.47
17	Tc (Murikassery) 17	1.77	1.30	1.53
18	Tc (Murikassery) 18	1.59	1.31	1.45
19	Tc (Murikassery) 19	1.59	1.24	1.41
20	Tc (Murikassery) 20	1.68	1.33	1.50
21	Tc (Rajapuram) 21	1.74	1.33	1.54
22	Tc (Rajapuram) 22	1.63	1.29	1.46
23	Tc (Rajapuram) 23	1.46	1.25	1.35
24	Tc (Rajapuram) 24	1.60	1.32	1.46
25	Tc (Rajapuram) 25	1.67	1.32	1.49
26	Tc (Rajapuram) 26	1.68	1.65	1.66
27	Tc (Rajapuram) 27	1.46	1.23	1.35
Mean		1.63	1.37	1.50
		P	I	P x I
SE (d)		0.02	0.006	0.03
CD (P=0.05)		0.06**	0.017**	0.09**

NS- Non Significant, *Significant, **Highly Significant

Table 8: Effect of irrigation regime on root phosphorous (%) of cocoa plus trees

S.No	Plus trees	Root phosphorous (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	0.60	0.15	0.37
2	Tc (Thopramkudi) 2	0.55	0.15	0.35
3	Tc (Thopramkudi) 3	0.35	0.27	0.31
4	Tc (Thopramkudi) 4	0.75	0.15	0.45
5	Tc (Thopramkudi) 5	0.25	0.14	0.19
6	Tc (Thopramkudi) 6	0.28	0.13	0.21
7	Tc (Thopramkudi) 7	0.38	0.16	0.27
8	Tc (Thopramkudi) 8	0.34	0.14	0.24
9	Tc (Thopramkudi) 9	0.36	0.14	0.25
10	Tc (Thopramkudi) 10	0.40	0.25	0.33
11	Tc (Thopramkudi) 11	0.30	0.14	0.22
12	Tc (Thopramkudi) 12	0.34	0.18	0.26
13	Tc (Thopramkudi) 13	0.34	0.13	0.23
14	Tc (Thopramkudi) 14	0.32	0.16	0.24
15	Tc (Murikassery) 15	0.35	0.17	0.26
16	Tc (Murikassery) 16	0.33	0.16	0.24
17	Tc (Murikassery) 17	0.35	0.14	0.24
18	Tc (Murikassery) 18	0.34	0.14	0.24
19	Tc (Murikassery) 19	0.35	0.14	0.24
20	Tc (Murikassery) 20	0.33	0.15	0.24
21	Tc (Rajapuram) 21	0.36	0.13	0.24

(Contd...)

Table 8: *(Continued)*

S.No	Plus trees	Root phosphorous (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
22	Tc (Rajapuram) 22	0.37	0.14	0.25
23	Tc (Rajapuram) 23	0.37	0.15	0.26
24	Tc (Rajapuram) 24	0.34	0.14	0.24
25	Tc (Rajapuram) 25	0.35	0.14	0.25
26	Tc (Rajapuram) 26	0.35	0.31	0.33
27	Tc (Rajapuram) 27	0.35	0.11	0.23
Mean		0.37	0.16	0.26
SE (d)		0.03	0.00	0.04
CD (P=0.05)		0.06**	0.01**	0.08**

NS- Non Significant, *Significant, **Highly Significant

Table 9: Effect of irrigation regime on root potassium (%) of cocoa plus trees

S.No	Plus trees	Root potassium (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Kumily) 1	1.23	1.09	1.16
2	Tc (Thopramkudi) 2	1.25	1.02	1.13
3	Tc (Thopramkudi) 3	1.25	1.02	1.13
4	Tc (Thopramkudi) 4	1.23	1.13	1.18
5	Tc (Thopramkudi) 5	1.27	1.13	1.12
6	Tc (Thopramkudi) 6	1.32	1.26	1.29
7	Tc (Thopramkudi) 7	1.27	1.04	1.15
8	Tc (Thopramkudi) 8	1.31	1.06	1.18
9	Tc (Thopramkudi) 9	1.33	1.03	1.18
10	Tc (Thopramkudi) 10	1.25	1.03	1.14
11	Tc (Thopramkudi) 11	1.27	1.06	1.16
12	Tc (Thopramkudi) 12	1.29	1.04	1.17
13	Tc (Thopramkudi) 13	1.33	1.12	1.23
14	Tc (Thopramkudi) 14	1.16	0.87	1.01
15	Tc (Murikassery) 15	1.14	0.70	0.92
16	Tc (Murikassery) 16	1.20	0.91	1.05
17	Tc (Murikassery) 17	1.32	1.04	1.18
18	Tc (Murikassery) 18	1.32	1.02	1.17
19	Tc (Murikassery) 19	1.28	1.19	1.23
20	Tc (Murikassery) 20	1.33	1.04	1.18
21	Tc (Rajapuram) 21	1.25	1.14	1.19
22	Tc (Rajapuram) 22	1.34	1.12	1.23
23	Tc (Rajapuram) 23	1.24	1.06	1.15
24	Tc (Rajapuram) 24	1.31	1.10	1.21
25	Tc (Rajapuram) 25	1.34	1.20	1.27
26	Tc (Rajapuram) 26	1.37	1.34	1.35
27	Tc (Rajapuram) 27	1.26	0.94	1.10
Mean		1.27	1.06	1.17
		P	I	P x I
SE (d)		0.02	0.007	0.04
CD (P=0.05)		0.05**	0.01**	0.08**

NS- Non Significant, *Significant, **Highly Significant

19 and Tc (Murikassery) 16 possess more number of roots in stress condition. Hence, these plus trees may be used for further future breeding programme.

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