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Root morphology and nutrient uptake pattern of different cocoa genotypes against water deficit condition

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Abstract
Abiotic stress due to drought is a worldwide issue. During drought condition, plants tend to reduce their activity and try to end their life cycle. Cocoa is considered as a third most important plantation beverage crop after tea and coffee. Whereas the cocoa production was considerably affected by drought and root is an effective parts under water stress condition. Hence, the study was carried out to select best cocoa genotypes based on root morphology and nutrient uptake pattern at Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore during 2018-2019. A survey was conducted in two different regions of Coimbatore districts namely Vedapatti and Thondamuthur and 35 plus trees were identified. These 35 plus trees were subjected to different irrigation regimes (100 per cent and 50 per cent field capacity). The performance of seedlings of plus trees under different irrigation regimes were evaluated based on root morphology and nutrient uptake characters like root length, root girth, fresh root weight, root volume, root girth, dry root weight, number of roots, root nitrogen, root phosphorus and root potassium. With respect to root morphology parameters, highest root length (38.6 cm) was registered in Tc (Vedapatti) 29 and maximum fresh root weight (16.38 g), root girth (2.98 g), dry root weight (6.76 g) and number of roots (62) were recorded in Tc (Vedapatti) 2 under water stress condition (50% field capacity) than control (100% field capacity). With regard to nutrient uptake pattern, the highest root nitrogen (1.84%) and root potassium (1.50%) were recorded in Tc (Vedapatti) 2 and root phosphorus (0.63%) in Tc (Vedapatti) 29 under drought condition than control. Based on statistical analysis, significant variation was observed among the 35 plus trees seedlings under 50 per cent field capacity. In respect of root morphology and nutrient uptake parameters, genotypes with highest root length, number of roots, root volume, root weight; likewise maximum root nitrogen, phosphorus and potassium can effectively tolerate drought condition. From this study it is concluded that Tc (Vedapatti) 2 and Tc (Vedapatti) 29 exhibited the exact root morphology and nutrient uptake mechanism required to withstand water stress and can be used for further breeding programmes and as parents for developing hybrids with positive characters.

Keywords: Cocoa, drought, root morphology and nutrient uptake

Introduction
Cocoa (*Theobroma cacao* L.) is a native of Amazon region of South America and is one of the important plantation crops. The genus *Theorem* belongs to the family Malvaceae (Alverson *et al.*, 1999) [2]. It is a cash crop grown throughout the humid tropics of the world between 20º N and 20º S of the equator and maximum cultivation is between 10º N and 10º S (Motamayor *et al.*, 2003) [14]. Crop comes up well at 300 m above mean sea level and it requires an annual precipitation of 1500-2000 mm. It grows within a temperature range of 15-39^{0}C and optimum temperature is around 25 ^{0}C. Cocoa needs high humidity throughout the year for optimum growth. There are over 20 species in the genus *Theobroma* but *T. cacao* is the only species cultivated commercially. It is a diploid species with 20 chromosomes in the somatic cells (2n=20). Although cocoa has been cultivated for centuries in Central America, it is started in India during early 1970s (Nair *et al.*, 2002). At present, cocoa is cultivated in 78,000 ha with a total production of 16,050 metric tonnes and productivity of 475 kg/ha in India. Cultivation of cocoa is mainly concentrated in South India, where cocoa forms an intercrop in coconut plantations except Kerala where it is grown in mixed stands of forest trees, rubber *etc*. Kerala accounts for about 76 percent of the area and 78 per cent of total production. Remaining area and production is contributed by Karnataka. In Tamil Nadu, the total area accounts for 26,969 ha, with an annual production of 1,650 metric tonnes (DCCD, 2018) [22]. The global demand for cocoa beans is increasing sharply and it is estimated that an additional one million metric tonnes is required by 2025 to meet the demand.

The supply of cocoa beans from major cocoa producing countries has been erratic during the past decade (2010-2020) with low output from Ivory Coast, the largest cocoa producing country. Cultivation of cocoa is done primarily for the production of chocolate and various by products are used in cosmetics, confectioneries, perfumeries, pharmaceuticals *etc.* (Cheesman, 1944) [5].

Effect of meteorological factors, especially rainfall on growth and development of perennial crops has to be taken into account for successful establishment and sustainable yield of a crop (Almeida and Valle, 2007; Reddy *et al.*, 2004) [1, 18]. Productivity of cocoa is greatly affected by extended period of water stress prevailing in the tropical regions during vital phases of growth (Alvim, 1960) [3]. The current climate changing scenario warrants selection of crop species tolerant to abiotic stress to sustain economic yield even at adverse conditions. Hence, there is an urgent need to utilize the genetic diversity available in cocoa to disseminate improved planting material with desirable character such as stress resistance. The present study was mainly focused to screen the desirable genotypes against water stress condition based on root morphology characters and nutrient uptake pattern.

Materials and Methods

The study on the root morphology and nutrient uptake pattern of different cocoa genotypes against water deficit condition was conducted at Department of Spices and Plantation Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu. The thirty five plus trees of cocoa available in the farmer's field at Vedapatti and Thondamuthur regions of Coimbatore were identified and pods were collected. The collected cocoa beans were sown in 16 × 14 inch polybags. Regular watering was done for germination and growth of seedlings. The trail was conducted during the period from 2018-2019. Gravimetric method of drought imposition was used to impose the treatments (Sivakumar, 2013) [20]. Five months old identified plus trees seedlings were transplanted in pots containing potting media and the treatments were imposed 15 days after transplanting. The seedlings were subjected to different water treatments like T_1 (100% field capacity) and T_2 (50% field capacity). All the root morphology and nutrient uptake pattern analysis were done only after 60 days of drought imposition.

In this study, the root morphology and nutrient uptake characters like root length, root girth, fresh root weight, root volume, root girth, dry root weight, number of roots, root nitrogen, root phosphorus and root potassium were recorded. Plants treated were uprooted after 60 days of treatment, cleaned and then root length and girth were measured and expressed in centimetre; likewise weight of fresh root was taken and expressed in grams. The number of roots were counted and expressed in numbers. The weighed fresh root was dried in oven for a week and weight of dry root was taken and expressed in grams. Volume of root was estimated after immersion of roots in a known volume of water and observed its displacement and expressed in cm^3.

The total nitrogen content was estimated by Kjeldahl's method by Humphries (1956) [8]. The sample of 0.1 g of dried powdered material was taken in Kjeldahl's flask. To this two ml of salicylic acid – sulphuric acid mixture was added and heated gently until the fumes disappeared. Flask was cooled and about 0.6 g of catalyst containing copper sulphate, potassium sulphate and selenium dioxide were added followed by one ml of concentrated sulphuric acid and digested till the digest turned green in colour. Then contents were cooled and volume made upto 100 ml with distilled water. Ten ml of the aliquot was taken in a micro kjeldahl distillation flask with 10 ml of 40 percent sodium hydroxide. The ammonia evolved was collected over 2 percent boric acid (20 ml) containing a drop of double indicator and was titrated against N/50 sulphuric acid. The nitrogen content was arrived and expressed as percentage on dry weight basis.

The phosphorous content of root samples of each seedling were estimated from the triple acid extract by colorimetric method (Jackson, 1967) [9] and the value was expressed in percentage. The potassium content of leaf was determined by Jackson (1973) [10]. The leaf samples from each treatment were allowed to dry and about one gram of dried sample was digested in a triple acid mixture (Nitric: hydrochloric: perchloric acid at 9:3:1 ratio). With the help of sand heater, the samples were allowed for cold digestion overnight. Using double distilled water, the entire content was made up to 100 ml. The aliquot extracted after the digestion was taken and feed into the flame photometer and recorded the reading. Available K content was calculated using a standard curve and expressed in percentage.

The experiment was laid out in Factorial Completely Randomized Design (FCRD) with three replications. The overall data were statistically analysed by SPSS method (Nei, 1978) [16].

Results and Discussion

Root characters

Significant differences were noticed in irrigation schedule, plus trees and their interaction for root length. The highest mean activity was found in Tc (Vedapatti) 29 (41.1 cm) and the lowest mean length was recorded in Tc (Vedapatti) 110 (14.3 cm). For different irrigation regime, the root length recorded was about 26.27 cm against control 27.97 cm. With regard to the interaction between irrigation schedule and plus trees, highest root length was found in Tc (Vedapatti) 29 (43.5 cm) and low value was registered in Tc (Vedapatti) 111 (15.8 cm) for the control plants. For treated plants, the lowest root length recorded was about 10.3 cm in Tc (Vedapatti) 110 against the highest root length of about 38.6 cm in Tc (Vedapatti) 29 (Table 1).

Table 1: Effect of different irrigation regime on root length (cm) on the seedlings of identified plus trees

S. No.	Plus trees	Root length (cm)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	29.6	20.2	24.9
2	Tc (Vedapatti) 2	34.5	37.8	36.2
3	Tc (Vedapatti) 9	26.6	24.2	25.4
4	Tc (Vedapatti) 15	25.1	26.4	25.8
5	Tc (Vedapatti) 18	33.1	30.8	32.0
6	Tc (Vedapatti) 29	23.5	38.6	31.1

7	Tc (Vedapatti) 31	26.3	21.2	23.8
8	Tc (Vedapatti) 33	19.8	23.6	21.7
9	Tc (Vedapatti) 37	30.8	19.2	25.0
10	Tc (Vedapatti) 40	32.8	27.6	30.2
11	Tc (Vedapatti) 41	28.3	27.8	28.1
12	Tc (Vedapatti) 42	25.9	24.8	25.4
13	Tc (Vedapatti) 45	29.2	28.6	28.9
14	Tc (Vedapatti) 48	23.6	29.5	26.6
15	Tc (Vedapatti) 55	29.2	32.8	31.0
16	Tc (Vedapatti) 61	28.6	30.5	29.6
17	Tc (Vedapatti) 63	23.8	12.8	18.3
18	Tc (Vedapatti) 64	26.8	29.2	28.0
19	Tc (Vedapatti) 66	28.5	36.3	32.4
20	Tc (Vedapatti) 67	30.8	25.6	28.2
21	Tc (Vedapatti) 68	29.8	23.5	26.7
22	Tc (Vedapatti) 72	24.5	23.8	24.2
23	Tc (Vedapatti) 75	25.8	34.2	30.0
24	Tc (Vedapatti) 76	20.4	25.6	23.0
25	Tc (Vedapatti) 78	26.5	18.8	22.7
26	Tc (Vedapatti) 85	29.1	32.8	31.0
27	Tc (Vedapatti) 86	18.2	13.8	16.0
28	Tc (Vedapatti) 88	25.6	21.8	23.7
29	Tc (Vedapatti) 90	35.6	29.8	32.7
30	Tc (Vedapatti) 91	37.6	32.8	35.2
31	Tc (Vedapatti) 94	29.8	18.5	24.2
32	Tc (Vedapatti) 99	30.5	31.8	31.2
33	Tc (Vedapatti) 110	18.2	10.3	14.3
34	Tc (Vedapatti) 111	15.8	26.5	21.2
35	Tc (Thondamuthur) 121	34.8	27.8	31.3
Mean		27.97	26.27	27.12
		P	I	P×I
SE(d)		0.442	0.106	0.625
CD (P=0.05)		0.873**	0.209**	1.235**

NS – Non significant, * - Significant, ** - Highly Significant

Significant variation for fresh root weight in plus trees, irrigation schedule and their interaction was recorded. Among 35 plus trees, Tc (Vedapatti) 2 recorded highest mean weight (16.03 g) and the lowest mean weight was recorded by Tc (Vedapatti) 1 (2.32 g). For different irrigation regime, the fresh root weight was increased about 5.37 g against control 4.79 g. For the interaction between the plus trees and irrigation schedule, highest fresh root weight was recorded in Tc (Vedapatti) 2 (15.67 g) and the lowest was recorded in Tc (Vedapatti) 1 (2.08 g) at 100 per cent field capacity. With regard to the plants kept under drought condition, the highest value was recorded in Tc (Vedapatti) 2 (16.38 g) and the lowest was recorded in Tc (Vedapatti) 1 (2.56 g), (Table 2).

Table 2: Effect of different irrigation regime on root weight (g) on the seedlings of identified plus trees

S. No.	Plus trees	Fresh root weight (g)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	2.08	2.56	2.32
2	Tc (Vedapatti) 2	15.67	16.38	16.03
3	Tc (Vedapatti) 9	3.41	6.62	5.02
4	Tc (Vedapatti) 15	2.92	3.56	3.24
5	Tc (Vedapatti) 18	2.56	2.98	2.77
6	Tc (Vedapatti) 29	8.48	12.56	10.52
7	Tc (Vedapatti) 31	4.56	5.75	5.16
8	Tc (Vedapatti) 33	2.48	3.61	3.05
9	Tc (Vedapatti) 37	2.95	2.62	2.79
10	Tc (Vedapatti) 40	2.62	3.38	3.00
11	Tc (Vedapatti) 41	5.61	4.85	5.23
12	Tc (Vedapatti) 42	2.81	3.51	3.16
13	Tc (Vedapatti) 45	5.08	7.81	6.45
14	Tc (Vedapatti) 48	9.88	11.85	10.87
15	Tc (Vedapatti) 55	3.61	3.72	3.67
16	Tc (Vedapatti) 61	4.25	5.61	4.93
17	Tc (Vedapatti) 63	4.01	5.62	4.82
18	Tc (Vedapatti) 64	3.51	2.85	3.18
19	Tc (Vedapatti) 66	3.61	2.78	3.20
20	Tc (Vedapatti) 67	6.61	5.56	6.09

21	Tc (Vedapatti) 68	3.91	3.51	3.71
22	Tc (Vedapatti) 72	4.42	3.68	4.05
23	Tc (Vedapatti) 75	5.62	3.81	4.72
24	Tc (Vedapatti) 76	3.15	4.35	3.75
25	Tc (Vedapatti) 78	2.67	3.18	2.93
26	Tc (Vedapatti) 85	3.62	4.81	4.22
27	Tc (Vedapatti) 86	4.07	3.08	3.58
28	Tc (Vedapatti) 88	4.45	6.62	5.54
29	Tc (Vedapatti) 90	3.61	4.85	4.23
30	Tc (Vedapatti) 91	4.85	3.23	4.04
31	Tc (Vedapatti) 94	5.12	4.95	5.04
32	Tc (Vedapatti) 99	5.62	4.51	5.07
33	Tc (Vedapatti) 110	4.38	3.51	3.95
34	Tc (Vedapatti) 111	7.81	10.56	9.19
35	Tc (Thondamuthur) 121	7.51	9.25	8.38
Mean		4.79	5.37	5.08
		P	I	P×I
SE (d)		0.075	0.017	0.106
CD (P=0.05)		0.149**	0.035**	0.210**

NS – Non significant, * - Significant, ** - Highly Significant

Significant variation in root volume for the identified 35 plus trees, irrigation schedule and their interactions were observed. Plus trees Tc (Vedapatti) 2 recorded highest mean root volume (34.50 cm^3) and Tc (Vedapatti) 85 recorded lowest mean root volume (16.50 cm^3). For different irrigation regimes, 50 per cent field capacity recorded 24.49 cm^3 root volume against 24.94 cm^3 for 100 per cent field capacity. Interaction between irrigation schedule and plus trees, highest root volume was found in Tc (Vedapatti) 76 (36.00 cm^3) and lowest value was found in Tc (Vedapatti) 68 (15.00 cm^3) for the control plants. Among the treated plants, the highest root volume recorded was 36.00 cm^3 in Tc (Vedapatti) 48 while Tc (Vedapatti) 85 recorded the lowest (16.00 cm^3), (Table 3).

Table 3: Effect of different irrigation regime on root volume (cm^3) on the seedlings of identified plus trees

S. No.	Plus trees	Root volume (cm^3)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	29.00	20.00	24.50
2	Tc (Vedapatti) 2	35.00	34.00	34.50
3	Tc (Vedapatti) 9	17.00	22.00	19.50
4	Tc (Vedapatti) 15	24.00	21.00	22.50
5	Tc (Vedapatti) 18	25.00	23.00	24.00
6	Tc (Vedapatti) 29	31.00	30.00	30.50
7	Tc (Vedapatti) 31	21.00	23.00	22.00
8	Tc (Vedapatti) 33	25.00	26.00	25.50
9	Tc (Vedapatti) 37	30.00	30.00	30.00
10	Tc (Vedapatti) 40	27.00	25.00	26.00
11	Tc (Vedapatti) 41	23.00	21.00	22.00
12	Tc (Vedapatti) 42	26.00	23.00	24.50
13	Tc (Vedapatti) 45	24.00	22.00	23.00
14	Tc (Vedapatti) 48	29.00	36.00	32.50
15	Tc (Vedapatti) 55	24.00	21.00	22.50
16	Tc (Vedapatti) 61	20.00	24.00	22.00
17	Tc (Vedapatti) 63	21.00	25.00	23.00
18	Tc (Vedapatti) 64	24.00	23.00	23.50
19	Tc (Vedapatti) 66	24.00	27.00	25.50
20	Tc (Vedapatti) 67	29.00	24.00	26.50
21	Tc (Vedapatti) 68	15.00	19.00	17.00
22	Tc (Vedapatti) 72	24.00	21.00	22.50
23	Tc (Vedapatti) 75	25.00	24.00	24.50
24	Tc (Vedapatti) 76	36.00	32.00	34.00
25	Tc (Vedapatti) 78	19.00	20.00	19.50
26	Tc (Vedapatti) 85	17.00	16.00	16.50
27	Tc (Vedapatti) 86	24.00	22.00	23.00
28	Tc (Vedapatti) 88	25.00	21.00	23.00
29	Tc (Vedapatti) 90	26.00	22.00	24.00
30	Tc (Vedapatti) 91	19.00	27.00	23.00
31	Tc (Vedapatti) 94	30.00	28.00	29.00
32	Tc (Vedapatti) 99	26.00	24.00	25.00
33	Tc (Vedapatti) 110	25.00	23.00	24.00
34	Tc (Vedapatti) 111	28.00	35.00	31.50

35	Tc (Thondamuthur) 121	26.00	23.00	24.50
Mean		24.94	24.49	24.71
		P	I	P×I
SE (d)		0.382	0.091	0.540
CD (P=0.05)		0.755**	0.181**	1.068**

NS – Non significant, * - Significant, ** - Highly Significant

Root girth showed significant difference between plus trees, irrigation regime and their interactions. Overall, Tc (Vedapatti) 1 recorded highest value (2.68 cm) and lowest was recorded by Tc (Vedapatti) 110 (1.31 cm). For different irrigation regimes, 50 per cent field capacity recorded 2.10 cm root girth against 2.00 cm for 100 per cent field capacity. With regard to the interaction between the plus trees and irrigation schedule, highest root girth was recorded in Tc (Vedapatti) 15 (2.72 cm) and the lowest was recorded in Tc (Vedapatti) 110 (1.21 cm) in 100 per cent field capacity. For the drought conditions, the highest value was recorded in Tc (Vedapatti) 2 (2.98 cm) and the lowest was recorded in Tc (Vedapatti) 63 (1.26 cm) (Table 4).

Table 4: Effect of different irrigation regime on root girth (cm) on the seedlings of identified plus trees

S. No.	Plus trees	Root girth (cm) Irrigation regime		Mean
		100% FC	50% FC	
1	Tc (Vedapatti) 1	2.70	2.65	2.68
2	Tc (Vedapatti) 2	2.23	2.98	2.61
3	Tc (Vedapatti) 9	1.63	1.71	1.67
4	Tc (Vedapatti) 15	2.72	2.19	2.46
5	Tc (Vedapatti) 18	2.14	1.96	2.05
6	Tc (Vedapatti) 29	1.62	2.50	2.06
7	Tc (Vedapatti) 31	2.47	2.56	2.52
8	Tc (Vedapatti) 33	2.16	2.75	2.46
9	Tc (Vedapatti) 37	2.44	1.79	2.12
10	Tc (Vedapatti) 40	2.03	2.42	2.23
11	Tc (Vedapatti) 41	1.76	2.15	1.96
12	Tc (Vedapatti) 42	2.33	1.64	1.99
13	Tc (Vedapatti) 45	1.38	1.72	1.55
14	Tc (Vedapatti) 48	2.31	2.51	2.41
15	Tc (Vedapatti) 55	1.67	2.27	1.97
16	Tc (Vedapatti) 61	2.58	2.13	2.36
17	Tc (Vedapatti) 63	1.79	1.26	1.53
18	Tc (Vedapatti) 64	2.20	1.89	2.05
19	Tc (Vedapatti) 66	1.82	1.97	1.90
20	Tc (Vedapatti) 67	1.74	2.23	1.99
21	Tc (Vedapatti) 68	1.98	2.55	2.27
22	Tc (Vedapatti) 72	1.24	1.65	1.45
23	Tc (Vedapatti) 75	2.13	2.41	2.27
24	Tc (Vedapatti) 76	1.86	1.92	1.89
25	Tc (Vedapatti) 78	1.78	1.69	1.74
26	Tc (Vedapatti) 85	1.76	1.85	1.81
27	Tc (Vedapatti) 86	2.25	2.38	2.32
28	Tc (Vedapatti) 88	1.29	1.96	1.63
29	Tc (Vedapatti) 90	1.85	1.69	1.77
30	Tc (Vedapatti) 91	2.49	2.18	2.34
31	Tc (Vedapatti) 94	2.03	2.01	2.02
32	Tc (Vedapatti) 99	2.31	2.05	2.18
33	Tc (Vedapatti) 110	1.21	1.40	1.31
34	Tc (Vedapatti) 111	2.12	2.23	2.18
35	Tc (Thondamuthur) 121	1.86	2.25	2.06
Mean		2.00	2.10	2.05
		P	I	P×I
SE (d)		0.031	0.007	0.044
CD (P=0.05)		0.062**	0.014**	0.088**

NS – Non significant, * - Significant, ** - Highly Significant

Dry root weight significantly varied among 35 plus trees, drought treatment and their interactions. The highest mean dry root weight (5.21 g) was recorded in Tc (Vedapatti) 2 while lowest value (0.54 g) was recorded in Tc (Vedapatti) 85. For different irrigation regime, the increased dry root weight of 2.01 g was recorded in 50 per cent field capacity against 1.58 g in 100 per cent field capacity. Among the interactions, the plants treated with 100 per cent field capacity recorded highest and lowest dry root weight in Tc (Thondamuthur) 121 (4.02 g) and Tc (Vedapatti) 75 (0.18 g) respectively. For 50 per cent field capacity, lowest value was observed in Tc (Vedapatti) 110 and highest value was in Tc (Vedapatti) 2 (0.35 g and 6.76 g respectively), (Table 5).

Table 5: Effect of different irrigation regime on dry root weight (g) on the seedling of identified plus trees

S. No.	Plus trees	Dry root weight (g)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	0.52	1.78	1.15
2	Tc (Vedapatti) 2	3.65	6.76	5.21
3	Tc (Vedapatti) 9	0.53	0.89	0.71
4	Tc (Vedapatti) 15	0.90	0.63	0.77
5	Tc (Vedapatti) 18	0.72	1.21	0.97
6	Tc (Vedapatti) 29	3.81	5.68	4.75
7	Tc (Vedapatti) 31	0.50	1.10	0.80
8	Tc (Vedapatti) 33	1.84	3.59	2.72
9	Tc (Vedapatti) 37	0.96	1.51	1.24
10	Tc (Vedapatti) 40	1.92	2.20	2.06
11	Tc (Vedapatti) 41	0.38	0.75	0.57
12	Tc (Vedapatti) 42	0.56	0.85	0.71
13	Tc (Vedapatti) 45	1.22	1.64	1.43
14	Tc (Vedapatti) 48	3.80	5.13	4.47
15	Tc (Vedapatti) 55	1.23	1.81	1.52
16	Tc (Vedapatti) 61	0.76	1.52	1.14
17	Tc (Vedapatti) 63	1.83	2.35	2.09
18	Tc (Vedapatti) 64	2.88	1.37	2.13
19	Tc (Vedapatti) 66	0.81	0.45	0.63
20	Tc (Vedapatti) 67	0.52	1.51	1.02
21	Tc (Vedapatti) 68	0.56	2.10	1.33
22	Tc (Vedapatti) 72	0.83	0.92	0.88
23	Tc (Vedapatti) 75	0.18	1.72	0.95
24	Tc (Vedapatti) 76	2.56	2.35	2.46
25	Tc (Vedapatti) 78	1.57	1.80	1.69
26	Tc (Vedapatti) 85	0.47	0.61	0.54
27	Tc (Vedapatti) 86	0.85	1.33	1.09
28	Tc (Vedapatti) 88	1.72	2.15	1.94
29	Tc (Vedapatti) 90	1.83	1.96	1.90
30	Tc (Vedapatti) 91	2.25	0.58	1.42
31	Tc (Vedapatti) 94	3.53	2.57	3.05
32	Tc (Vedapatti) 99	0.86	1.58	1.22
33	Tc (Vedapatti) 110	0.97	0.35	0.66
34	Tc (Vedapatti) 111	3.85	5.16	4.51
35	Tc (Thondamuthur) 121	4.02	2.53	3.28
Mean		1.58	2.01	1.80
		P	I	P×I
SE (d)		0.031	0.007	0.044
CD (P=0.05)		0.062**	0.014**	0.088**

NS – Non significant, * - Significant, ** - Highly Significant

Significant variation was observed between drought application, plus trees and their interaction for the number of roots. Among 35 plus trees, the highest mean was recorded in Tc (Vedapatti) 2 (58.50) and the lowest was recorded in Tc (Vedapatti) 18 (20.00). For different irrigation regimes, the number of roots for 50 per cent field capacity was 34.34 against 28.63 in 100 per cent field capacity. The interaction effect showed that, the highest and lowest number of roots, 63 and 12 was recorded by Tc (Vedapatti) 99 and Tc (Vedapatti) 86 respectively for the plants treated with 100 per cent field capacity. Tc (Vedapatti) 2 and Tc (Vedapatti) 18 recorded the highest and lowest number of roots 62 and 18 respectively for drought imposed plants (50% field capacity), (Table 6).

Table 6: Effect of different irrigation regime on number of roots on the seedlings of identified plus trees

S. No.	Plus trees	Number of roots		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	29.00	27.00	28.00
2	Tc (Vedapatti) 2	55.00	62.00	58.50
3	Tc (Vedapatti) 9	17.00	29.00	23.00
4	Tc (Vedapatti) 15	38.00	32.00	35.00
5	Tc (Vedapatti) 18	22.00	18.00	20.00
6	Tc (Vedapatti) 29	22.00	51.00	36.50
7	Tc (Vedapatti) 31	29.00	58.00	43.50
8	Tc (Vedapatti) 33	24.00	22.00	23.00

9	Tc (Vedapatti) 37	20.00	22.00	21.00
10	Tc (Vedapatti) 40	15.00	39.00	27.00
11	Tc (Vedapatti) 41	25.00	26.00	25.50
12	Tc (Vedapatti) 42	27.00	38.00	32.50
13	Tc (Vedapatti) 45	28.00	35.00	31.50
14	Tc (Vedapatti) 48	27.00	38.00	32.50
15	Tc (Vedapatti) 55	26.00	38.00	32.00
16	Tc (Vedapatti) 61	21.00	25.00	23.00
17	Tc (Vedapatti) 63	15.00	28.00	21.50
18	Tc (Vedapatti) 64	48.00	29.00	38.50
19	Tc (Vedapatti) 66	18.00	32.00	25.00
20	Tc (Vedapatti) 67	40.00	32.00	36.00
21	Tc (Vedapatti) 68	42.00	35.00	38.50
22	Tc (Vedapatti) 72	48.00	51.00	49.50
23	Tc (Vedapatti) 75	19.00	32.00	25.50
24	Tc (Vedapatti) 76	45.00	47.00	46.00
25	Tc (Vedapatti) 78	19.00	43.00	31.00
26	Tc (Vedapatti) 85	21.00	23.00	22.00
27	Tc (Vedapatti) 86	12.00	37.00	24.50
28	Tc (Vedapatti) 88	21.00	26.00	23.50
29	Tc (Vedapatti) 90	33.00	25.00	29.00
30	Tc (Vedapatti) 91	28.00	47.00	37.50
31	Tc (Vedapatti) 94	21.00	25.00	23.00
32	Tc (Vedapatti) 99	63.00	35.00	49.00
33	Tc (Vedapatti) 110	35.00	38.00	36.50
34	Tc (Vedapatti) 111	27.00	22.00	24.50
35	Tc (Thondamuthur) 121	22.00	35.00	28.50
Mean		28.63	34.34	31.49
		P	I	P×I
SE (d)		0.506	0.121	0.716
CD (P=0.05)		1.000**	0.239**	1.415**

NS – Non significant, * - Significant, ** - Highly Significant

Cocoa growth and development is mainly affected by moisture stress and adaptations for survival under such conditions is met out by adaptations and alterations in morphological characteristics (Almeida and Valle, 2007) [1]. Morphological changes of genotypes during drought can be used as selection criteria for screening at early stages for tolerance (Moser *et al.,* 2010) [13]. During drought condition, plants tend to reduce their activity and try to end their life cycle. Studies under greenhouse condition showed depressive effect of water deficit stress on biomass, leaf emergence, girth, height and mortality of cocoa. The root and aerial biomass of cocoa decreased according to the degree of severity of stress. These results confirmed the sensitivity of cocoa to the slightest variation of soil moisture as reported by (Elain Apshara *et al.* (2013) [6]. In contrast to the shoot length, it was noted that root parameters such as root length, root girth, number of roots and root volume was higher in plants subjected to water stress than in control (Fig. 1). Among the genotypes, Tc (Vedapatti) 29 recorded the highest root length (38.6 cm respectively) under 50 per cent FC while it was about 23.5 cm in control. Root girth also followed the same trend and relatively higher root girth was observed under 50 per cent FC (2.98 cm) than 100 per cent FC (2.72 cm). The expansion of root system under moisture stress was due to growth of several fine and coarse secondary roots. The root girth was reported to show 18 per cent increase under water-stress and tolerant cocoa genotypes maintained root growth similar to the control plants (Santos *et al.*, 2016) [21]. Root volume showed significant variation among irrigation regimes, Tc (Vedapatti) 48 recorded highest root volume in 50 per cent FC. Plants subjected to low soil water regimes can develop an extensive root system to capture the available soil water (Orchard and Saltos, 1988) [17]. Drought has been reported to increase the root length due to an increase in biomass allocation to the root which facilitates increase in root length thereby facilitating exploration of large soil volume for water (Fageria, 2012) [7]. Traits which favour drought tolerance in plants include greater allocation of biomass to root than above ground parts, lower evaporative surface (leaf area) and thicker leaves (Ludlow, 1989) [11]. In general, soil water deficit significantly influenced biomass production, reducing dry weight in all plant parts. In contrast to the previous reports, present study revealed that the mean fresh root weight, dry root weight, root girth and root volume tend to increase in plants subjected to water stress. These root traits can be relied upon to select drought tolerant cocoa genotypes. Root dynamics can effectively influence nutrient and water uptake by plant which in turn affects plant water status (Silva and Kummerow, 1998) [19].

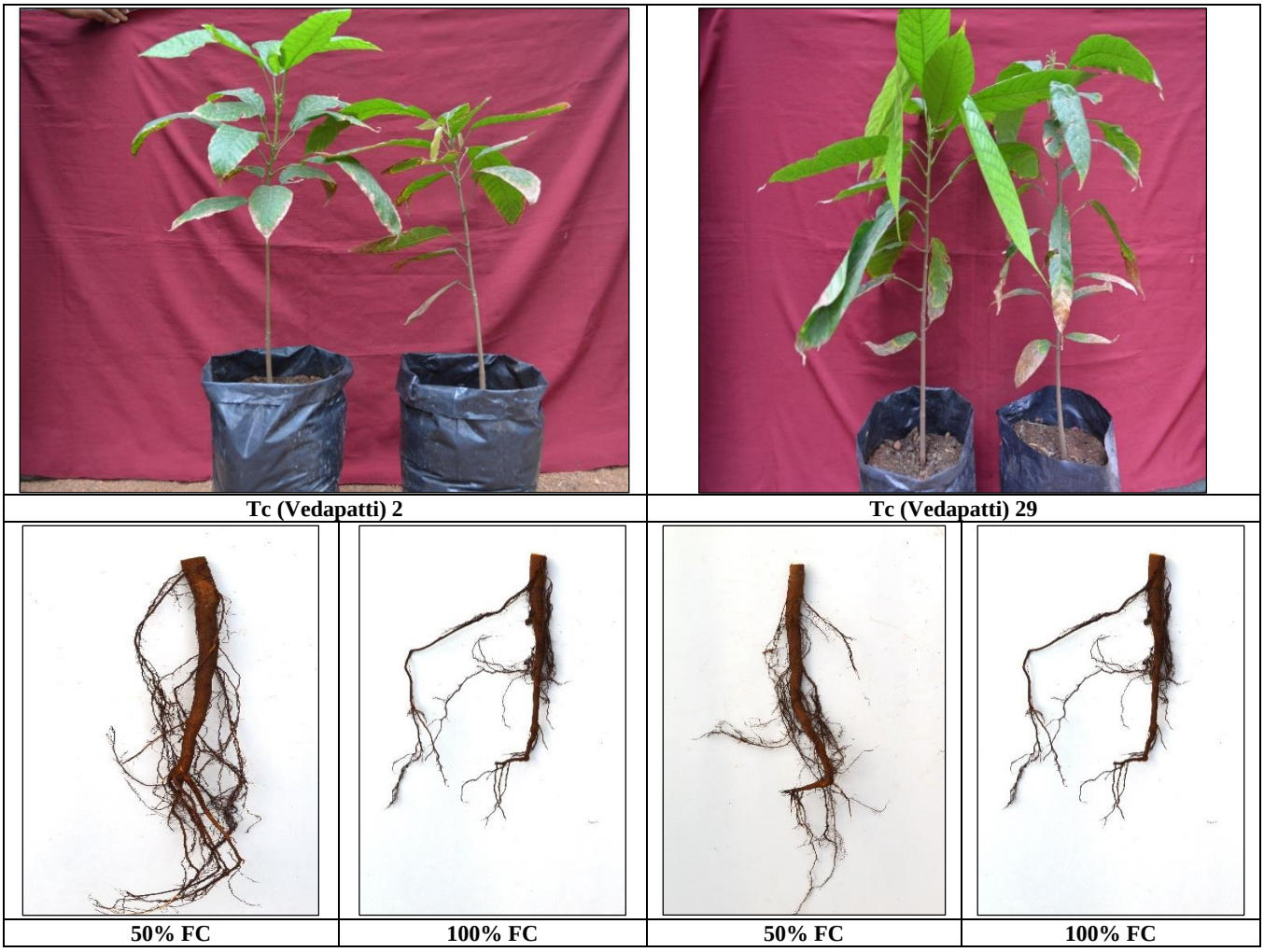

Fig 1: Effect of different irrigation regime on performance of seedlings in different identified plus trees of cocoa

Nutrient characters

Root nitrogen was highly significant among 35 plus trees, drought treatment and their interactions. In plus trees, the highest mean content was recorded in Tc (Vedapatti) 72 (1.88%) and the lowest was observed in Tc (Vedapatti) 37 (1.22%). For different irrigation schedule, the nitrogen recorded was 1.49% in case of treated plants against 1.57% in control. The interaction between plus trees and irrigation schedule showed variation. The highest nitrogen content 1.95% was recorded in Tc (Vedapatti) 72 and the lowest was recorded in Tc (Vedapatti) 67 (1.25%) for the plants treated with 100 per cent field capacity. For those plants subjected to 50 per cent field capacity, the highest nitrogen content was recorded in Tc (Vedapatti) 2 (1.84%) and the lowest was recorded in Tc (Vedapatti) 37 (1.18%), (Table 7).

Table 7: Effect of different irrigation regime on root nitrogen (%) on the seedlings of identified plus trees

S. No.	Plus trees	Root nitrogen (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	1.51	1.48	1.50
2	Tc (Vedapatti) 2	1.85	1.84	1.85
3	Tc (Vedapatti) 9	1.68	1.56	1.62
4	Tc (Vedapatti) 15	1.46	1.38	1.42
5	Tc (Vedapatti) 18	1.56	1.42	1.49
6	Tc (Vedapatti) 29	1.76	1.62	1.69
7	Tc (Vedapatti) 31	1.59	1.47	1.53
8	Tc (Vedapatti) 33	1.46	1.37	1.42
9	Tc (Vedapatti) 37	1.26	1.18	1.22
10	Tc (Vedapatti) 40	1.42	1.26	1.34
11	Tc (Vedapatti) 41	1.38	1.26	1.32
12	Tc (Vedapatti) 42	1.63	1.57	1.60
13	Tc (Vedapatti) 45	1.48	1.35	1.42
14	Tc (Vedapatti) 48	1.56	1.42	1.49
15	Tc (Vedapatti) 55	1.85	1.78	1.82
16	Tc (Vedapatti) 61	1.56	1.48	1.52

17	Tc (Vedapatti) 63	1.48	1.55	1.52
18	Tc (Vedapatti) 64	1.73	1.65	1.69
19	Tc (Vedapatti) 66	1.58	1.48	1.53
20	Tc (Vedapatti) 67	1.25	1.19	1.22
21	Tc (Vedapatti) 68	1.62	1.55	1.59
22	Tc (Vedapatti) 72	1.95	1.81	1.88
23	Tc (Vedapatti) 75	1.62	1.61	1.62
24	Tc (Vedapatti) 76	1.56	1.42	1.49
25	Tc (Vedapatti) 78	1.41	1.25	1.33
26	Tc (Vedapatti) 85	1.32	1.28	1.30
27	Tc (Vedapatti) 86	1.62	1.55	1.59
28	Tc (Vedapatti) 88	1.71	1.62	1.67
29	Tc (Vedapatti) 90	1.85	1.73	1.79
30	Tc (Vedapatti) 91	1.46	1.62	1.54
31	Tc (Vedapatti) 94	1.62	1.58	1.60
32	Tc (Vedapatti) 99	1.42	1.38	1.40
33	Tc (Vedapatti) 110	1.68	1.56	1.62
34	Tc (Vedapatti) 111	1.73	1.62	1.68
35	Tc (Thondamuthur) 121	1.38	1.25	1.32
Mean		1.57	1.49	1.53
		P	I	P×I
SE (d)		0.025	0.006	0.036
CD (P=0.05)		0.052**	0.012**	0.072**

NS – Non significant, * - Significant, ** - Highly Significant

Significant variation was observed between drought application, plus trees and their interaction with regard to root phosphorous content. The highest mean root phosphorous content was recorded in the plus trees, Tc (Vedapatti) 29 and Tc (Vedapatti) 64 (0.70%) and the lowest was found in Tc (Vedapatti) 85 (0.24%). For different irrigation regimes, treated plants recorded 0.33% phosphorous content against 0.55% in control. Interaction between plus trees and treatment showed variation in phosphorous. It was observed that, Tc (Vedapatti) 64 (0.98%) and Tc (Vedapatti) 85 (0.15%) recorded highest and lowest phosphorous content respectively for 100 per cent field capacity. For 50 per cent field capacity, the rates recorded were about 0.63% (highest) and 0.12% (lowest) in Tc (Vedapatti) 29 and Tc (Vedapatti) 111 respectively (Table 8).

Table 8: Effect of different irrigation regime on root phosphorus (%) on the seedlings of identified plus trees

S. No.	Plus trees	Root phosphorus (%) Irrigation regime		Mean
		100% FC	50% FC	
1	Tc (Vedapatti) 1	0.48	0.35	0.42
2	Tc (Vedapatti) 2	0.81	0.56	0.69
3	Tc (Vedapatti) 9	0.31	0.25	0.28
4	Tc (Vedapatti) 15	0.48	0.36	0.42
5	Tc (Vedapatti) 18	0.41	0.32	0.37
6	Tc (Vedapatti) 29	0.76	0.63	0.70
7	Tc (Vedapatti) 31	0.51	0.36	0.44
8	Tc (Vedapatti) 33	0.58	0.49	0.54
9	Tc (Vedapatti) 37	0.71	0.28	0.50
10	Tc (Vedapatti) 40	0.56	0.38	0.47
11	Tc (Vedapatti) 41	0.53	0.41	0.47
12	Tc (Vedapatti) 42	0.38	0.26	0.32
13	Tc (Vedapatti) 45	0.42	0.25	0.34
14	Tc (Vedapatti) 48	0.63	0.42	0.53
15	Tc (Vedapatti) 55	0.53	0.28	0.41
16	Tc (Vedapatti) 61	0.85	0.41	0.63
17	Tc (Vedapatti) 63	0.68	0.25	0.47
18	Tc (Vedapatti) 64	0.98	0.42	0.70
19	Tc (Vedapatti) 66	0.55	0.41	0.48
20	Tc (Vedapatti) 67	0.49	0.38	0.44
21	Tc (Vedapatti) 68	0.48	0.31	0.40
22	Tc (Vedapatti) 72	0.56	0.15	0.36
23	Tc (Vedapatti) 75	0.62	0.19	0.41
24	Tc (Vedapatti) 76	0.65	0.18	0.42
25	Tc (Vedapatti) 78	0.56	0.35	0.46
26	Tc (Vedapatti) 85	0.15	0.32	0.24
27	Tc (Vedapatti) 86	0.42	0.38	0.40
28	Tc (Vedapatti) 88	0.55	0.26	0.41

29	Tc (Vedapatti) 90	0.41	0.25	0.33
30	Tc (Vedapatti) 91	0.38	0.21	0.30
31	Tc (Vedapatti) 94	0.45	0.36	0.41
32	Tc (Vedapatti) 99	0.62	0.42	0.52
33	Tc (Vedapatti) 110	0.62	0.25	0.44
34	Tc (Vedapatti) 111	0.38	0.12	0.25
35	Tc (Thondamuthur) 121	0.63	0.23	0.43
Mean		0.55	0.33	0.44
		P	I	P×I
SE (d)		0.021	0.003	0.023
CD (P=0.05)		0.035	0.008	0.056

NS – Non significant, * - Significant, ** - Highly Significant

Root potassium showed significant difference between plus trees, irrigation regime and their interactions. Maximum root potassium content for plus trees recorded was 1.46% in Tc (Vedapatti) 66 and minimum was recorded in Tc (Vedapatti) 110 (0.99%). For different irrigation regimes, potassium content recorded was 1.20% in drought imposed plants against 1.36% in control. The interaction between plus trees and drought condition showed highest potassium content in Tc (Vedapatti) 66 (1.55%) and the lowest was recorded in Tc (Vedapatti) 110 (1.12%) in control. For drought treated plants, highest potassium content was observed in Tc (Vedapatti) 2 (1.50%) and lowest potassium content was in Tc (Vedapatti) 91 (0.72%), (Table 9).

Table 9: Effect of different irrigation regime on root potassium (%) on the seedlings of identified plus trees

S. No.	Plus trees	Root potassium (%)		Mean
		Irrigation regime		
		100% FC	50% FC	
1	Tc (Vedapatti) 1	1.38	1.25	1.32
2	Tc (Vedapatti) 2	1.38	1.50	1.44
3	Tc (Vedapatti) 9	1.45	1.38	1.42
4	Tc (Vedapatti) 15	1.48	1.21	1.35
5	Tc (Vedapatti) 18	1.35	1.28	1.32
6	Tc (Vedapatti) 29	1.39	1.42	1.41
7	Tc (Vedapatti) 31	1.42	1.28	1.35
8	Tc (Vedapatti) 33	1.28	0.85	1.07
9	Tc (Vedapatti) 37	1.33	1.25	1.29
10	Tc (Vedapatti) 40	1.36	1.29	1.33
11	Tc (Vedapatti) 41	1.48	1.32	1.40
12	Tc (Vedapatti) 42	1.35	1.19	1.27
13	Tc (Vedapatti) 45	1.23	1.02	1.13
14	Tc (Vedapatti) 48	1.53	1.32	1.43
15	Tc (Vedapatti) 55	1.38	1.17	1.28
16	Tc (Vedapatti) 61	1.42	1.25	1.34
17	Tc (Vedapatti) 63	1.35	1.21	1.28
18	Tc (Vedapatti) 64	1.42	1.18	1.30
19	Tc (Vedapatti) 66	1.55	1.36	1.46
20	Tc (Vedapatti) 67	1.41	1.22	1.32
21	Tc (Vedapatti) 68	1.46	1.35	1.41
22	Tc (Vedapatti) 72	1.25	1.31	1.28
23	Tc (Vedapatti) 75	1.26	1.12	1.19
24	Tc (Vedapatti) 76	1.45	1.36	1.41
25	Tc (Vedapatti) 78	1.31	1.25	1.28
26	Tc (Vedapatti) 85	1.42	1.25	1.34
27	Tc (Vedapatti) 86	1.31	0.75	1.03
28	Tc (Vedapatti) 88	1.21	1.15	1.18
29	Tc (Vedapatti) 90	1.36	1.19	1.28
30	Tc (Vedapatti) 91	1.31	0.72	1.02
31	Tc (Vedapatti) 94	1.42	1.35	1.39
32	Tc (Vedapatti) 99	1.21	1.13	1.17
33	Tc (Vedapatti) 110	1.12	0.85	0.99
34	Tc (Vedapatti) 111	1.25	1.19	1.22
35	Tc (Thondamuthur) 121	1.38	1.25	1.32
Mean		1.36	1.20	1.28
		P	I	P×I
SE (d)		0.018	0.004	0.025
CD (P=0.05)		0.036	0.009	0.051

NS – Non significant, * - Significant, ** - Highly Significant

Drought sensitive genotypes when subjected to soil water deficit showed the significant reductions in leaf N, P and K content compared to control plants (Santos *et al*., 2016) [21]. In this study, similar trends were observed in case of N, P and K content. Under water stress condition, the availability of nutrients and their subsequent uptake by roots was impaired. Reports have shown that high N concentration in plants deposited as $NO3^-$ in the vacuole, contributes significantly to the maintenance of cell turgor, P concentration increases water use efficiency and stomata conductance while K regulates osmotic potential, thus conferring drought tolerance to plants (MacRobbie, 1998) [12].

Conclusion

Among the 35 plus trees seedlings, Tc (Vedapatti) 2 and Tc (Vedapatti) 29 showed the highest root length, root girth, number of roots, fresh root weight and dry root weight under 50 per cent field capacity irrigation regime. For nutrient uptake analysis also, Tc (Vedapatti) 2 and Tc (Vedapatti) 29 recorded maximum nitrogen, phosphorus and potassium. In this study, highly significance variation was observed in all the 35 plus trees. These variation was mainly based on both environment and genetic characters. Hence, these plus trees can be used in the future breeding program and to develop drought tolerant genotype.

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