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Phenotyping for root traits and carbon isotope discrimination in rice genotypes of Kerala

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ABSTRACT

Root traits and water use efficiency play an important role in breeding for drought tolerance in rice. Water captured by roots after flowering, is valuable for grain yield and quality because it is immediately used for grain development and filling. A set of 80 rice germplasm accessions were phenotyped for various root traits and water use efficiency ($\Delta^{13}C$) at R.A.R.S., Pattambi for three years from 2011 to 2013. Deep and thick, shallow root genotypes were selected on the basis of phenotypic data. Similarly, based upon $\Delta^{13}C$ values, high and low WUE plant types were selected. Varieties identified for deep and thick roots were Chuvanna modan, Ptb1 (Aryan), Ptb2 (Ponnaryan), Ptb 6 (Athikkiraya) and Ptb15 (Kavunginpoothala). Varieties identified for high WUE (based on $\Delta^{13}C$ value) were Ptb5 (Veluthari kayama), Ptb7 (Parambuvattan), Ptb9 (Thavalakannan), Ptb10 (Thekkancheera) and Ptb19 (Athikiraya). It is found that Uma (MO-18), a high yielding variety with low carbon isotope discrimination (22.17 per mil) having high WUE. Otherwise, most of the high yielding varieties have high carbon isotope discrimination values under normal condition. This variety also recorded the higher SPAD chlorophyll meter reading (SCMR) values in three consecutive years. These selected genotypes can be used as donor parents for drought resistance breeding programmes in rice.

Key words: *Rice, root traits, carbon isotope discrimination, water use efficiency*

INTRODUCTION

Root system plays an important role in crop adaptation in the changing climate scenario. Water scarcity will be a threatening problem in the coming years. It is recognized now that in dry environments and dry seasons crop yield depends on the ability of the root system to capture as much water from soil as possible between germination and physiological maturity (Palta and Watt, 2009). A crop root system that is deep and abundant at depth would contribute to maintain yield stability in dry seasons and dry environments where drought spells during the season often occur (Palta and Watt, 2009; Palta et al., 2011; Panda et al., 2017). The contribution of a deep and abundant at depth root system to maintain yield stability in dry seasons depends on its ability to continue extending into moist soil throughout the season, enabling access to more soil volume and water particularly around flowering and grain filling. Water captured by roots after flowering, is valuable for grain yield and quality because it is immediately used for grain development and filling (Passioura, 1983; Angus and van Herwaarden, 2001). Thus, in dry seasons and dry environments, if deep soil water is available any breeding or management effort that produced a deeper root system to capture this water will increase grain yields. Root morphology and physiology are closely associated with the growth and development of above ground part of plant (Yang, 2011). According to Den Herder et al. (2010), it is the time to improve the plant's capacity for uptake and fixation of nutrients and the focus should be on improving the root system. Carbon isotope discrimination is not an instantaneous measurement of water use efficiency (WUE), which could be affected by environmental changes but it is an estimation of WUE for all the term during which $\Delta^{13}C$ was assimilated. In Kerala, rice growing conditions are divergent in different locations. It varies from hilly area to below main sea level. Genotypes are adapted to different growing conditions; hence its root traits will also vary according to the environment. Hence, the objective of the study is to characterize the phenotypic variations in root traits and carbon isotope discrimination ($\Delta^{13}C$) in rice genotypes.

MATERIALS AND METHODS

Phenotyping for root traits

Phenotyping for root traits were done in specially constructed "root structure" of 5ft tall, 10ft width and 60 ft length. 80 varieties were planted in rows with a spacing of 20 x 15 cm. At the end of the experiment, the brick wall along the sides was dismantled with care and the soil washed away using strong jet of water. The roots were separated carefully from soil particles and then used to record root length, shoot length, root volume, root dry weight. Specific leaf area (SLA) and SPAD chlorophyll meter readings (SCMR) were taken 70 days after planting.

Assessment of genetic variability in water use efficiency (WUE)

Genetic variability in WUE was measured using $\Delta^{13}C$ values. The theory linking $\Delta^{13}C$ and WUE has been well studied and the physiological basis of such relationship is also well understood that $\Delta^{13}C$ is negatively correlated with WUE. An isotope ratio mass spectrometer (IRMS) interfaced with a suitable combustion system is used for the determination of $\Delta^{13}C$.

The experimental materials for this study consisted of 80 rice accessions including improved rice varieties and landraces. The entries were evaluated in a randomized complete block design with two replications during *kharif* 2011, 2012 and 2013. Each replication had 80 entries. The experiment was laid out in a specially built root structure. The size of root structure was 20x3x1m which was filled with soil. The wall of the structures was dismantled and the soil was carefully washed to extract the root. On completion of the experiment, shoot length, root length, root volume, root and shoot dry weight, SCMR (SPAD Chlorophyll Meter Reading) and $\Delta^{13}C$ were measured. Fertilizer and plant protection measures were done according to the recommended package of practices. The SPAD chlorophyll meter (SPAD-502, Minolta, USA) readings were made 80 days after sowing. After recording SCMR, the leaves were processed for specific leaf area (SLA) measurement. In field trial, seventy three varieties were evaluated for yield trial during the *rabi* 2011. Each entry was replicated thrice with the plot size of $3.78m^2$. Fertilizer and plant protection measures were done according to the recommended package of practices. Observations were taken for yield and yield components.

RESULTS AND DISCUSSION

Analysis of the data (Table 1) revealed that genotypic variation was significant for specific leaf area (SLA), SPAD chlorophyll meter reading (SCMR), shoot length, root length, root volume, root dry weight and water use efficiency (WUE) (Table1). For specific leaf area (SLA), lowest value was recorded for Karuna (Ptb 54) ($259.7 cm^2g^{-1}$) followed by Ptb26 (Chenkayama) ($276.06\ cm^2g^{-1}$). Higher SLA values represent a larger surface area for transpiration, hence, SLA and WUE would be inversely related (Wright et al., 1994; Nageswara Rao et al., 2001; Bindu Madhava et al. 2003). There was a significant variation for SCMR among the rice entries. Highest SCMR values were recorded by Ramnath New (44.14) followed by Ptb38 (Triveni) (43.28) and Uma (43.12). As a noninvasive surrogate of transpiration efficiency, SCMR is easy to operate, reliable, fairly stable and low cost (Sheshshayee et al. 2006). SCMR is reported to be more stable than SLA (Upadhyaya, 2005). It is also correlated with pod yield in groundnut (Reddy et al., 2004; Upadhyaya, 2005). Highest shoot length of 174cm was recorded by Ptb24 (Chuvanna Vattan), followed by Ptb 22 (Velutha vattan) (154cm) and Ptb23 (Cheriya Aryan) (152cm). For upland situation, shoot length is also an important factor for weed competition. Highest root length was recorded by Chovanna Modan (90.60cm), which was followed by Karanavara (77.6cm), Ptb19 (Athikkiriya) (59.8cm) and Ptb15 (Kavunginpoothala) (58.8cm). For root volume also, Ptb15 recorded the highest value of ($74\ cm^3$) followed by Ptb13 (Kayama) (66cm3), Ptb2 (Ponnaryan) ($62\ cm^3$) and Ptb1 (Aryan) (60cm3). There is a significant positive correlation between shoot length and root length (Fig. 1). This is supported by (Chu et al., 2104) and reported that root growth was closely

Table 1. Phenotypic variation in physio-morphological parameters in rice genotypes (2011)

S.No.	Genotypes	$\Delta^{13}C$ (per mil)	SLA (cm^{-2}/g)	SCMR	Shoot Length (cm)	Root Length (cm)	Root volume (ml)	Shoot wt (g)	Root wt(g)
1	PTB 1	23.33	378.13	34.32	125.00	49.60	60.00	24.36	27.47
2	PTB 2	22.76	344.69	33.96	127.40	43.60	62.00	27.01	25.72
3	PTB 4	22.73	373.03	38.78	100.00	29.20	23.00	15.67	4.89
4	PTB 5	21.97	293.33	26.74	95.64	38.80	25.00	24.92	8.52
5	PTB7	22.26	361.09	26.66	98.88	39.92	26.00	24.13	7.79
6	PTB8	22.67	343.07	35.76	74.88	27.70	8.40	14.30	10.44
7	PTB9	21.60	348.79	39.08	121.06	43.24	25.00	12.04	4.29
8	PTB10	22.21	362.32	37.08	126.60	37.80	20.00	18.44	5.80
9	PTB 12	23.08	373.86	33.86	104.40	30.10	18.40	5.24	4.11
10	PTB13	22.57	361.47	38.56	134.80	50.80	66.00	14.66	28.28
11	PTB 14	23.07	360.15	34.96	140.20	41.60	35.00	24.67	14.57
12	PTB 15	22.44	346.11	33.30	135.60	58.80	74.00	7.95	29.24
13	PTB 16	23.00	377.06	35.50	121.00	50.00	47.00	16.36	6.76
14	PTB 17	23.17	398.55	30.46	99.00	37.00	18.00	7.13	7.07
15	PTB18	23.05	403.87	36.32	121.80	40.60	40.00	22.68	15.21
16	PTB 19	22.26	307.24	34.84	115.80	59.80	38.20	14.50	9.10
17	PTB 20	22.49	382.72	36.80	111.40	50.00	48.00	25.23	20.48
18	PTB21	23.39	396.90	27.20	92.60	38.60	29.00	35.94	13.38
19	PTB22	22.17	413.39	36.20	154.00	52.60	32.00	24.37	17.01
20	PTB23	22.59	363.71	35.34	152.70	45.40	46.00	23.18	8.14
21	PTB24	22.94	331.29	37.42	174.40	49.20	58.00	19.62	28.73
22	PTB25	22.51	433.40	35.40	147.40	37.20	42.00	22.31	10.98
23	PTB 26	22.96	276.06	33.18	128.40	32.00	28.00	16.77	10.34
24	PTB27	23.59	421.66	35.96	87.38	34.40	15.00	20.60	18.77
25	PTB28	22.32	324.14	32.44	158.20	46.60	43.00	23.49	18.55
26	PTB29	22.86	375.69	36.08	132.80	52.80	32.00	31.78	16.36
27	PTB30	22.87	384.58	38.46	133.80	44.60	17.00	22.52	6.69
28	PTB31	23.09	361.95	35.80	134.00	39.80	40.00	23.42	13.95
29	PTB32	22.60	353.16	34.34	105.80	28.20	20.40	18.49	10.02
30	PTB33	22.65	381.79	32.70	111.00	41.00	35.00	14.21	15.16
31	PTB34	22.85	353.24	36.70	101.60	33.60	29.00	20.42	11.44
32	PTB35	23.49	344.20	39.02	96.90	35.70	11.80	18.51	6.47
33	PTB36	23.63	345.30	40.56	95.20	44.80	34.60	18.74	12.04
34	PTB37	23.51	383.92	34.98	87.00	45.20	56.00	8.70	25.07
35	PTB38	23.82	302.89	43.28	89.80	46.80	34.00	26.52	17.03
36	PTB39	23.45	370.61	39.82	87.50	35.76	22.00	25.79	6.01
37	PTB40	22.41	376.91	37.84	87.30	52.20	32.00	15.10	9.92
38	PTB41	23.39	317.81	36.30	97.10	43.30	41.00	19.73	11.58
39	PTB43	23.29	359.02	40.34	131.50	48.60	40.00	23.78	12.21
40	PTB 44	23.80	278.80	34.06	103.60	42.20	45.00	10.46	15.52
41	PTB 45	23.77	321.52	40.08	74.84	33.30	17.20	17.43	4.08
42	PTB 46	23.32	326.19	40.10	81.80	35.00	33.00	13.89	9.88
43	PTB 47	22.85	325.17	35.10	92.60	28.20	25.00	7.57	5.36
44	PTB 48	22.74	312.14	33.86	95.40	31.40	33.00	28.82	12.60
45	PTB 49	23.03	349.43	39.94	80.20	30.80	30.00	23.51	9.67
46	PTB 50	23.26	311.79	38.76	76.20	29.50	25.80	14.15	14.46
47	PTB 51	23.21	341.85	36.78	92.90	33.60	28.00	17.17	9.62
48	PTB 52	23.58	299.85	38.54	91.00	39.30	43.00	15.65	11.52
49	PTB 53	22.80	424.76	31.78	102.60	35.20	35.00	32.16	12.52
50	PTB 54	22.27	259.70	29.98	119.40	33.60	53.00	6.74	24.35
51	PTB 58	23.37	338.55	38.84	100.10	35.30	17.00	14.62	6.14
52	PTB 60	23.38	356.53	38.76	123.60	47.70	42.00	13.04	8.78
53	Makaram	22.93	321.70	31.44	87.50	35.20	43.00	12.88	14.09
54	Mashoori	22.58	454.45	38.56	78.80	31.20	23.00	22.25	10.85

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55	Vytilla 4	23.03	367.36	34.76	152.60	34.80	54.00	23.52	23.46
56	Ramnath New	22.91	427.40	44.14	95.40	28.40	9.00	13.56	17.31
57	Suvarnamodan III	23.03	363.83	44.88	126.60	32.30	20.80	36.26	15.51
58	Suvarnamodan II	22.10	382.15	41.22	82.80	27.40	27.00	17.64	12.51
59	Suvarnamodan I	22.83	372.52	35.54	97.90	30.40	18.00	39.55	13.55
60	Red Ponmani	23.29	378.61	38.66	91.70	35.80	40.00	22.30	10.51
61	Kalyani II 1	22.37	375.61	35.70	104.60	28.40	24.00	16.66	8.36
62	VSL-01-12-Kattamodan	23.94	297.64	32.76	148.00	31.40	36.00	11.62	8.95
63	KK VARNA	22.04	440.94	38.72	62.90	32.40	13.60	21.48	20.04
64	UMA	22.17	352.51	43.12	79.60	47.80	16.00	19.25	20.57
65	CHOMALA	22.71	459.41	35.56	106.00	43.00	22.60	6.36	7.68
66	CHEMALA	22.64	398.91	34.60	101.40	38.20	8.40	14.41	11.80
67	Chovanna Modan	24.31	401.28	40.64	127.40	90.60	35.00	31.01	6.61
68	Karanavara	23.54	361.39	39.42	146.60	77.60	40.00	11.64	12.40
69	Karuthamodan	22.65	356.10	37.24	140.80	48.40	11.20	25.40	20.55
70	Kalldiyar	22.34	351.67	35.34	146.40	43.20	19.60	18.63	17.30
71	Karuthadukkan	23.07	339.30	33.72	150.20	47.60	17.80	13.50	13.07
72	Parambuvattan	22.80	375.01	35.96	135.00	38.20	21.00	29.34	8.77
73	Thottacheera	22.41	322.82	35.56	154.80	31.20	23.00	22.18	6.97
74	KRH-2	23.13	301.00	40.20	97.00	44.60	31.00	8.58	4.91
75	PA-6124	22.86	354.56	41.68	91.60	49.20	16.60	24.17	6.49
76	PA-6201	22.95	353.43	39.84	89.60	45.60	28.00	19.55	10.62
77	PA-6444	22.61	391.55	38.18	87.80	49.20	38.00	11.63	6.28
78	PHB-71	22.93	369.78	36.78	96.20	44.40	32.00	14.87	11.34
79	Akshadhan	23.72	326.01	41.62	105.00	33.40	23.00	17.57	7.18
80	Varadhan	23.42	328.35	42.96	93.40	34.00	18.00	31.72	6.39
	Average	22.92	358.23	36.65	110.65	40.82	31.36	19.33	12.60
	Maximum	24.31	459.41	44.88	174.40	90.60	74.00	39.55	29.24
	Minimum	21.60	259.70	26.66	62.90	27.40	8.40	5.24	4.08
	S.D.	0.51	40.01	3.64	24.77	10.58	14.02	7.25	6.30

associated with shoot growth in rice and improved root morphological and physiological performance for water saving drought resistant rice benefits shoot physiological processes, leading to higher grain yield and water productivity under alternate wetting and drying condition. Deep root system is the most consensual of the traits contributing to drought avoidance. There is significant variation for $\Delta^{13}C$ among the genotypes and it varied from 21.60 to 24.31%. There is a positive relationship between $\Delta^{13}C$ and yield (Fig. 2). Most of the traditional varieties showed higher WUE (low $\Delta^{13}C$) than high yielding varieties. Highest WUE was showed by Ptb9 (Thavalakannan) ($\Delta^{13}C$=21.6 ‰) and lowest by Chovanna Modan ($\Delta^{13}C$=24.31 ‰). There is significant variability for yield and yield components among the rice varieties.

During 2012, observations were taken for plant height, specific leaf area and SCMR. For these parameters, there a positive correlation between 2011 and 2012 data. During 2013, observations were taken

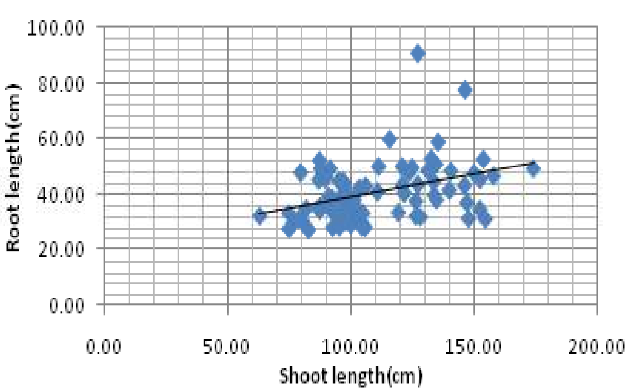

Fig. 1. Relationship between shoot length and root length in rice genotypes.

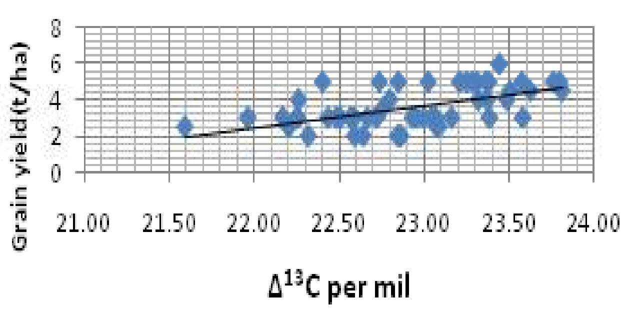

Fig. 2. Relationship between grain yield and carbon isotope discrimination ($\Delta^{13}C$) in rice genotypes

Table 2. Genetic variability in physio-morphological traits in rice (2013)

S.No.	Genotype	Plant Height (cm)	Root Length (cm)	Root volume (ml)	Root biomass (g)	Shoot biomass (g)	Canopy Temp (°C)	SCMR	Chlorophyll content(mg/g)
1	Ptb 1	127.6	96	90	8.89	17.05	29.1	34.1	0.71
2	Ptb 2	131.6	70.3	67.6	9.01	28.21	28.7	30.3	0.98
3	Ptb 3	119.6	55.3	43.3	5.81	21.93	28.7	36.6	1.31
4	Ptb 4	135.6	73.6	80	6.4	28.51	28.6	31.7	1.36
5	Ptb 5	135.3	54.6	83.3	10	27.89	28.9	34.5	1.12
6	Ptb 6	143.6	79	86.6	8.34	21.26	28.8	32.3	1.22
7	Ptb 7	127	49	33.3	6.88	27.74	28.6	32.2	1.21
8	Ptb 8	94	62	76.6	8.82	16.56	28.7	39	1.38
9	Ptb 9	134.3	60	81.6	6.25	19.09	28.1	37.6	1.03
10	Ptb 10	145.3	76.3	90	8.09	31.81	28.4	36.6	1.15
11	Ptb 12	146.5	54	45	5.06	21.62	28.8	34.6	1.24
12	Ptb 13	125	43	43.3	6.08	22.86	29.1	33.8	1.08
13	Ptb 14	141.3	45	63.3	10.72	31.81	29.2	39.2	0.91
14	Ptb 15	132.3	52	56.6	8.27	18.65	28.7	32.4	1.13
15	Ptb 16	114.3	47.6	36.6	7.77	20.12	28.6	32.2	1.12
16	Ptb 17	109.3	56	66.6	6.2	20.92	28.6	35.1	1.02
17	Ptb 18	110	41.3	36.6	7.49	22.81	28.8	33.7	1.1
18	Ptb 19	106.6	45.6	53.3	9.39	17.56	28.9	36.8	1.06
19	Ptb 20	94	50.3	36.6	7.98	13.42	28.5	37.3	0.92
20	Ptb 21	89.5	59	53.3	7.78	13.74	28.6	34.5	1.36
21	Ptb 22	112	40	13.3	2.39	8.73	28.7	33.3	1.12
22	Ptb 23	128	47.3	43.3	6.34	19.37	28.6	33.7	1.13
23	Ptb 24	126.3	47	36.6	3.88	24.57	28.8	34.9	1.1
24	Ptb 25	128	40	23.3	3.6	20.39	28.9	40.4	1.11
25	Ptb 26	135.3	39	23.3	4.38	18.52	28.7	31.5	1.35
26	Ptb 27	96.3	41	36.6	7.49	23.01	28.6	34.1	1.2
27	Ptb 28	133	41	20	2.53	8.36	28.5	33.7	1.15
28	Ptb 29	105.3	37.3	16.6	6.26	25.09	28.7	35.1	1.26
29	Ptb 30	128.3	50.3	33.3	4.17	16.32	28.3	32.1	1.18
30	Ptb 31	78.6	35.6	16.6	1.7	10.22	28.6	29.9	1.19
31	Ptb 32	119.3	36.2	20	2.82	9.92	29	31.9	1.26
32	Ptb 33	129	52	36.6	6.5	11.06	29.1	34.9	1.13
33	Ptb 34	79	58.3	40	6.97	11.55	29.2	30.3	1.05
34	Ptb 35	89.3	51	15	3.9	8.92	29	36.1	1.16
35	Ptb 36	78.3	43.3	20	2.75	7.2	29.1	34.2	1.3
36	Ptb 37	85.6	61.6	30	4.47	16.86	29.2	33.3	0.99
37	Ptb 38	79.6	43.2	26.6	3.95	16.74	29.2	38.3	1.07
38	Ptb 39	86.3	61.6	40	4.8	12.16	29.1	37.9	1.03
39	Ptb 40	96.3	54.3	40	5.98	11.66	29.1	31.8	1.14
40	Ptb 41	121.3	83.3	45	9.6	23.97	28.4	37.2	1.01
41	Ptb 42	95.4	50.1	42	8.9	22.6	28.5	36.4	0 .98
42	Ptb 43	92.6	53.3	40	3.92	20.7	28.9	30.6	1.31
43	Ptb 44	136.6	59.3	33.3	4.75	20.89	28.8	32.8	1.29
44	Ptb 45	86.3	65.6	33.3	3.81	19.95	28.7	36.6	0.97
45	Ptb 46	98.3	39.6	36.6	3.83	20.65	28.3	38.7	1.23
46	Ptb 47	86.6	50.3	36.6	5.21	16.52	28.3	35.3	1.9
47	Ptb 48	99.6	67	46.6	5.19	16.36	28.3	32.2	1.28
48	Ptb 49	104.6	63.6	33.3	2.43	22.89	28.4	32.1	1.45
49	Ptb 50	87	35.6	23.3	3.85	18.04	28.6	33.8	1.71
50	Ptb 51	115	51.6	30	5.19	19.45	28.7	32.7	1.81
51	Ptb 52	104	51.3	25	2.97	16.56	28.6	34.2	1.73
52	Ptb 53	138	55	46.6	9.07	22.71	28.7	32.7	1.26
53	Ptb 54	112	60.6	40	5.54	14.54	28.5	33.4	0.67
54	Ptb 55	90.3	41	20	2.82	15	28.8	38.7	0.86

Continued...........

55	Ptb 56	82.6	48	16.6	2.47	8.99	28.7	29.4	0.83
56	Ptb 57	82.6	44.3	20	4.6	9.28	28.8	27.2	0.64
57	Ptb 58	93	52.6	33.3	4.04	19.36	28.2	30.1	1.11
58	Ptb 59	121.6	41	26.6	2.95	18.14	28.4	30.3	0.7
59	Ptb 60	115	36	18.3	1.82	16.75	28.8	27.3	0.54
60	Chomala	91.3	60.6	20	3.69	14.33	28.7	32.8	0.62
61	Cherady	97	51	33.3	5.4	11.75	28.7	31.9	0.5
62	Karuthadukkan	125.6	55.6	20	2.49	17.03	28.7	35.3	0.61
63	Kalladiyar	128	66	46.6	4.94	23.82	28.8	33.5	0.67
64	Karanavara	122	53.3	20	3.26	20.52	28.6	33.7	0.7
65	Thottacheera	120.3	49.3	23.3	2.12	14.54	28.5	38.6	0.71
66	Uma	82	47.6	26.6	2.67	10.8	28.4	40.6	1.34
67	Makaram	115.3	44	36.6	6.11	16.6	28.5	33.1	0.96
68	KK Varna	85.3	47	23.3	4.64	14.36	28.6	39.1	0.52
69	N-22	121.6	49	20	4.59	15.18	28.8	33.2	0.36
70	Sampada	82.3	39	30	4.64	16.42	28.8	36.4	0.8
71	Vellanavara	108	49.3	23.3	2.28	11.39	28.9	38.9	0.76
72	Deepthi	127.6	36	30	4.83	20.93	28.7	38.3	0.62
73	Jeerakasala	106	40.3	23.3	5.84	11.29	28.7	30.9	0.57
74	Gandhakasala	101	36.6	20	4.55	13.97	28.6	30.2	0.74
75	Bhadra	77	54.6	43.3	13.83	20.43	28.5	39.9	0.94
76	Makom	81	59.3	40	7.3	24	28.8	39.9	1.23
77	Ponmani	84.3	54	36.6	10.2	29.27	28.9	31.8	0.83
78	Prathyasha	85	46.6	18.3	2.72	11.04	29.1	33.2	0.54
79	Jaya	81.3	42	26.6	5.04	13.24	29.1	40	0.91
80	PHB-71	86.6	54	36.6	9.12	25.82	29.1	39.1	0.8
	Mean-	108.53	51.67	37.44	5.45	17.90	28.72	34.34	1.05
	Max-	146.5	96	90	13.83	31.81	29.2	40.6	1.9
	Mini-	77	35.6	13.3	1.7	7.2	28.1	27.2	0.36
	SD-	20.5	11.6	18.9	2.5	5.8	0.3	3.2	0.3

for plant height, shoot dry weight, root length, root volume, root dry weight, SCMR and chlorophyll content. There is significant variability for these traits under this period (Table 2). Highest SCMR values were recorded by Uma (40.6) followed by Ptb25 (40.4). Highest root length was recorded by Ptb1 (96.0cm), which was followed by Ptb41 (83.3cm). For root volume, Ptb1 recorded the highest value of (90.0cm3) followed by Ptb6 (86.6cm3). Even though there is variation in genotypes for highest recorded values, there is consistency in various parameters recorded during three consecutive years. Detailed analysis of phenotypic data enabled to identify donor parents for root traits and water use efficiency. Varieties identified for deep and thick roots were Chuvanna modan local, Ptb1 (Aryan), Ptb2 (Ponnaryan), Ptb 6 (Athikkiraya) and Ptb15 (Kavunginpoothala). Varieties identified for high WUE (based on $\Delta^{13}C$ value) were Ptb5 (Veluthari kayama), Ptb7 (Parambuvattan), Ptb9 (Thavalakannan), Ptb10 (Thekkancheera) and Ptb19 (Athikiraya). Both the traits

Plate 1. showing root structure experiment

Plate 2. Root washing

1 2 3 4 5

Plate 3. Selected deep root rice genotypes (1-Ptb 1, 2-Ptb 2, 3-Chovanna modan, 4-Ptb 15, 5-Ptb 6)

1 2 3 4 5 6

Plate 4. Varietal variation in root traits (1-Kayama, 2-Kavuginpothala, 3- Vadakkan chitteni, 4- Jeddu Halliga, 5-Kodiyan, 6-Aruvakkari)

are equally important under water limited conditions. It is found that Uma (MO-18) is a high yielding variety with low carbon isotope discrimination (22.17 per mil) having high WUE. Otherwise, most of the high yielding varieties showed high carbon isotope discrimination values. This variety also recorded the higher SCMR values in three consecutive years. A combination of water-saving and drought-resistant rice varieties produce higher grain yield and water productivity than paddy rice under water-saving irrigation (Bouman and Tuong, 2001; Yang et al., 2007; Chu et al., 2014). They argue that the main reason is because drought resistant rice varieties have better root morphological and physiological performance, such as greater root biomass, root length density, specific root length, deeper distribution of roots in soil and active absorption area. Drought resistant rice varieties also are able to maintain a higher root activity during soil drying and faster functional recovery during re-watering. It is found that genotype having deep roots and high WUE can bring advantages to the physiological processes of the shoot, resulting in higher grain yield and water productivity.

CONCLUSION

Identification of donor parents is important for drought resistance breeding programmes. In this study we identified donor parents for deep and thick root system, and high water use efficient rice genotypes. Among the high yielding varieties, Uma (MO-18) showed low $\Delta^{13}C$ with high water use efficiency. Thus this variety may be recommended for water limited condition.

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