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Physiological Studies on Ratoonability of Sugarcane Varieties under Tropical Indian Condition

Raju Gomathi[1], Polur Nagaraja Gururaja Rao[1], Palaniappan Rakkiyappan[2], Babu Poojary Sundara[3], Srinivasan Shiyamala[1]

[1]Plant Physiology, Division of Crop Production, Sugarcane Breeding Institute (ICAR), Coimbatore, India; [2]Soil Science, Division of Crop Production, Sugarcane Breeding Institute (ICAR), Coimbatore, India; [3]Agronomy, Division of Crop Production, Sugarcane Breeding Institute (ICAR), Coimbatore, India.
Email: gomathi_sbi@yahoo.co.in

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ABSTRACT

The ratoon crop occupies approximately 40% of the total area of sugarcane crop in tropical India. The main reason for the lower average cane productivity is the yield decline in ratoon crops (40 - 50 t/ha) despite the release of the high yielding varieties and advanced cane production technology. The physiological factors associated with ratooning performance and the variation in growth and yield were studied in 11 sugarcane varieties in two cycles of one plant and two ratoon crops each. The first ratoon and second ratoon crop showed 17.0% and 28.1% reduction in tiller production and 15.5% and 15.7% reduction in NMC, respectively, over plant crop. The differences in growth parameters between the plant and ratoon crops at the formative phase were lesser than that of grand growth and maturity phases. Varieties Co 86032, Co 97008, Co 95020 Co 99004 and Co 2000-10 showed better physiological efficiency in terms of plant height, shoot population, leaf size, TDMP, partitioning efficiency, chlorophyll content and nitrate reductase activity and significantly higher yield components such as NMC, SCW, cane length, internodal length as well as cane yield compared to other varieties. The higher reduction in ratoon yield in Co 99008, Co 94012, Co 8021 and Co 97009 (>35.00% reduction) was due to higher reduction in tiller production associated with stunted plant growth and root system, reducetion in individual leaf size and LAI, TDMP, total chlorophyll content, NMC, internodal length and SCW. The results obtained indicated that the plant height, TDMP, stem partitioning, leaf size, total chlorophyll content, SCW, cane length and cane girth were highly associated with yield of first and second ratoon crops than that of plant crop. Therefore the difference in the association between physiological parameters with yield of plant and ratoon crops therefore decides the ratooning potential of the crop.

Keywords: Sugarcane; Ratoon; Physiological Efficiency; LAI; TDMP; SCW; Yield

1. Introduction

Ratooning of sugarcane is a common practice throughout the world and ratoon occupies almost 50 per cent of the total area under sugarcane cultivation and contributes 30% to the total cane production in the country [1]. The area under ratoons is relatively greater in the tropical states (50% - 55%) than in the sub-tropical states (40% - 45%). The decline in cane yield in successive ratoons is common in most of the sugarcane growing areas. The average yield gap between plant and ratoon crop in the country is 20% - 25%. One of the major bottlenecks in increasing the productivity of ratoon crops in the sub tropics is the poor sprouting of stubbles in winter-harvested cane. Reports are available that the poor sprouting, uneven and continuous tillering during entire period of crop results in sixty percent mortality of tillers and thus less millable canes at harvest [2]. A number of attempts have been made to increase the yield of winter-initiated ratoons and ethrel (500 ppm) proved the best among the different hormones tested [3-6]. Also, investigations on different aspects of ratoon *viz.*, physiology, genetics, biochemistry etc., have not been given due attention to unravel the reasons for low ratoonability and productivity potential of different sugarcane genotypes [7].

Ratoon productivity is the ultimate expression of interplay of several factors such as the ratooning ability of a given variety, the influence of environment and ratoon management. Ratooning ability is one of the important economic considerations in many sugarcane growing countries to decide the suitability of sugarcane varieties for commercial cultivation. Good ratooning ability of cane cultivars is an essential pre-requisite determined by a number of factors. Various plant characters were associated with ratooning ability of sugarcane varieties and success of the variety depended on its ability to give more profitable ratoons [8-10]. Identification of physiological plant traits that are responsible for better ratoonabilty therefore helps the breeders to screen a large number of clones for better ratooning types. The research work on physiological aspects of ratoonability is rather meagre. The present study aiming on identification of physiological traits associated with ratooning performance of sugarcane varieties.

2. Material and Methods

Field experiments were conducted at Sugarcane Breeding Institute, Coimbatore during 2006-2010 in two cycles of one plant and two ratoon crops each. The first cycle plant crop and its ratoon crops was conducted during 2006-09 with eleven popular sugarcane varieties *viz*., Co C 671, Co 8021, Co 85019, Co 86032, Co 94012, Co 95020, Co 97008, Co 97009, Co 99004, Co 99008 and Co 2000-10 in randomized block design (RBD, replicated thrice. The second cycle of experiments was conducted during 2007-2010 with the same set of varieties. The cultural operations of ratoon crop were followed as per the local recommendations. No gap-filling was done in any of the ratoon crops.

Plant samples were made periodically for recording various morphological, physiological, growth characters, dry matter production and its partitioning. The total chlorophyll content was estimated as per method suggested by Yoshida [11]. Nitrate reductase activity was assayed following the method of [12] at 60, 90 and 120 days after planting**.** Number of millable canes per plot was recorded at harvest and the data on cane height, cane thickness, internode number, internodal length and single cane weight were recorded in 5 canes in each genotype and the mean was calculated. The cane yield per plot was recorded and expressed as tonnes/ha. On completion of 2 cycles of plant and ratoon crops each, data were pooled and analysed statistically to test the significance of the parameters.

3. Results & Discussion

3.1. Tillering and Stalk Population

The tiller population was maximum at 90 DAP and it was significant among the crops and the varieties studied. Results obtained from the first ratoon and second ratoon crop showed 17.0% and 28.1% reduction in tiller production and 16.5% and 15.7% reduction in NMC over the plant crop. However, the reduction was less than 15% in varieties Co 86032, Co 97008, Co 95020, Co 2000-10 and Co 85019 (**Figures 1(a)** and **(c)**). In the first ratoon crop, tiller mortality (30.0%) was almost similar to that of plant crop (29.6%), while in the II ratoon crop, the tiller mortality was 28.50% (**Figure 1(b)**). Varieties, Co 8021 and Co 97009 recorded significantly higher tiller mortality of 48.3% and 44.0% in first ratoon and 47.7% and 40.0% in second ratoon crop respectively. The results suggested that the production of tiller itself limiting factor for poor NMC in ratoon crops than the tiller mortality per se. Tilllering behaviour of ratoon crops was extensively studied under sub-tropical condition [9,13-15]. According to them, tillering of ratoon crops was earlier and more profuse than in corresponding plant crop and the early formed tillers have greater chance of survival than the later shoots. Further they reported that the tiller mortality was determined by the time of emergence of individual tillers and tiller growth type. However, the early formed tillers have grater chance of survival than the later shoots. It was even suggested that varietal variation in tiller production was up to 120 - 135 DARI in ratoon crops; however, in plant crop exhibited more such variation during 85 - 90 days after planting [14].

The reduction in tiller production in ratoon crops was

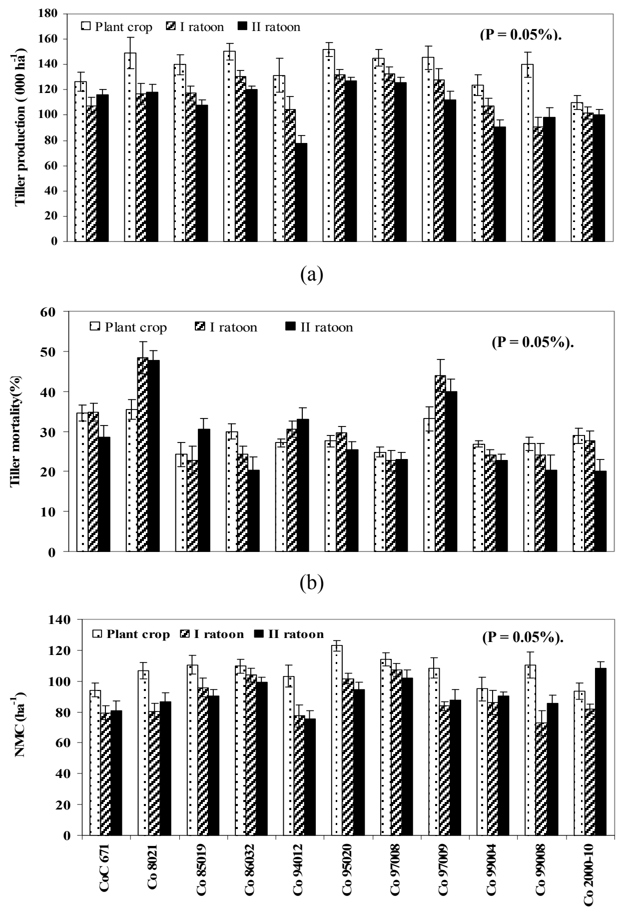


Figure 1. Varietal variation in tiller production (000 ha^{-1}) at 120 DAP and NMC (ha^{-1}) at harvest of the plant and ratoon crops. The values given here are means of three four replications and the vertical bars represent the standard error (P = 0.05%).

associated with gappiness in ratoons particularly in varieties Co 8021, Co 94012, Co 97009 and Co C 671. Tiller production was highly associated with yield of first ratoon (r = 0.630*) and second ratoon crops (0.553*). (**Table 1**). A significant difference in association of NMC with yield of plant and ratoon crops was also observed. NMC was highly and significantly associated with yield in first (r = 0.750**) and second ratoon crops (r = 0.809**). A similar result was reported by [7].

Table 1. Correlation coefficients between physiological parameters with yield of plant and ratoon crops.

Parameters	Plant crop (r value)	First ratoon crop (r value)	Second ratoon crop (r value)
Tiller production	0.378*	0.630*	0.553*
NMC	0.475*	0.750**	0.809*
SCW	0.711**	0.809**	0.840**
Cane length	0.604*	0.823**	0.900**
Inter nodal length	0.613*	0.752**	0.789*
Cane girth	NS	0.600*	0.401*
Number of internodes/cane	−0.355*	−0.350*	−0.353*
Sucrose%	−0.100	−0.250	−0.284
Plant height FP	0.545*	0.685*	0.747**
Plant height GGP	0.614*	0.751**	0.797**
Leaf production at FP	0.345*	NS	NS
Leaf production at GGP	0.700	0.540*	0.327*
Leaf production at maturity	NS	−0.415*	−0.506*
LAI at FP	0.660*	NS	NS
LAI at GGP	0.670*	0.467*	0.367*
LAI at maturity	0.314*	−0.310*	−0.436*
Leaf area	0.595*	0.754*	0.780*
TDMP at FP	0.439*	0.381*	0.360*
TDMP at GGP	0.665*	0.728*	0.752**
TDMP at maturity	0.690*	0.802**	0.850**
Partitioning efficiency leaf	0.345*	−0.625*	−0.605*
Partitioning efficiency sheath	- NS	- NS	- NS
Partitioning efficiency stem	0.704*	0.910**	0.887**
Chlorophyll content at FP	0.635*	0.785**	0.810**
Nitrate reductase activity at FP	0.701	0.815**	0.789**

*FP- Formative phase, *GGP- Grand growth phase, NS-Not significant; *P = 0.05; **P = 0.01.

3.2. Growth Observations

Data on plant height, leaf production, leaf size and LAI at different growth phases of plant and ratoon crop indicated that the differences in growth parameters at formative phase was narrow than at grand growth and maturity phases. At grand growth phase, the first and second ratoon crop recorded an average reduction in plant height of 12.8% and 22.0%, respectively, over plant crop, while at maturity phase the reduction was 12.42% and 17.8%, respectively (**Table 2**). Reports were available that the ratoon shoots in initial stages grew faster than the plant crop but the plant crop had overtaken during monsoon season [13,15-17]. Significant variation was observed among the varieties in plant height. Varieties, Co 97008, Co 99004, Co 95020, Co 2000-10 and Co 86032 maintained better stem growth than the other varieties studied. Similar varietal variation in stem growth was reported in sugarcane [7,9]. The ability of varieties to develop shoots quickly and rapidly early in the season in the ratoon crop had a distinct advantage over the plant crop.

Leaf development in sugarcane is important for the study of photosynthesis, canopy closure and light interception. Among the physiological attributes, the leaf area had significant positive association with cane yield and dry matter [18]. In present study, leaf growth parameters viz., LAI, leaf production (data not sown) and individual leaf size was recorded at important growth phases of plant and ratoon crops. However, the magnitude of variation of these parameters in plant and ratoon crops was significant at grand growth phase and maturity phase. LAI of first and second ratoon crop at grand growth phase showed 13.0% and 26.6% mean reduction over plant crop (**Figure 2(a)**). This might be due to the difference in leaf growth pattern between plant and ratoon crops, *i.e.*, decline in LAI at maturity phase was more sharp in plant crop as compared to ratoon crops (**Figure 2(b)**). The higher reduction in LAI at grand growth phase was mainly due to the reduction in individual leaf size (29.7%) and leaf number (17.20%) over plant crop. Varietal variation in individual leaf size was highly significant in ratoon crops than the plant crop (**Figure 2(c)**). Varieties Co 99008, Co 94012 and Co 97009 showed higher reduction in leaf size of 44.3%, 41.5% and 36.5% over plant crop. However, varieties Co 99004, Co 97008, Co 95020 and Co 86032 maintained better leaf growth in terms of LAI, leaf size and leaf production (**Figures 2(a)** and **(c)**). Similar varietal variation in leaf growth parameters was reported in sugarcane [7,19]. The rate of leaf production of ratoon crop increased as age advanced and it continued even during the maturity phase of the crop as that of earlier report [17]. A significant association of leaf production with yield between plant and ratoon crops was observed at all the growth phases. In ratoon crops, leaf production (r = −0.415* and −0.506*) and LAI

Table 2. Plant height (cm) at different growth phases of plant and ratoon crops.

Variety	Formative Phase			Grand Growth Phase			Maturity Phase		
	Plant crop	I Ratoon	II Ratoon	Plant crop	I Ratoon	II Ratoon	Plant crop	I Ratoon	II Ratoon
Co C 671	94.10	106.1	83.50	183.2	163.7	136.5	187.8	172.1	158.2
Co 8021	107.6	94.2	91.67	176.8	153.2	142.5	187.9	171.1	161.7
Co 85019	114.7	100.1	89.50	186.3	161.6	149.2	200.0	172.4	168.2
Co 86032	104.5	102.5	100.50	184.2	175.0	159.5	207.9	195.5	180.5
Co 94012	96.2	87.81	70.00	178.7	139.8	122.6	195.4	165.6	138.0
Co 95020	97.2	110.5	100.20	203.7	182.7	165.5	221.5	190.8	191.2
Co 97008	119.5	120.5	108.00	222.5	191.8	173.5	230.5	212.0	190.5
Co 97009	89.5	84.35	83.50	194.5	153.2	134.2	188.0	155.7	158.2
Co 99004	121.4	122.8	104.25	210.5	192.5	193.0	247.5	210.4	195.7
Co 99008	99.40	91.2	75.50	204.0	167.2	130.5	185.3	149.6	142.8
Co 2000-10	110.0	107.8	95.50	207.7	195.3	170.1	242.8	205.5	190.5
Mean	**104.9**	**102.5**	**91.1**	**195.6**	**170.5**	**152.4**	**208.6**	**181.8**	**171.3**
SE	1.24	1.10	1.01	1.87	1.60	1.41	2.27	2.10	1.41
CD	2.5^{**}	2.2^{**}	2.10^{*}	3.65^{*}	3.20^{**}	2.80^{**}	4.50^{**}	4.20^{**}	2.90^{**}

*P = 0.05; **P = 0.01.

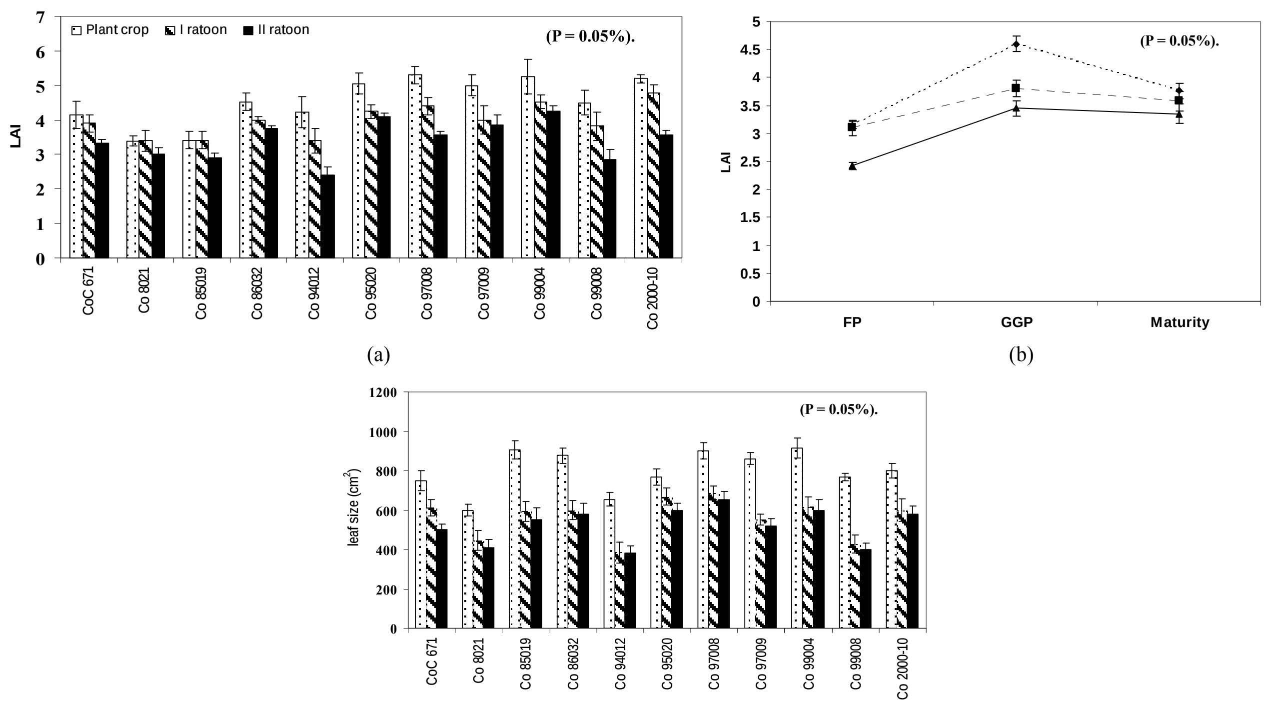


Figure 2. Varietal variation in LAI (a), pattern of LAI (b) and leaf size (c) of plant and ratoon crops at GGP. The values given here are means of three replications and the vertical bars represent the standard error (P = 0.05%).

(r = −0.310* and −0.436*) were negatively but significantly associated with yield while the plant crop showed non-significant results (**Table 1**). Hence, the differences in leaf growth among the varieties in both plant and ratoon crops significantly influenced the source-sink relationship.

3.3. Total Chlorophyll Content and Nitrate Reductase Activity

Total chlorophyll content was estimated at different physiological stages of ratoon crop. A significant reduction in total chlorophyll content was noticed over plant crop; however the reduction was high at early growth phase (26.50%) compared to grand growth phase (22.45%) and maturity phase (18.45%). This is also evident in prominent expression of yellowing symptoms in poor ratooners CoC 671, Co 97009, Co 94012 and Co 99008 (**Figure 3**). However, in both the ratoons, varieties Co 86032, Co 99004, Co 97008 and Co 95020 maintained higher chlorophyll content. The total chlorophyll content at formative phase was highly significantly associated with yield of first ($r = 0.785^{**}$) and second ratoon ($r = 0.810^{**}$) crops. Nitrate reductase (NRase) activity at 120 days in the first and second ratoon crops showed 20.5% and 23.5% reduction over plant crop respectively. Varieties Co 97008, Co 85019, Co 99004 and Co 86032 possessed higher NRase activity than the other varieties (**Figure 4**). Similar varietal variation in nitrate reductase activity between poor ratooners (CoC 671 & Co 775) and good ratooners (Co 8021 and Co 1148) was reported in sugarcane [20].

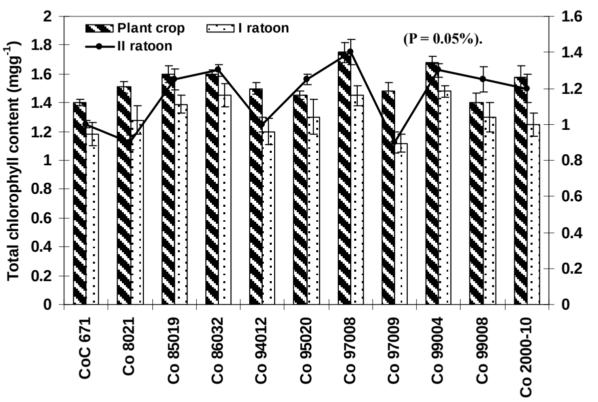


Figure 3. Varietal variation in total chlorophyll content (mgg^{-1}) at formative phase of first ratoon crop. The values are means of three replications and the vertical bars represent the standard error (P = 0.05%).

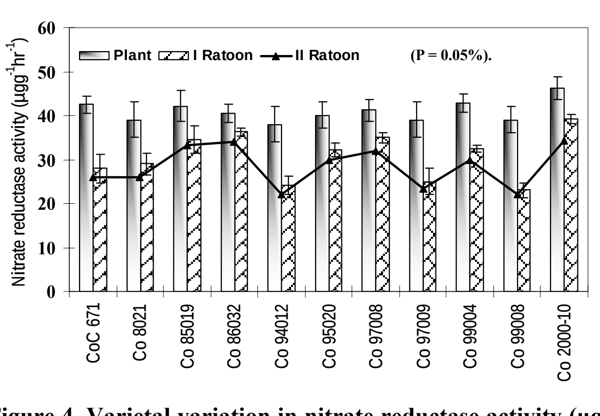
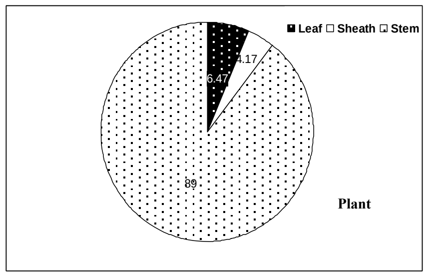


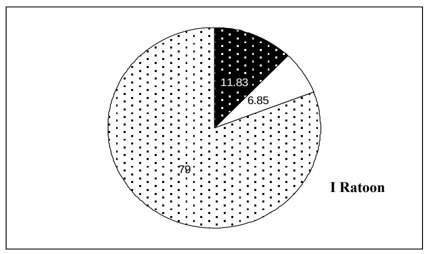
Figure 4. Varietal variation in nitrate reductase activity (µg $g^{-1}hr^{-1}$) mgg^{-1}) at formative phase of plant and ratoon crops. The values given here are means of three four replications and the vertical bars represent the standard error (P = 0.05%).

3.4. Biomass Production and Partitioning Efficiency (%) of Ratoon Crop

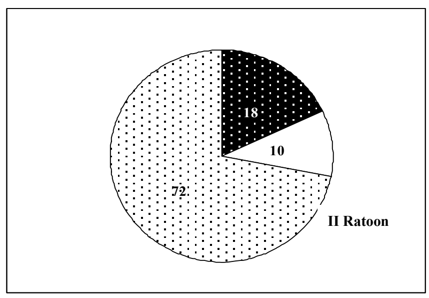
At early growth phase, production of biomass was comparable in both plant crop and ratoon crops because of faster early growth. However, at the later stages of the crop, the difference in biomass production was marked between plant and ratoon crops (**Table 3**). At grand growth phase, the reduction in total dry matter production was 23.4% and 32.5% in first and second ratoon crops, respectively. At maturity phase the reduction was 25.1% and 31.0% respectively. Higher reduction in total dry matter production in ratoon crops might be due to higher reduction in tiller production, shoot growth, LAI and higher tiller mortality over plant crop particularly in varieties Co 97009, Co 99008 and Co 94012. A similar varietal difference in biomass production was reported in sugarcane [7,19]. At maturity phase both the ratoon crops showed higher leaf and sheath partitioning efficiency compared to plant crop (**Figure 5**). However, the partitioning efficiency towards stem was less in first (79.0%)



(a)



(b)



(c)

Figure 5. Differences in partitioning efficiency (%) of biomass in plant, first and second ratoon crop at maturity phase of the crop.

Table 3. Total Dry matter production (kg·m^{-2}) at different growth phases of plant and ratoon crops.

Variety	Formative Phase			Grand Growth Phase			Maturity Phase		
	Plant crop	I Ratoon	II Ratoon	Plant crop	I Ratoon	II Ratoon	Plant crop	I Ratoon	II Ratoon
CoC 671	1.14	1.59	1.13	4.46	3.42	3.24	5.20	3.95	3.90
Co 8021	1.10	1.66	1.24	4.80	3.30	3.24	5.55	3.80	3.88
Co 85019	1.32	1.86	1.76	4.92	3.56	2.94	5.95	4.03	3.70
Co 86032	1.18	1.56	1.70	5.10	4.05	3.90	5.80	4.60	4.51
Co 94012	1.25	1.28	1.45	4.79	3.35	2.70	5.35	3.60	3.48
Co 95020	1.65	1.94	1.89	5.17	4.17	3.45	6.10	4.80	4.77
Co 97008	1.31	1.86	1.70	4.46	4.07	3.62	5.90	4.60	4.63
Co 97009	1.00	1.57	1.31	4.86	3.20	2.98	5.25	3.20	3.00
Co 99004	1.25	1.68	1.25	5.35	3.85	3.18	6.66	5.00	4.93
Co 99008	0.91	1.20	0.89	3.15	3.08	2.80	5.00	2.64	3.71
Co 2000-10	12.11	16.2	1.02	4.31	3.39	3.10	6.20	4.85	4.40
Mean	**1.10**	**1.47**	**1.39**	**4.67**	**3.58**	**3.19**	**5.71**	**4.09**	**4.08**
SE	0.010	0.012	0.11	0.015	0.013	0.011	0.026	0.018	0.17
CD	0.025*	0.015**	0.26*	0.03*	0.017**	0.022**	0.054**	0.036**	0.035**

*P = 0.05; **P = 0.01.

and second (72.0%) ratoon crop than the plant crop (89.0%). In both the ratoon crops, varieties Co 86032, Co 97008, Co 99004 and Co 95020 showed higher partitioning efficiency towards stem.

3.5. Yield and Yield Components

Data on yield and its components viz., NMC, cane length, inernodal length, cane girth, single cane weight and cane yield were recorded at harvest. First ratoon crop showed 16.5, 15.06, 12.5, 6.32, 20.4 & 22.20 mean reductions in NMC, cane length, inernodal length, cane girth, single cane weight, respectively and 27.38% reduction in cane yield. The reduction in yield and yield components was comparatively higher in second ratoon crop, with a mean reduction of 16.0%, 22.4%, 22.3%, 15.2% and 32.4% in NMC, cane length, inernodal length, cane girth, single cane weight. Varieties varied significantly in cane yield and yield components excepting cane girth of both first and second ratoon crops. Varieties, Co 86032, Co 97008, Co 95020 Co 99004 and Co 2000-10 showed better physiological efficiency in terms of plant height, shoot population, leaf size, TDMP, partitioning efficiency, chlorophyll content and nitrate reductase activity and significantly higher yield components (NMC, SCW, cane length, internodal length) and cane yield as compared to poor ratooners Co 99008, Co 94012, Co 8021 and Co 97009. Reports are available that the good ratooning cultivars are those which had attributes for rapid canopy development, early development of adequate stalk numbers for increased interception of light in the early growth, stability of harvested stalk weights to maintain yields over ratoon cycles [8,21,22]. In the sub- tropical region, sugarcane is harvested under low temperature (early harvesting) and high temperature (late harvest) conditions. The yield of ratoon crop is affected and much influenced by environmental factors [14]. However, in present study Co 94012, Co 97009, Co 671 and Co 99008 were appeared stunted in all the growth phases of ratoon crops which resulted in higher reduction of SCW (**Tables 2** and **4**). Further, higher reduction in ratoon yield in Co 99008, Co 94012, Co 8021, and Co 97009 (>35.00% reduction) due higher reduction in tiller produc- tion associated with stunted plant growth and root system, reduction in individual leaf size and LAI, TDMP, total chlorophyll content, poor NMC, intermodal length and SCW. The result obtained in correlation analysis sug- gested that the variation in the growth, physiological and yield attributing parameters such as plant height, TDMP, stem partitioning efficiency, leaf size, total chlorophyll content, SCW, cane length and cane girth) were highly associated with yield of first and second ratoon crops than that of plant crop (**Table 1**). Hence, the difference in the association between physiological parameters with yield of plant and ratoon crops therefore decides the ra- tooning potential of the crop.

4. Conclusion

To conclude that the identified physiological markers in the present study such as higher plant height, shoot population, leaf size, LAI, TDMP, partitioning efficiency, chlorophyll pigment content and NMC, SCW, cane length, & internodal length could help the breeders to

Table 4. Cane yield and yield components of plant and ratoon crops.

Variety	Internodal Length (cm)			Cane Girth (cm)			Single Cane Weight (kg)			Cane Yield($t \cdot ha^{-1}$)		
	Plant crop	First Ratoon	Second Ratoon	Plant crop	First Ratoon	Second Ratoon	Plant crop	First Ratoon	Second Ratoon	Plant crop	First Ratoon	Second Ratoon
CoC 671	8.30	7.41	7.03	2.75	2.45	2.35	1.04	0.85	0.75	85.02	66.54	63.50
Co 8021	7.64	7.05	6.86	3.05	2.80	2.50	1.00	0.86	0.83	93.80	74.65	65.50
Co 85019	7.94	7.14	6.80	2.69	2.45	2.00	1.08	0.89	0.75	109.25	78.02	70.22
Co 86032	9.44	8.25	8.00	2.78	2.70	2.50	1.15	1.06	1.00	119.83	103.42	89.50
Co 94012	7.92	6.44	6.06	3.00	2.78	2.40	1.21	0.74	0.56	110.08	71.96	59.50
Co 95020	9.67	8.54	7.73	3.10	2.90	2.75	1.22	1.03	0.95	111.20	102.62	88.50
Co 97008	11.37	10.62	10.03	2.89	2.65	2.60	1.25	1.00	1.00	125.95	105.06	86.00
Co 97009	8.46	7.38	7.23	2.80	2.65	2.20	0.95	0.75	0.65	83.40	76.11	56.43
Co 99004	12.30	10.35	9.50	2.75	2.53	2.35	1.36	1.12	1.13	119.53	91.91	81.20
Co 99008	8.67	7.84	6.25	2.48	2.26	2.04	0.84	0.66	0.57	95.00	63.74	51.71
Co 2000-10	11.75	10.17	10.00	2.75	2.84	2.70	1.30	1.07	1.00	105.56	87.21	79.00
Mean	**9.46**	**8.26**	**7.77**	**2.82**	**2.63**	**2.39**	**1.12**	**0.91**	**0.84**	**105.32**	**83.74**	**71.90**
% reduction	-	**12.55**	**22.30**		6.73	15.24	-	20.41	32.00	-	**27.38**	**31.42**
SE	0.17	0.12	0.10	0.04	0.03	0.02	0.015	0.013	0.10	2.91	2.52	1.82
CD	0.35^{**}	0.24^{**}	0.20^{**}	0.08^{*}	0.06^{*}	0.04^{*}	0.03^{**}	0.028^{**}	0.20^{**}	4.80^{**}	3.10^{**}	3.64^{**}

$^{*}P = 0.05$; $^{**}P = 0.01$.

screen large number of clones for better ratooning types. On the basis of four years of multi ratooning field experiments, the varieties Co 86032, Co 97008, Co 95020 Co 99004 and Co 2000-10 proved as good ratooners in tropical India.

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