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Stability analysis for forage yield in *Cenchrus ciliaris* under hot arid climate

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Abstract
A field experiment was conducted from 2010 to 2014 at Jodhpur to assess the stability of ten genotypes of *Cenchrus ciliaris*. The genotypes were sown in a randomized complete block design with three replications under rainfed conditions. Observations were recorded on fodder yield and it components from the same plots at different monsoonal growth stages for the period under study. Pooled analysis showed that variance due to environments was significant for all the characters. Variance due to genotypes was significant for plant height at first cut, dry matter yield of first cut and total dry matter yield. G x E interaction was also significant for all the characters, except green fodder yield of the first cut, which indicated that the behaviour of genotypes differed over the time. Significant mean squares due to environment (linear) indicated the environmental influence on the performance of the genotypes. G x E (linear) was higher in magnitude than pooled deviation (non-linear) for plant height at second cut, tiller production at both the cut, green fodder yield of second cut and total green fodder yield. Genotype CAZRI 231 and CAZRI 2177 were found stable for green fodder production, whereas CAZRI 231 and CAZRI 327 showed suitability for higher dry matter production for wider environmental conditions.

Keywords: Dry matter yield, Environment, Genotype, Green fodder yield, Regression coefficient

Introduction

Cenchrus ciliaris L., a C_4 tropical grass commonly called as buffel grass belongs to the family Poaceae, is most suitable and highly nutritive perennial species and considered excellent for pastures in hot dry areas. This grass is one of the dominant species of *Dichanthium-Cenchrus-Lasiurus* grass cover of India (Dabadghao and Shankarnarayan, 1973). The species is well distributed in hotter and drier parts of India, Mediterranean region, tropical and southern Africa. The grass is well adapted to sub-humid and semi-arid regions with annual rainfall between 300 and 900 mm (Hernández and Simon, 1980). The rhizomatous drought resistant plants are dormant during summer months and with the onset of rains, they regenerate quickly and produce heavy canopy to cover soil (Bose and Balakrishnan, 2001). The grass has ability to withstand heavy grazing and trampling by livestock (Nagar and Meena, 2015). The fodder of the species is very nutritive for animals as 100 g fresh plant is reported to contain on a zero-moisture basis, 11.0 g protein, 2.6 g fat, 73.2 g total carbohydrate, 31.9 g fibre, and 13.2 g ash (Gohl, 1981).

Genotype × environment interaction is a universal phenomenon when different genotypes are evaluated across the environments. Most agronomic and economically important characteristics are quantitative in nature and usually exhibit G × E interaction. An understanding of environmental and genotypic causes leading to G × E interactions are important at all stages of plant breeding including ideotype design, parental selection, selection based on traits and yield. This necessitates genotype evaluation across multiple environments. Several statistical procedures are now available for estimating phenotypic stability but the joint regression analysis described by Yates and Cochran (1938), Finlay and Wilkinson (1963), Eberhart and Russell (1966), Perkins and Jinks (1968) and Arain and Siddiqui (1977) is one of the most commonly used procedure for studying the yield stability. *Cenchrus ciliaris* being perennial in nature faces different kinds of environmental adversities during its different growth and developmental stages which make stability studies more pertinent in this important range species. Further, information on forage yield stability of *C. ciliaris* genotypes over the years is meager in general and in hot arid areas in particular. Therefore, an attempt was made to assess the stability for different traits in this grass species.

Materials and Methods

Plant materials: Ten genotypes, *viz*., CAZRI 358, CAZRI 231, CAZRI 327, CAZRI 421, CAZRI 585, CAZRI 2162, CAZRI 2177, CAZRI 2178, CAZRI 2221 and CAZRI 75 of

C. ciliaris (L.) were evaluated for their forage yield and its components' stability from 2010 to 2014 at the Central Research Farm of ICAR-Central Arid Zone Research Institute, Jodhpur, Rajasthan (India). The genotypes were arranged in a randomized complete block experiment with three replications. The plots of size 3 m × 4 m were established in the second fortnight of July 2010 through direct seeding using 5 kg seeds per hectare with plant to plant distance of 50 cm between rows. The climate of the area is typically arid characterized by very hot, dry summers, sub-humid monsoon and cold-dry winters. The soil of the experimental site was loamy sand with low fertility level. The experiment was rainfed and no fertilizer/manure was applied during the period of study. Data were recorded on plant height, tillers per meter row length and green fodder yield from different fodder harvests of *Kharif* season growth. Plots of size 2 m × 3 m were harvested to a stubble height of 10 cm with sickle three times during establishment year and two times during 2011 to 2014. Herbage samples of 100 g were dried in an oven at 85°C for 24 h for dry matter content determination.

***Meteorological data*:** The annual rainfall varied during the period of study and it was 562.2 mm in the year of establishment (2010), which was maximum during the period of study. In subsequent years, it was 320.3, 484.6, 493.1 and 366.6 mm in year 2, 3, 4 and 5, respectively. Out of which 79-95% were in July to September of the individual years but during July 2012, it was only 11.7 mm. Rainy days ranged from 20 in 2011 to 28 in 2010. Relative humidity values were maximum during August in 2010 (83%) and 2013 (85%), whereas in 2011 and 2014, it was maximum (88 and 83%) in September and during 2012 in the months of August and September (84%). May was the hottest month during first four years and the values for highest mean maximum temperature were 43.4, 41.4, 41.6 and 41.8 °C, respectively, while in 2014, June was the hottest month (41.7°C).

Statistical analysis: Data were subjected to analysis of variance for one factor and combined over the years following Gomez and Gomez (1984), and for combined analysis the variances due to genotypes were tested against mean squares of G × E interactions, whereas pooled error mean squares were used to test the significance of G × E interactions. Stability analysis was performed as per the model suggested by Eberhart and Russell (1966).

Results and Discussion

Analysis of variance for yield and its attributes: In this investigation, individual years were considered as separate environments. The differences in environments were caused by climatic variations such as temperature, rainfall, solar radiation etc in each year. The combined analysis showed that variance due to environments was significant (P<0.01) for all the characters, except plant height of second cut for which genotypes were significant at 5% level of significance (Table 1). Variance due to genotypes was significant for plant height at first cut, dry matter yield of first cut and total dry matter yield. Variance due to G × E interaction was significant for all the characters, except green fodder yield of the first cut (P<0.06). Significant G × E interaction showed that genotypes behaved differently in different years for the expression of the characters under study. It means a particular genotype may not show the same phenotypic

Table 1. Pooled analysis of variance for fodder yield and its components in *Cenchrus ciliaris*

Source of variance	d.f.	Mean Sum of Squares				
		Plant height - I cut	**Plant height -II cut**	**Tiller/mrl - I cut**	**Tiller/mrl - II cut**	**Green fodder yield- I cut**
Years (E)	4	4009.35**	2034.36*	6996.71**	35910.76**	19534.45**
Replication within year	10	99.71	375.71	236.91	976.63	442.93
Genotypes (G)	9	529.32**	732.15	1431.99	1762.02	546.79
G x E	36	172.70**	607.15**	1019.75**	1479.98**	413.85
Pooled error	90	74.53	97.67	505.25	480.69	273.14
		Green fodder yield- II cut	**Dry matter yield- I cut**	**Dry matter yield- II cut**	**Total green fodder yield**	**Total dry matter yield**
Years (E)	4	8461.28**	1356.86**	362.12**	35965.77**	817.73**
Replication within year	10	180.90	35.88	13.17	1038.93	83.50
Genotypes (G)	9	1035.94	115.38*	26.13	2779.80	174.54*
G x E	36	800.85**	44.55**	25.76**	1438.02**	66.72*
Pooled error	90	102.56	17.91	7.60	626.35	40.75

*(P<0.05), **(P<0.01); mrl: meter row length

performance in different years or different genotypes may respond differently in a particular year. Significant G × E interaction was recorded earlier for forage yield in *Bromus cathaticus* (prairie grass) by Abbott *et al.* (2012). Helgadóttir and Kristjánsdóttir (1991) observed large genotype × environment interactions for most characters in timothy grass (*Phleum pratense*). Significant species × year interactions were observed for the yield of eight cool season pasture grass species when grown at five different irrigation levels (Waldron *et al.,* 2002). In an experiment conducted over the years, Ram *et al.* (2013) observed significant G × E interaction for plant height, number of tillers/plant, green fodder yield and dry fodder yield in *Dichanthium annulatum,* a perennial pasture species. Many investigators concluded that the year interaction effects are often the most important environmental factors affecting the yield and major components of G × E interaction (Lin and Binns, 1988; 1989; Yang and Baker, 1991). In the present study, G × E interaction was found significant for all the characters, the stability analysis (Eberhart and Russell, 1966) was performed as suggested by Singh and Chaudhary (1985) and Singh and Narayanan (2013).

The variance due to environment (linear) was found significant for all the characteristics, indicating differences between environments and their influence on genotypes for expression of these characters (Table 2). This is in accordance with previous reports on rice by Panwar *et al.* (2008). The environment + (genotype × environment) was significant for all the attributes, except plant height at the second cut indicating distinct nature of environments and genotype × environment interactions in phenotypic expression of the characters studied. The genotype × environment (linear) interaction component showed significance for tiller number at both the cuts and green fodder yield of the second harvest. This indicated significant differences among the genotypes for linear response to environments (b_i) behavior of the genotype could be predicted over environments more precisely and G × E interaction was outcome of the linear function of environmental components for these characteristics. Hence, prediction of performance of genotypes based on stability parameters would be feasible and reliable for these traits. Pooled deviation was significant for all the characteristics, except tiller number at the first cut. This indicated that the genotypes differed considerably with respect to their stability for almost all the characters. Ram *et al.* (2013) also noticed significant linear component of G × E for plant height, tillers/plant, green and dry fodder yields in *D. annulatum.* Significant linear and non-linear components of G × E interaction (pooled deviation) were observed for seed yield in maize by Ulaganathan *et al.* (2015). In a stability analysis, both linear (b_i) and non-linear (S^2d_i) components of G × E interaction should be considered for measuring the stability of genotypes (Eberhart and Russell, 1966).

Plant height**:** Plant height was found to be positively and significantly associated with fodder yield in *C. ciliaris* (Rajora, 1998; Rajora *et al*., 2016). Similarly in the present

Table 2. Analysis of variance for stability in *C. ciliaris* for fodder yield and its components

Source of variance	d.f.	Mean sum of squares				
		Plant height - I cut	**Plant height -II cut**	**Tiller/mrl - I cut**	**Tiller/mrl - II cut**	**Green fodder yield- I cut**
Genotypes (G)	9	176.44*	244.05	477.33	587.34	182.26
Year (E) + (G × E)	40	185.46**	249.96	539.15*	1641.02**	775.30**
Years (Lin.)	1	5345.80**	2712.48**	9329.00**	47881.04**	26045.96**
G ×E (Lin.)	9	19.44	226.55	569.83*	939.48*	54.18
Pooled Deviation	30	63.25**	174.90**	236.95	310.14**	149.28*
Pooled Error	90	24.84	32.56	168.42	160.23	91.05
		Green fodder yield- II cut	**Dry matter yield- I cut**	**Dry matter yield- II cut**	**Total green fodder yield**	**Total dry matter yield**
Genotypes (G)	9	345.31	38.46*	8.71	926.60	58.18*
Year (E) + (G × E)	40	522.30**	58.59**	19.80*	1630.27**	47.27*
Years (Lin.)	1	11281.70**	1809.15**	482.82**	47954.37**	1090.31**
G × E (Lin.)	9	447.18*	6.36	4.87	452.47	15.74
Pooled Deviation	30	186.18**	15.91**	8.84**	439.47**	21.96*
Pooled Error	90	34.19	5.97	2.53	208.78	13.58

*(P<0.05), **(P<0.01); mrl: meter row length

study, positive and significant correlation (r= 0.574**, n= 50) was observed between plant height and dry matter yield of the first cut, therefore, plant height emerged an important component of fodder yield. Genotypes CAZRI 231, CAZRI 421 and CAZRI 2221 had taller plants than general mean (111.0 cm) (Table 3). All the ten genotypes showed regression coefficient approaching to unity (b_i= 1). Eight genotypes appeared with non-significant deviation from regression (S^2d_i= 0), whereas CAZRI 421 and CAZRI 75 were found unstable for plant height of the initial growth as these were having significant deviation from regression. The stability parameters exhibited that CAZRI 231 and CAZRI 2221 had high mean, unit regression coefficient and non-significant deviation from regression showed general stability and thereby would produce taller plants over the years.

Stability parameters for the plant height at the second cut revealed that genotypes CAZRI 358, CAZRI 421, CAZRI 585, CAZRI 2162, CAZRI 2177 and CAZRI 75 appeared with significant deviation from regression, hence considered unstable. Only genotype CAZRI 231 had high mean height (91.6 cm) than general mean (82.6 cm), unit regression coefficient and non-significant deviation from regression, hence showed general stability and found suitable for growing over the years. The analysis of both the cuts revealed that CAZRI 231 had taller plants during stages of initial growth as well as aftermath and showed general stability for the height of the grass.

***Tiller number*:** Tiller number is an important fodder yielding component in grasses. Grass tillering ability has a direct impact on pasture establishment and longevity (Abbott *et al.* 2012). From production standpoint, tiller number and weight are the main components that

Table 3. Stability parameters for plant height and tillers in *C. ciliaris* grown over five years

Genotypes	Plant height- I cut (cm)			Plant height- II cut (cm)		
	Mean	**b_i**	**S^2d_i**	**Mean**	**b_i**	**S^2d_i**
CAZRI 358	110.7	0.811	31.219	85.4	1.265	139.214**
CAZRI 231	120.7	1.075	-17.918	91.6	2.120	65.301
CAZRI 327	113.0	1.055	-0.336	80.7	1.489	28.826
CAZRI 421	115.8	0.898	84.028**	75.9	1.454	196.308**
CAZRI 585	103.8	0.898	18.414	85.1	1.157	93.776*
CAZRI 2162	105.6	0.964	-13.870	84.3	1.449	91.154*
CAZRI 2177	106.3	0.738	16.975	91.1	1.015	80.465*
CAZRI 2178	111.9	1.426	5.441	68.9	0.108	17.586
CAZRI 2221	117.9	1.098	-8.556	85.5	1.114	55.002
CAZRI 75	104.4	1.038	260.275**	77.6	-1.170	563.079**
Population mean	111.0			82.6		
SE (mean) ±	4.0			6.6		
SE (b_i) ±	0.3			0.8		
Genotypes	**Tiller/mrl- I cut**			**Tiller/mrl- II cut**		
	Mean	**b_i**	**S^2d_i**	**Mean**	**b_i**	**S^2d_i**
CAZRI 358	89.4	0.029	-57.993	77.6	0.990	150.179
CAZRI 231	93.9	0.939	237.894	97.6	1.447	21.962
CAZRI 327	108.1	1.575	66.085	77.7	0.699	-5.963
CAZRI 421	93.6	1.451*	-154.768	77.3	0.714	332.742*
CAZRI 585	93.7	0.252	7.107	91.8	1.235	114.401
CAZRI 2162	106.6	0.497	63.154	103.5	1.655*	-170.080
CAZRI 2177	92.3	0.396	-1.284	101.9	1.202	224.192
CAZRI 2178	106.5	1.810	-64.651	84.7	0.973	-156.778
CAZRI 2221	110.0	2.428	110.537	80.3	1.016	-141.940
CAZRI 75	118.3	0.624	568.694**	76.7	0.069	965.132**
Population mean	101.2			86.9		
SE (mean) ±	7.7			8.8		
SE (b_i) ±	0.5			0.3		

*(P<0.05), **(P<0.01); mrl: meter row length

Table 4. Stability parameters for fodder yield in *C. ciliaris* grown over five years

Genotypes	**Green fodder yield- I cut (q/ha)**			**Green fodder yield- II cut (q/ha)**		
	Mean	b_i	S^2d_i	**Mean**	b_i	S^2d_i
CAZRI 358	71.18	1.028	149.30	38.30	1.676	423.31**
CAZRI 231	81.89	0.941	23.03	42.54	1.831	53.60
CAZRI 327	74.60	0.974	-27.28	30.49	0.524	9.82
CAZRI 421	72.10	0.974	172.19*	27.58	0.458	164.77**
CAZRI 585	72.57	1.079	29.48	39.78	1.385	106.14*
CAZRI 2162	67.01	0.914	43.07	36.74	1.309	-2.87
CAZRI 2177	81.07	1.235	-54.57	44.40	1.604	179.77**
CAZRI 2178	67.90	1.088	-7.68	24.66	0.605	318.56**
CAZRI 2221	66.81	1.082	172.94*	26.84	0.592	153.06**
CAZRI 75	63.52	0.686	25.30	19.98	0.016	87.68*
Population mean	71.87			33.13		
SE (mean) ±	6.11			6.82		
SE (b_i) ±	0.2			0.4		
Genotypes	**Dry matter yield- I cut (q/ha)**			**Dry matter yield- II cut (q/ha)**		
	Mean	b_i	S^2d_i	**Mean**	b_i	S^2d_i
CAZRI 358	15.99	0.929	8.11	9.50	1.166	13.50**
CAZRI 231	21.04	0.694	-0.04	11.21	1.721	6.47*
CAZRI 327	22.59	1.152	7.88	11.25	1.050	-1.40
CAZRI 421	21.55	1.340	38.11**	10.86	0.911	10.77**
CAZRI 585	14.98	0.776	-3.52	10.42	0.888	3.72
CAZRI 2162	14.97	0.889	-2.41	10.17	0.925	-1.76
CAZRI 2177	17.64	1.005	-0.73	11.96	1.021	7.37*
CAZRI 2178	19.47	1.042	7.57	8.01	0.906	6.47*
CAZRI 2221	17.21	1.091	11.07	9.46	0.980	6.27*
CAZRI 75	19.99	1.082	27.38**	8.15	0.433	9.83**
Population mean	18.54			10.10		
SE (mean) ±	1.99			1.49		
SE (b_i) ±	0.3			0.4		
Genotypes	**Total green fodder yield (q/ha)**			**Total dry matter yield (q/ha)**		
	Mean	b_i	S^2d_i	**Mean**	b_i	S^2d_i
CAZRI 358	112.84	1.046	1447.49**	26.41	1.014	30.61*
CAZRI 231	130.70	1.487	140.23	34.25	1.530	11.54
CAZRI 327	111.42	0.779	-87.31	35.22	0.929	-5.31
CAZRI 421	107.24	0.822	662.19*	34.29	0.678	48.42**
CAZRI 585	118.13	1.106	2.08	26.81	0.868	-12.76
CAZRI 2162	110.36	0.930	-171.45	26.88	0.730	-13.86
CAZRI 2177	135.19	1.490	-103.17	31.91	1.673*	-12.79
CAZRI 2178	99.06	0.889	388.37*	28.96	0.477	8.42
CAZRI 2221	100.32	0.961	-89.60	27.96	1.259	-9.86
CAZRI 75	91.67	0.491	-19.52	30.13	0.841	25.17
Population mean	111.69			30.28		
SE (mean) ±	10.48			2.34		
SE (b_i) ±	0.3			0.4		

*(P<0.05), **(P<0.01)

determine forage production in pasture (Jewis, 1972; Zarrough, 1983). In the present study, tillers were counted from one meter row length selected randomly from the middle rows of the plots. The analysis of data for the character at the first harvest revealed that only two genotypes, *viz*., CAZRI 2221 and CAZRI 75 were found to have more tillers than the general mean (101.2), whereas CAZRI 421 appeared with significantly higher regression coefficient than unity (b_i>1) and CAZRI 75 showed instability ($S^2d_i \neq 0$). Therefore, only CAZRI 2221 exhibited general adaptability across the years for tiller production during initial growth stage.

The stability parameters for tiller number at the second harvest revealed that the tiller production was more in CAZRI 231, CAZRI 2162 and CAZRI 2177 than general mean (86.9), whereas CAZRI 2162 had regression coefficient more than one (b_i > 1). Thus CAZRI 2162 is considered as below average in stability and specifically adapted to favourable environment. CAZRI 231 and CAZRI 2177 appeared with higher mean than the general mean, regression coefficient equal to unity and non-significant S^2d_i than zero considered as adaptable across the years for tiller production by aftermath and suitable for varied conditions.

***Green fodder yield*:** Although statistically the variation among the genotypes was non-significant for the green fodder yield of first harvest, the G × E interaction was significant (P<0.06).The stability parameters for green fodder yield of the first cut revealed that CAZRI 231 and CAZRI 2177 produced more green fodder than the general mean (71.87 q/ha), whereas all the genotypes appeared with unit regression coefficient and S^2d_i values were significant for CAZRI 421 and CAZRI 2221 (Table 4). Therefore, CAZRI 231 and CAZRI 2177 were considered stable for varied environments and ideally suitable for growing over the years for more green fodder from first harvest.

Similar to the first harvest, non-significant variation was observed among the genotypes for the green fodder yield of the second harvest, but the G × E interaction was significant (P<0.01). Similar to the first harvest, genotypes CAZRI 231 and CAZRI 2177 produced more yield than general mean (33.13 q/ha) but the S^2d_i values were non-significant only for CAZRI 231, hence the genotype was considered stable. All the genotypes were having unit regression coefficient. Therefore, CAZRI 231 showed broader adaptability for varied climatic conditions.

Stability parameters for the total green fodder yield of the three harvests in the first year and two harvests in rest of the years showed that mean yield was more than general mean (111.69 q/ha) for genotypes CAZRI 231 and CAZRI 2177, regression coefficient was equal to unity for all the genotypes and deviation from regression was equal to zero for all the genotypes, except CAZRI 358, CAZRI 421 and CAZRI 2178. Genotype CAZRI 231 and CAZRI 2177 produced more green fodder than general mean, regression coefficients equal to unity and non-significant deviation from regression (S^2d_i = 0), hence considered stable for wider conditions. Therefore, CAZRI 231 and CAZRI 2177 were found suitable for growing over the years under dry climate to harvest more seasonal green fodder.

***Dry matter yield*:** The stability parameters for dry matter yield of the first cut revealed that CAZRI 231, CAZRI 327 and CAZRI 421 produced more yield than the general mean (18.54 q/ha), whereas all the genotypes appeared with unit regression coefficient and S^2d_i values were significant for CAZRI 421 and CAZRI 75. Therefore, CAZRI 231 and CAZRI 327 were considered stable for varied environments and ideally suitable for growing over the years for more dry matter yield.

Although statistically the variation among the genotypes was non-significant for the dry matter yield of the second cut, the G × E interaction was significant. Only CAZRI 2177 produced more yield than general mean (10.09 q/ ha) but the S^2d_i value was significant, hence the genotype considered unstable. All the genotypes were having unit regression coefficient while deviation from regression was non-significant for CAZRI 327, CAZRI 585 and CAZRI 2162. These three genotypes with average dry matter yield, b_i=1, and S^2d_i =0 showed stability for average conditions, may be considered for average rainfall areas.

Stability parameters for the total dry matter yield of the three harvests in year one and two harvests in rest of the years showed that mean yield was more than general mean (30.28 q/ha) for genotypes CAZRI 231, CAZRI 327 and CAZRI 421, regression coefficient was equal to unity for all the genotypes, except CAZRI 2177 and deviation from regression was equal to zero for all the genotypes, except CAZRI 358 and CAZRI 421. The results showed that genotype CAZRI 2177 had regression coefficient more than unity, deviation from regression equal to zero and average yield, therefore, considered as below average stability. Genotype CAZRI 421 had high mean than general mean, regression coefficient equal to unity and significant deviation from regression ($S^2d_i \neq 0$), was considered unstable. Genotypes CAZRI 231 and CAZRI 327 produced higher dry matter yield, had unit regression coefficient and non-significant deviation from regression, hence considered stable for wider conditions. Therefore, CAZRI 231 and CAZRI 327 were found suitable for growing over the years under hot dry climate.

Conclusion

This investigation provides information to assist the choice of buffel grass genotypes in arid zone of western Rajasthan. Among the ten genotypes, CAZRI 231 was found stable for total dry matter yield, dry matter yield of first harvest, green fodder yield of both the harvests as well as total green fodder yield, plant height at both the harvests and tiller number at second harvest. Another genotype CAZRI 327 showed stability for dry matter yield of both the harvests as well as total dry matter productivity. Therefore, CAZRI 231 and CAZRI 327 can be considered in breeding programmes where the objective is to develop high fodder yielding stable genotype over the years under hot arid climate.

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