

# Ecotypic Variability for Drought Resistance in *Cenchrus ciliaris* L. Germplasm from Cholistan Desert in Pakistan

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## ABSTRACT

Buffel grass (*Cenchrus ciliaris* L.) plays an important role in the development of grassland/meadow in arid and semi-arid regions. Studies were conducted to examine the influence of water stress on some agro-botanical characters of 16 biotypes of this species based on distinct morpho-genetical features. Under limited moisture availability, E92008\*\* excelled the others by showing a substantial increase in plant height, number of leaves, fresh and dry weight of plant and length and dry weight of root. Individual scores of certain biotypes were quite impressive with regard to various characters. Under stress, E92039 produced maximum tillers whereas E92036 showed greatest fresh and dry weights. Maximal root length was depicted by E92020. Increased foliage and its hairiness displayed a good association with tillering potential, fresh and dry weight of plant under stress, which was linked to increased water balance and good overall growth of biotypes. Prolific root system appeared to be a good yardstick to judge the level of drought resistance. Individualistic behavior of every biotype in relation to stress and non-stress environments exhibited a very unique feature associated with survival of this grass in the desert. Incredible potential for selection/breeding under stressful environments exists in this grass in addition to valuable edaphic adaptations.

**Key Words:** Biotypes; *Cenchrus ciliaris*; Drought; Hairiness; Leaf area; Root proliferation; Survival

## INTRODUCTION

Water plays an important role in dry matter accumulation, because all nutrients are transported through this medium. Crop growth and dry matter yield decreases with decreasing soil water content (Ashraf *et al.*, 1998; Karsten & MacAdam, 2001; Mahiwal & Sutaria, 1992). Prominent effects of water stress include stunted growth and reduced leaf and internode size (Ilahi, 1982), leading to hampered biomass accumulation of various plant parts (Coyne & Bradford, 1985). Relative growth rate and total leaf area decreased in response to water stress but its effect on leaf weight ratio was not much pronounced (Joshi, 1985). Water stress reduced the tillering capacity, but panicles per plant, grain yield and grains per tiller increased (Mahalakshmi & Bidinger, 1985).

Root/shoot ratio was enhanced with increasing soil moisture stress in *Dactylis glomerata* (Ashenden *et al.*, 1975), *Dichanthium annulatum* (Singh & Sinia, 1983) and *Festuca arundinacea* (Huang & Fry, 1998), but reduction in dry weight of root at 7% soil moisture was noted in *Aristida contorta* (Mott & McComb, 1975). Nevertheless, higher root dry weight was related to drought resistance (Ogata *et al.*, 1985; Jensen *et al.*, 2000). Root density in soil profile increased under irrigation but there was an increased specific root length and deeper penetration under moisture stress (Narayan & Misra, 1989; Huang & Gao, 2000).

Resistance against drought in *Cenchrus ciliaris* based on decrease in plant height, leaf area and yield is less than Bermuda grass (Okamoto *et al.*, 1976). However, it shows

high tolerance in relation to tiller and leaf length (Machado *et al.*, 1983). Seed production in *Cenchrus ciliaris* decreased significantly under water stress condition (Sarroca *et al.*, 1981), nonetheless its digestibility under drought was higher than under well-watered conditions (Wilson, 1983). Performance of *C. ciliaris* in arid region was appreciable in terms of plant height, number of tillers and dry matter yield (Sharma & Verma, 1983).

Drought hardy and perennial grasses are very important stuffs of the desert. Being palatable and nutritive, they become the first choice of the grazing animals. Genetic variability of some perennial species of grasses is very high and is well spread in Cholistan desert (Rao *et al.*, 1989). Such species have been surviving some of the severest drought spells of the past. An insight into changes in growth under water stress of these deserted plants will be a highly desirable piece of information for dry-land research.

*Cenchrus ciliaris* L. (African foxtail grass, buffalo grass or buffel grass) is a valuable perennial species especially in the deserts of Pakistan. It grows well on sandy to sandy-loam soils in semiarid and arid regions, forming mats or tussocks. Present studies were conducted to investigate the influence of water stress on different biotypes of *C. ciliaris* focusing on agro-morphological adaptations to withstand under adverse condition of severe drought.

## MATERIALS AND METHODS

University of Agriculture, Faisalabad (UAF) and

\*\* E92002 = entry or biotype followed by its number in the text.

Cholistan Institute of Desert Studies (CIDS), Islamia University, Bahawalpur, Pakistan jointly collected surviving germplasm of *C. ciliaris* L. from various ecozones of Cholistan desert during 1987-88 immediately after a severe and prolonged drought of 1985-87. The material comprising of 51 biotypes was multiplied vegetatively at irrigated farms of CIDS and UAF for five years. To examine the influence of water stress on some agro-botanical and morphogenetical characters of this grass, seeds of 16 biotypes were selected in accordance with the pre-determined selection procedure based on distinct morphogenetical characters (Table I). The selected biotypes were grown up to earing

## RESULTS

**Growth characteristics.** Although *C. ciliaris* biotypes showed decreasing trend for most of the characters under water stress, few of them responded positively. Plant height ranged from 24.8 (E92008) to 60.4 cm (E92039) under control and from 25.9 (E92049) to 41.2 cm (E92008) under stress (Table II). Only E92008 showed a substantial increase under drought, showing 66% increase over control, while E92035 remained almost stable under both the water regimes (Fig. 1). This character in the other biotypes

**Table I. Selection procedure of 16 *Cenchrus ciliaris* entries based upon morpho-genetic characteristics**

| Plant height | Internodal length | Leaf area   | Ears per plant | Ear length | Biotype number |
|--------------|-------------------|-------------|----------------|------------|----------------|
| Small        | Medium            | Medium      | Very low       | Very small | E92001         |
|              | Very short        | Medium      | Very low       | Small      | E92008         |
| Medium       | Short             | Very large  | Very low       | Medium     | E92011         |
|              |                   | Very large  | Low            | Medium     | E92014         |
|              | Medium            | Very small  | Low            | Small      | E92017         |
|              |                   | Small       | Abundant       | Very small | E92020         |
|              | Very short        | Small       | Abundant       | Small      | E92022         |
|              |                   | Very small  | Low            | Very small | E92027         |
| Large        | Short             | Medium      | Medium         | Medium     | E92029         |
|              |                   | Extra large | Low            | Large      | E92032         |
|              | Medium            | Very small  | Low            | Large      | E92035         |
|              |                   | Large       | Medium         | Medium     | E92036         |
|              | Large             | Small       | High           | Large      | E92039         |
|              |                   | Very large  | Medium         | Large      | E92041         |
|              | Very large        | Large       | Small          | Medium     | Large          |
| Short        |                   | Extra large | Medium         | Small      | E92049         |

### Selection criteria

Plant height: Small (up to 37 cm), medium (38-52 cm), large (53-67 cm), very large (above 82 cm)

Internodal length: Very short (up to 10 cm), short (10-14 cm), medium (14-18 cm), large (18-22 cm), very large (above 22 cm)

Leaf area per plant: Very small (up to 2 cm<sup>2</sup>), small (2-4 cm<sup>2</sup>), medium (4-6 cm<sup>2</sup>), large (6-8 cm<sup>2</sup>), very large (8-10 cm<sup>2</sup>), extra large (above 10 cm<sup>2</sup>)

Ears per plant: Very low (up to 10), low (11-20), medium (21-30), high (31-40), abundant (above 41)

Ear length: Very small (up to 5 cm), small (5-6 cm), medium (6-7 cm), large (above 7 cm)

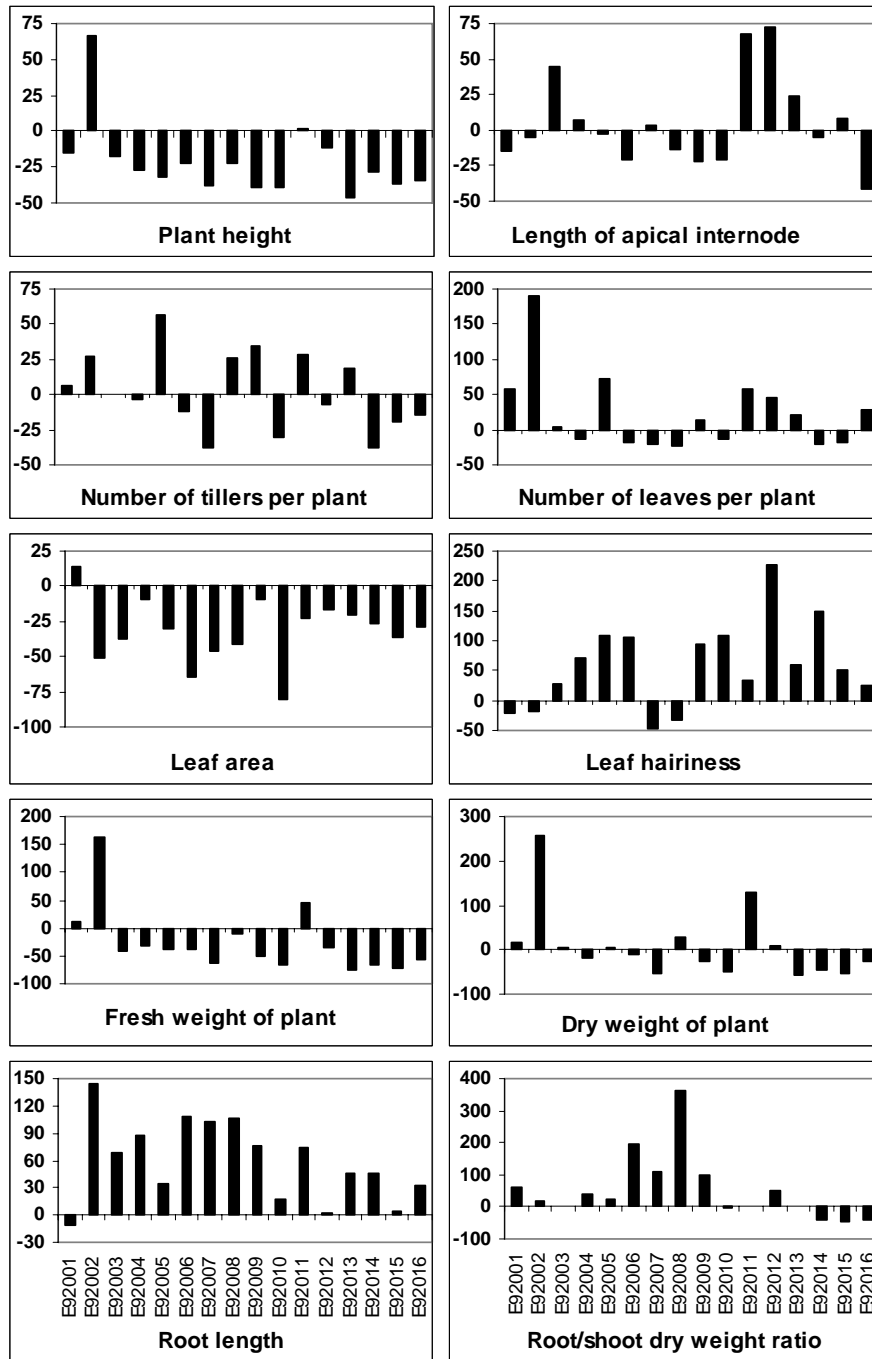
under two moisture regimes in earthen pots filled with 10 kg of sandy loam soil. Control had 20%±2 and stress treatment had 8%±2 soil water content. These moisture levels were maintained on the basis of loss in pot weight due to evapotranspiration. The reported experiment lasted consecutively for three years (April to August, 1993-95). Both the experimental treatments were always replicated at least thrice.

Plant height, apical internodal length, number of tiller and number and area of leaves per plant were counted/measured of the intact plants. Leaf area was taken as maximum leaf length X maximum width X 0.68 (correction factor). Leaf hairiness was determined as number of hairs on surface per mm<sup>2</sup> area under the microscope. Fresh weight of shoot was taken immediately after cutting the shoots at ground level, while the roots were carefully removed by flooding the pots a day before the operation in order to ensure maximum recovery, blotted dry and determined for length and fresh weight. Dry weight of shoot and root was determined after drying them at 70°C for five days.

decreased under limited moisture availability, and the maximum decrease was noted in E92039 (47%). Apical internodal length ranged from 6.9 (E92035) to 13.4 cm (E92049) under control and 7.9 (E92049) to 12.9 cm (E92036) under stress. Seven biotypes showed enhanced values under stress, and the maximum apical internodal length was noted in E92036 (72%), closely followed by E92035 (68%). Maximum decrease in this character was seen in E92049 (41%). Six entries (E92008, E92014, E92017, E92022, E92041 and E92047) remained relatively stable under stress treatment (Table II; Fig. 1).

Variation with regard to tillers per plant ranged from 3.7 (E92008) to 14.0 (E92041) under control and from 4.7 (E92008) to 10.7 (E92039) under stress. Nearly half biotypes depicted professed tillering under stress; E92017 displayed maximum increase (57%). The worst affecters were E92022 and E92041, each showing a decrease of 38% in this parameter (Table 2; Fig. 1). Number of leaves per plant ranged from 36.7 (E92008) to 146.7 (E92041) under control and from 50.0 (E92011) to 135.3 (E92039) under stress. Nine biotypes responded positively under limited moisture availability. Maximum increase (191%) was noted

**Fig. 1. Per cent increase or decrease due to water stress in *Cenchrus ciliaris* entries as compared to control**



in E92008, which was much higher than the second best E92017 (73%). The decrease in this attribute under water stress was not well marked, the one worst affected (E92041) showed a reduction of only 21% (Fig. 1). Likewise, five biotypes exhibited an increase and eleven got reduction in leaf area under drought while two remained stable. Greatest increase in leaf area under drought was found in E92001

(37%), while it was maximally decreased in E92032 (58%) over control. Leaf hairiness ranged from 4.3 (E92036) to 10.3 per mm<sup>2</sup> (E92027) under normal moisture supply and from 4.0 (E92022) to 16.7 (E92041) per mm<sup>2</sup> under stress (Table II). Four biotypes depicted reduced values of leaf hairiness; among them E92022 showed maximum decrease (47%). E92036 exhibited greatest (224%) increase followed by E92047 and E92020 where an increase of more than 100% over control was noted (Fig. 1).

Variation in fresh weight per plant was quite high particularly under limited water supply (Table II). Except three all biotypes showed reduction under stress going up to 74% (E92047), but E92008 exhibited an increase of 164% (Fig. 1). Similarly, dry weight per plant varied from 0.52 (E92008) to 4.62g (E92041) under control and 0.63 (E92011) to 2.61g (E92036) under stress. Four biotypes showed enhanced dry weight under stress; the best in this respect was E92008 showing an increase of 256% over control. Contrarily, E92036 was the worst affected showing a decrease of 58% due to water stress, while E92047, E92041, E92032 and E92022 had more or less 50% reduction in this parameter (Fig. 1). Variation in root/shoot ratio was very low ranging from 0.17 (E92029) to 0.64 (E92049) under control and 0.28 (E92047) to 0.88 (E92027) under stress. Maximum increase in root/shoot ratio under water stress was recorded in E92027 (363%), while E92020, E92007 and E92029 showed over 100% increase. Only three biotypes showed a reduction under water deficit, each by about 40% (Fig. 1).

All biotypes revealed a great variation in the dry weight of root and shoot per plant. Minimum root dry weight ranged from 0.12 (E92008) to 1.60 (E92041) under control and from 0.16 (E92011) to 0.73 (E92036) under stress (Table II). Seven biotypes displayed increase over control; the greatest increase of 367% (E92008), six got reduction

**Table II. Effect of water stress on some morphological characteristics of *Cenchrus ciliaris* biotypes under normal and limited water supply**

| Biotype | Treatment | Plant height (cm) | Apical internode length (cm) | Number of tillers per plant | Number of leaves per plant | Leaf area per plant (cm <sup>2</sup> ) | Leaf hairiness (mm <sup>2</sup> ) | Fresh weight per plant (g) | Dry weight per plant (g) | Root length (cm) | Root dry weight (g) | Shoot dry weight (g) | Root/shoot ratio |
|---------|-----------|-------------------|------------------------------|-----------------------------|----------------------------|--|-----------------------------------|----------------------------|--------------------------|------------------|---------------------|----------------------|------------------|
| E92001  | Control   | 40.3              | 11.9                         | 5.0                         | 44.7                       | 35.8                                   | 6.0                               | 2.55                       | 0.73                     | 27.7             | 0.19                | 0.54                 | 0.35             |
|         | Stress    | 34.3              | 10.1                         | 5.3                         | 70.7                       | 56.6                                   | 4.7                               | 2.84                       | 0.84                     | 24.4             | 0.32                | 0.32                 | 0.57             |
| E92008  | Control   | 24.8              | 10.7                         | 3.7                         | 36.7                       | 58.4                                   | 8.7                               | 1.89                       | 0.52                     | 18.8             | 0.12                | 0.39                 | 0.36             |
|         | Stress    | 41.2              | 9.2                          | 4.7                         | 106.7                      | 83.2                                   | 7.0                               | 4.98                       | 1.85                     | 45.9             | 0.54                | 1.31                 | 0.42             |
| E92011  | Control   | 32.2              | 8.3                          | 5.7                         | 48.0                       | 51.4                                   | 4.7                               | 2.30                       | 0.59                     | 18.3             | 0.14                | 0.46                 | 0.30             |
|         | Stress    | 26.6              | 12.0                         | 5.7                         | 50.0                       | 33.5                                   | 6.0                               | 1.37                       | 0.63                     | 30.7             | 0.16                | 0.47                 | 0.31             |
| E92014  | Control   | 40.4              | 9.9                          | 10.0                        | 102.0                      | 94.9                                   | 8.0                               | 5.39                       | 1.73                     | 24.2             | 0.44                | 1.29                 | 0.32             |
|         | Stress    | 29.4              | 10.6                         | 9.7                         | 88.7                       | 74.5                                   | 13.7                              | 3.73                       | 1.41                     | 45.5             | 0.44                | 0.97                 | 0.45             |
| E92017  | Control   | 41.0              | 11.7                         | 5.3                         | 43.7                       | 74.3                                   | 6.7                               | 5.03                       | 1.18                     | 26.3             | 0.37                | 0.81                 | 0.41             |
|         | Stress    | 28.1              | 11.4                         | 8.3                         | 75.7                       | 90.1                                   | 14.0                              | 3.15                       | 1.24                     | 35.3             | 0.41                | 0.83                 | 0.50             |
| E92020  | Control   | 40.5              | 12.6                         | 10.3                        | 102.3                      | 106.4                                  | 5.7                               | 6.87                       | 1.70                     | 23.8             | 0.32                | 1.38                 | 0.23             |
|         | Stress    | 31.3              | 10.0                         | 9.0                         | 83.0                       | 51.5                                   | 11.7                              | 4.22                       | 1.54                     | 49.5             | 0.62                | 0.92                 | 0.68             |
| E92022  | Control   | 51.0              | 11.0                         | 9.7                         | 77.0                       | 133.2                                  | 7.7                               | 8.76                       | 1.97                     | 18.2             | 0.43                | 1.53                 | 0.27             |
|         | Stress    | 31.4              | 11.4                         | 6.0                         | 61.3                       | 57.6                                   | 4.0                               | 3.17                       | 0.93                     | 36.9             | 0.33                | 0.60                 | 0.56             |
| E92027  | Control   | 35.3              | 12.0                         | 5.3                         | 74.7                       | 99.4                                   | 10.3                              | 3.01                       | 1.00                     | 19.8             | 0.15                | 0.85                 | 0.19             |
|         | Stress    | 27.3              | 10.3                         | 6.7                         | 56.7                       | 44.8                                   | 7.0                               | 2.68                       | 1.27                     | 40.7             | 0.58                | 0.69                 | 0.88             |
| E92029  | Control   | 48.2              | 11.9                         | 4.7                         | 62.7                       | 41.4                                   | 5.0                               | 5.71                       | 1.62                     | 18.6             | 0.22                | 1.40                 | 0.17             |
|         | Stress    | 29.2              | 9.3                          | 6.3                         | 70.7                       | 42.4                                   | 9.7                               | 2.91                       | 1.20                     | 32.7             | 0.31                | 0.89                 | 0.34             |
| E92032  | Control   | 46.1              | 12.4                         | 9.0                         | 77.0                       | 101.6                                  | 5.3                               | 7.59                       | 2.17                     | 28.7             | 0.60                | 1.56                 | 0.40             |
|         | Stress    | 28.2              | 9.8                          | 6.3                         | 66.0                       | 42.9                                   | 11.0                              | 2.66                       | 1.07                     | 33.9             | 0.29                | 0.77                 | 0.38             |
| E92035  | Control   | 30.7              | 6.9                          | 6.0                         | 55.7                       | 42.3                                   | 8.0                               | 2.74                       | 0.58                     | 19.1             | 0.14                | 0.44                 | 0.31             |
|         | Stress    | 31.1              | 11.6                         | 7.7                         | 88.0                       | 51.9                                   | 10.7                              | 3.97                       | 1.34                     | 33.2             | 0.32                | 1.02                 | 0.31             |
| E92036  | Control   | 42.5              | 7.5                          | 8.3                         | 87.0                       | 80.0                                   | 4.3                               | 10.24                      | 2.43                     | 37.2             | 0.48                | 1.95                 | 0.27             |
|         | Stress    | 37.4              | 12.9                         | 7.7                         | 126.7                      | 97.6                                   | 14.0                              | 6.66                       | 2.61                     | 38.3             | 0.73                | 1.88                 | 0.41             |
| E92039  | Control   | 60.4              | 8.9                          | 9.0                         | 111.0                      | 102.1                                  | 5.0                               | 17.76                      | 4.37                     | 27.3             | 1.33                | 3.03                 | 0.43             |
|         | Stress    | 32.1              | 11.0                         | 10.7                        | 135.3                      | 98.8                                   | 8.0                               | 4.56                       | 1.83                     | 39.9             | 0.57                | 1.27                 | 0.44             |
| E92041  | Control   | 52.9              | 13.3                         | 14.0                        | 146.7                      | 170.2                                  | 6.7                               | 8.70                       | 4.62                     | 26.3             | 1.60                | 3.02                 | 0.50             |
|         | Stress    | 37.6              | 12.7                         | 8.7                         | 116.0                      | 98.6                                   | 16.7                              | 6.24                       | 2.43                     | 38.2             | 0.58                | 1.85                 | 0.30             |
| E92047  | Control   | 57.2              | 11.3                         | 8.3                         | 99.0                       | 121.8                                  | 7.7                               | 17.07                      | 3.72                     | 34.2             | 1.09                | 2.63                 | 0.50             |
|         | Stress    | 36.3              | 12.2                         | 6.7                         | 82.0                       | 64.8                                   | 11.7                              | 4.62                       | 1.75                     | 35.8             | 0.38                | 1.37                 | 0.28             |
| E92049  | Control   | 39.2              | 13.4                         | 7.0                         | 56.0                       | 45.9                                   | 5.0                               | 6.14                       | 1.27                     | 22.6             | 0.49                | 0.78                 | 0.64             |
|         | Stress    | 25.9              | 7.9                          | 6.0                         | 72.3                       | 41.9                                   | 6.3                               | 2.67                       | 0.93                     | 30.0             | 0.23                | 0.70                 | 0.37             |

and three remained stable (Fig. 1). Shoot dry weight was relatively more affected under drought and only two biotypes (E92008 and E92035) indicated enhancement in this attribute, nine got reduction and five remained stable. Root length and its ramification varied from 18.2 (E92022) to 37.2 cm (E92036) under control and from 24.4 (E92001) to 49.5 cm (E92020) under stress (Table II; Fig. 2). All biotypes depicted an increase in root length under stress excepting E92001, which showed a decline of 12%. The best biotype was E92008 showing an increase of 144%. Some biotypes (viz. E92020, E92022, E92027) showed an increase (>95%) in root length over control (Fig. 2).

**Correlation studies.** Plant height showed a positive correlation ( $p < 0.01$ ) with fresh and dry weight of plant under both the water regimes (Table III). Increased number of tillers per plant was strongly correlated ( $p < 0.01$ ) with fresh, dry weight and number of leaves per plant under control only. Leaf hairiness was not related ( $p > 0.05$ ) with any of the character under control, but was positively correlated ( $p < 0.01$ ) with plant fresh and dry weight, shoot dry weight, leaf area and number of tillers per plant under drought. Number and area of leaves per plant indicated a good association ( $p < 0.01$ ) with fresh and dry weight of plant

and number of tillers per plant under control, but this was not evident ( $p > 0.05$ ) under drought stress in case of number of tillers. Dry weight of both shoot and root was correlated ( $p < 0.01$ ) with total fresh and dry weight and number and area of leaves per plant under both the moisture regimes. However, shoot dry weight indicated no correlation ( $p > 0.05$ ) with leaf hairiness under control but indicated a strong correlation ( $p < 0.01$ ) under stress treatment. Root length was only correlated with plant fresh and dry weight under normal moisture availability but not under drought (Table III).

## DISCUSSION

Water stress, whether natural or induced, adversely affects growth and related attributes of various plant species. However, drought-hardy species can still withstand longer dry spells and display significant yields (Jensen *et al.*, 2000). Buffel grass is thought to be highly drought tolerant with regard to plant height (Machado *et al.*, 1983). However, the reverse may be true as only two biotypes showed increased values. Biotype E92008 displaying lowered plant height under control emerged as the most

**Table III. Correlation coefficient (r) of various morphological characteristics in *Cenchrus ciliaris* biotypes (n=16; correlation values given only where “r” was significant under any of the conditions)**

| Variable 1                 | Variable 2                  | Control  | Stress  |
|----------------------------|-----------------------------|----------|---------|
| Fresh weight per plant     | Plant height                | 0.869**  | 0.809** |
|                            | Number of tillers per plant | 0.721**  | 0.405ns |
|                            | Number of leaves per plant  | 0.822**  | 0.816** |
|                            | Leaf area per plant         | 0.733**  | 0.797** |
|                            | Leaf Hairiness              | -0.205ns | 0.599** |
|                            | Root length                 | 0.564*   | 0.458ns |
|                            | Shoot dry weight            | 0.976**  | 0.956** |
|                            | Root dry weight             | 0.959**  | 0.785** |
|                            | Root length                 | 0.564*   | 0.458ns |
|                            | Plant height                | 0.873**  | 0.730** |
| Dry weight per plant       | Number of tillers per plant | 0.749**  | 0.450ns |
|                            | Number of leaves per plant  | 0.866**  | 0.781** |
|                            | Leaf area per plant         | 0.754**  | 0.792** |
|                            | Leaf Hairiness              | 0.200ns  | 0.658** |
|                            | Root length                 | 0.549*   | 0.497ns |
|                            | Shoot dry weight            | 0.911**  | 0.979** |
|                            | Root dry weight             | 0.964**  | 0.833** |
|                            | Root length                 | 0.549*   | 0.497ns |
|                            | Number of leaves per plant  | 0.905**  | 0.544*  |
|                            | Shoot dry weight            | 0.870**  | 0.791** |
| Number of leaves per plant | Root dry weight             | 0.813**  | 0.585*  |
|                            | Number of tillers per plant | -0.135ns | 0.602** |
|                            | Leaf area per plant         | 0.225ns  | 0.527   |
| Leaf hairiness             | Shoot dry weight            | -0.213ns | 0.676** |

Significant at \*, p<0.05; \*\*, p<0.01; ns, non-significant

drought resistant (Table II). Internodal length, known to be reduced under water stress (Ilahi, 1982), in this study showed highly unpredictable behaviour for apical internode. A significant correlation of plant height with plant fresh and dry matter yield (Table III) suggests that reduced apical internodal length and overall plant height is a beneficial strategy in the use of photosynthates for greater biomass production and reproductive growth by diverting rapid supply of photoassimilates to flowering and grain filling.

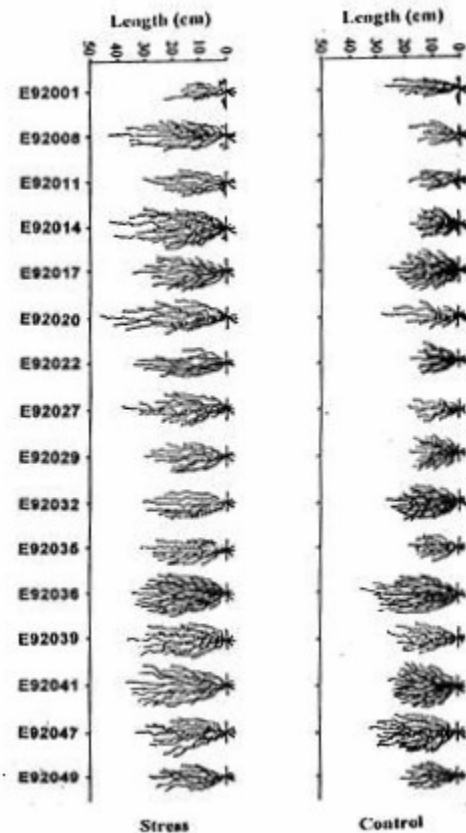
Tillering capacity, which determines the final productivity of any species in arid regions (Sharma & Verma, 1983), was highly variable under both water regimes (Table II). Majority of the biotypes suffered reduction in tillering, which is probably the reason for not being correlated with plant biomass under drought (Table III). Contrarily, exposure to drought brought about a meaningful increase in the number and area of leaves, which is a highly desirable adaptation under water stress (Table II; Fig. 1). Five biotypes including the top notcher (E92008) maintained greater leaf area, while rest of them showed reduced leaf area per plant, as has been established for other grass species (Coyne & Bradford, 1985; Huang & Gao, 2000). These findings have been substantiated by significant relationships of increased foliage with fresh and dry matter yield (of shoot, root and their total) under both the water regimes (Table III). It is plausible that greater number and area of leaves are crucial for sustenance and increased productivity of this grass under longer dry spells.

Increased hairiness appears to be a good indicator of

droughted state of germplasm because its dense growth can check transpiration to some extent (Martin & Juniper, 1974; Grace & Russel, 1977; Cutler, 1978). Interestingly, this attribute was not correlated with any of the growth and dry matter yield parameter under control but was strongly correlated under limited water supply (Table III). This alludes to its role in the enhanced drought tolerance of *C. ciliaris*. This provides additional aid in minimizing water loss from leaf surface and improving the plant water status under drought. Dense hairiness in E92014, E92017, E92036 and E92041 makes them suitable for drought tolerance (Table II; Fig. 1).

Most of the biotypes manifested a decrease in fresh weights under stress, except four of them showing appropriate adaptations (Table II). Sharma and Verma (1983) reported best performance of this grass in arid region with regard to fodder yield. Prodigious increase in E92008 followed by E92036, E92039 and E92041 indicates their potential to withstand against severe droughts and making them suitable stuff for arid or semi-arid regions. Dry matter production reduces as a result of soil moisture stress (Coyne & Bradford, 1985; Joshi, 1985; Karsten & MacAdam, 2001), as has been noted in this study (Table II). However, E92008 again showed substantial increase under drought,

**Fig. 2. Root proliferation of *Cenchrus ciliaris* biotypes under control and water stress**



about twice over the second best (E92035).

Root/shoot ratio is thought to be higher in drier areas (Ashenden *et al.*, 1975), but this ratio did not hold good to judge the drought resistance of *C. ciliaris* (Table II). Greater root mass than shoot has been found as a good criterion for assessing drought resistance, as its density increases under irrigation, though its penetration is deeper and wide spread under moisture stress (Narayan & Misra, 1989; Jensen *et al.*, 2000). Undoubtedly, the biotypes resisting drought here were able to proliferate elongate their root systems well. E92008 emerged out to be the best biotype depicting the maximally proliferated root system under limited moisture supply, whereas, E92020, E92022 and E92027 got over 100% enhancement (Fig. 1,2). Some biotypes showing a dense root system under normal conditions behaved otherwise under limited moisture supply. Seven biotypes depicted very poorly developed, four showed moderately developed while another five had highly developed root systems under stress (Table II; Fig. 2). The root dry weight was found to hold good relationship with most of the above ground characters (Table III). From the above it is conceived that root proliferation, increased foliage and plant dry weight, specifically of root, are good yardsticks to measure drought tolerance of this species. This enabled the plant to efficiently extract and conserve any amount of water available in the vicinity.

Four major categories can be recognized (Table II). First is, E92001, E92011, E92027, E92036 and E92049, displaying the lowest values of almost all the characters studied. Drought showed a slight effect on their values. Second category, E92008, E92035 and E92041 exhibited a considerable increase in almost all the characters under drought. Third category, E92039, E92041 and E92047, possessed the maximum of all the characters under normal moisture conditions. The last category contains the rest biotypes (E92014, E92017, E92020, E92022, E92029 and E92032) showing uncertain behaviour.

This is incredible to note that no biotype at any level or for any single character showed uniformity. Surprisingly, every biotype is exhibiting an individualistic behaviour in relation to stressed and non-stressed environments, which along with others, appears to be a unique adaptation helping its survival in the desert. Similarly, every minor or major morphogenetic character has a definite role to play towards the survival of biotypes. Edaphic factors in Cholistan desert quickly change. The germplasm under study is fully geared to cope with them due to a number of eco-physiological adaptations found among them collectively or individually.

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