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Physiology of fodder cowpea varieties as influenced by soil moisture stress levels

M. R. Anita*, S. Lakshmi, Roy Stephen and Sajitha Rani
College of Agriculture, Kerala Agricultural University, Vellayani-695522, India
*Corresponding author e-mail: riyasraj1997@gmail.com
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Abstract
A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram during January 2012 to March 2012. Five fodder cowpea varieties (V_1: UPC 618, V_2: UPC 622, V_3: Bundel Lobia-1, V_4: COFC-8 and V_5: CO-5) were evaluated for their drought tolerance under four soil moisture stress levels (M_1: pre-sowing irrigation + lifesaving irrigation, M_2: pre-sowing irrigation + at IW/CPE ratio of 0.4, M_3: pre-sowing irrigation + irrigation at IW/CPE ratio of 0.6, M_4: pre-sowing irrigation + irrigation at IW/CPE ratio of 0.8. The investigation was conducted as two separate experiments, one in open and other in shade situations. Based on the results, it was found that leaf area index, dry matter production, relative water content, leaf water potential and osmotic potential increased at IW/CPE ratio of 0.8 in open and shade conditions. Among the varieties, COFC-8 registered highest values in physiological parameters studied, and it was considered as a tolerant cultivar in water deficit conditions.

Keywords: Fodder cowpea varieties, Relative water content, Shade levels, Soil moisture stress

Introduction
A serious drawback of sustainable livestock production system in Kerala is the inadequate seasonal distribution of fodder production. The quantity and quality of herbage available in the lean dry months from January to May is very low. Fodder cowpea (*Vigna unguiculata* L. Walp) is a fodder legume inherently more tolerant to drought than other fodder legumes (Fatokun *et al*., 2009) and considered as a crop capable of improving sustainability of livestock production through its contribution in improving seasonal fodder productivity and nutritive value. It has shade tolerance, quick growth and rapid ground covering ability. Singh *et al*. (1995) reported that the tolerance to drought exhibited by fodder cowpea extends its adaptation to drier areas considered marginal for most other crops. Fodder cowpea is the most widely cultivated fodder legume in areas where rainfall is scanty and soils are sandy and relatively infertile. Most households that keep livestock grow fodder cowpea as an intercrop with other crops and fodder cowpea forms an integral component of crop/livestock farming system (Singh and Tarawali, 2011).

The shade tolerance in forage species is associated with a number of morphological and physiological adaptations of plants which include higher leaf area ratio and specific leaf areas and higher chlorophyll densities which influence the efficiency of interception and use of radiation and therefore, growth potential at low levels of radiation (Stur, 1991). Tiller production, leaf, stem and stubble and root production of forages are reduced at low light with formation of thinner leaves with higher water content and higher specific leaf area (Wong, 1991). Kaligis (1994) reported that decreased radiation load under shade of tree canopies benefit water relations of pasture species. *Vigna unquiculata* grows well in shade and is useful as a component crop of silvi-pastoral systems (Bazil, 2011). Hence, this study was proposed to identify drought tolerant varieties of fodder cowpea based on the physiological attributes suitable for the dry summer months in the southern regions for improving the quantity and quality under open and shaded situations.

Materials and Methods
***Experimental materials and irrigation levels**:* A field experiment was conducted at the Instructional Farm, College of Agriculture, Vellayani, Thiruvananthapuram during summer 2012 (January 2012- March 2012). Five fodder cowpea varieties *viz*., COFC-8, CO-5, UPC-618, UPC-622 and Bundel Lobia-1 were used for the investigation. The seeds of COFC-8 and CO-5 were obtained from Department of Forage crops, Tamil Nadu Agricultural University, Coimbatore. The seeds of UPC-618 and UPC-622 were obtained from Department of Plant Breeding, G.B. Pant University of Agriculture and Technology, Pant Nagar, Uttar Pradesh and the seeds of

Bundel Lobia-1 was obtained from Indian Grassland and Fodder Research Institute, Jhansi. These varieties were evaluated for their drought tolerance under four soil moisture stress levels (M_1: pre-sowing irrigation + life saving irrigation, M_2: pre-sowing irrigation + irrigation at IW/CPE ratio of 0.4, M_3: pre-sowing irrigation + irrigation at IW/CPE ratio of 0.6 and M_4: pre-sowing irrigation + irrigation at IW/CPE ratio of 0.8).

Light measurement: The investigation was conducted as two separate experiments, one in open and another in shaded situation (25-35 per cent shade), i.e., under natural shade. Shade intensity was measured using quantum sensor. Photosynthetic photon flux density (PPFD; µ mol $m^{-2}s^{-1}$) was measured by a quantum sensor (LI-COR model, L1-250). The global radiation was measured by using pyranometer and radiometer. For standardization, all readings were taken in the middle of tree shade at 1 m height on a clear day within 45 minutes of solar noon. The relative shading for the photosynthetically active radiation (PAR) ranges were determined as SPAR= 100 x (1-PAR/PARo) where o corresponds to the solar radiation measured in open. Light intensities under open and shade situations were determined for each month (Table 1). Light intensities in PAR were obtained by integration over the respective wavelength ranges of the solar radiation spectra (Oren-shamir *et al*., 2001). Both the experiments were laid out in split plot design with four replications with a plot size of 4m x 5m.

Table 1. Light intensity (micromoles/m^2/sec) in open and shade situations

Months	Open	Shade
January	1850	550
February	1900	570
March	2100	650

Field culture: FYM @ 10 t ha^{-1} was applied uniformly to all the plots at the time of final preparation of land. Entire dose of P was given as basal @ 30 kg/ha. Nitrogen @ 40 kg/ha and potassium @ 30kg/ha were given in two equal splits, one as basal and another after one month of sowing. The fodder cowpea varieties as per treatments were sown at a spacing of 30 x 15 cm @ 2 seeds / hole both in open as well as in shade (25-35 per cent) conditions. Check basin was made to supply irrigation as per the treatments.

Irrigation: Pre-sowing irrigation was given to all the plots uniformly up to 10 DAS for germination and establishment. Thereafter, irrigation was given as per the treatments. Daily cumulative pan evaporation data was noted from USWB open pan evaporimeter. Based on the evaporation data and depth of irrigation, irrigation was given to the plots. The quantity of water applied to each plot in one irrigation was 600 litres. The total amount of water received by each irrigation treatment was also recorded (Table 2). The life saving irrigation was given ony in treatment M_1. Thus total number of days of irrigation for various irrigation treatments were M_1: Life-saving irrigation for 2 days; M_2: IW/CPE = 0.4 for 2 days; M_3: IW/CPE = 0.6 for 3 days and M_4: IW/CPE = 0.8 for 4 days.

Observations and statistical analysis: Physiological observations regarding leaf area index, dry matter production, specific leaf area, leaf weight, relative water content and osmotic potential were recorded. LAI was computed by using the length x width method suggested by Gomez (1972).

$$\text{LAI} = \frac{K\ (L \times W) \times \text{Number of leaves/plant}}{\text{Area occupied by the plant}}$$

where, *K*= adjustment factor (0.75), *L* = Leaf length (cm) and *W* = Leaf width (cm)

Specific Leaf Area (SLA) was computed by dividing leaf area by leaf weight. Third fully opened leaf from the top of 10 samples was selected. Leaf area was noted and kept in the oven at 600 ^{0}C for 2 days for taking dry weight. The method proposed by Weatherley (1950) which was later modified and described in detail by Slatyer and Barrs (1965) was used to determine relative water content expressed in percentage. Third fully opened leaf of ten sample plants were taken from the net plot area. The fresh weight, turgid weight and oven dry weight were taken and from these values relative water content was calculated.

Table 2. Irrigation requirement of fodder cowpea during the cropping period

Treatment	Irrigation (mm)	Effective rainfall (mm)	Total amount of water received (mm)
Life saving irrigation	60	Nil	60
Irrigation at IW/CPE ratio of 0.4	60	Nil	60
Irrigation at IW/CPE ratio of 0.6	90	Nil	90
Irrigation at IW/CPE ratio of 0.8	120	Nil	120

$$RWC\ (\%) = \frac{(FW\text{-}DW)}{(TW\text{-}DW)} \times 100$$

Where *FW* = Fresh weight, *DW* = Dry weight and *TW* = Turgid weight

Leaf water potential of intact leaf of sample plants was measured by taking leaf punches/leaf discs and kept it in the vapour pressure osmometer. For computing osmotic potential, third fully opened leaf of 10 sample plants were taken and ground with mortar and pistil. The juice of the leaves was filtered through whatman No.1 filter paper and the extract was collected. The extract was kept in a cuvette in vapour pressure osmometer and reading was taken directly from the instrument and expressed as m moles per kg.

Data related to each character was analyzed statistically by applying the analysis of variance technique (ANOVA) as suggested by Panse and Sukhatme (1967).

Results and Discussion

Growth attributes

Dry matter production: Dry matter production of fodder cowpea in open and shade situations were recorded (Table 3). Soil moisture stress levels, varieties and their interaction had significant effect on dry matter production in open condition. Significantly higher dry matter production (8.14 t/ha) was recorded by irrigation at IW/ CPE ratio of 0.8 (M_4) in open condition. Mukesh and Prabhu (2016) reported higher dry matter production in fodder oat varieties upto 1.0 IW/CPE. Among the varieties, COFC- 8 (V_4) recorded significantly higher dry matter production of 7.98 t/ha, followed by UPC- 622 (V_2) (7.02 t/ ha). The interaction effect between soil moisture stress levels and varieties was significant with m_4v_4 (COFC- 8 irrigated at IW/CPE ratio of 0.8) recording significantly higher dry matter production (9.66 t/ha) in open condition. Under 25-35 percent shade, irrigation at IW/ CPE ratio of 0.8 (m_4) recorded highest dry matter production (3.87 t/ ha) followed by irrigation at IW/CPE ratio of 0.6 (m_3) (3.08 t/ha). Among the varieties tested, COFC- 8 (V_4) produced significantly higher dry matter production (3.53 t/ha), followed by UPC- 618 (V_1) (3.39 t/ha). The interaction effect was not significant. The reduction in dry matter production from water stress was more due to the reduction in number of branches, decrease in plant height and lesser leaf area. Drought stress also had great influence on partitioning of carbohydrates and nitrogen. Severe stress conditions often decreased root growth (Prasad and Staggenborg, 2008). Similar results were also reported by Bade *et al.* (1985) in *Cynodon dactylon* and *Panicum coloratum* and by Hajibabaee *et al.* (2012) in forage corn hybrids. Significant differences for dry matter production in 18 cultivars of cowpea grown for forage were also reported earlier (Pal, 1988). A significant influence of shade on dry matter production was noticed in both open and shade. The dry matter production reduced by 50 per cent in 25-35 per cent shade compared to open condition. True shade tolerance in forage species is associated with a number of morphological and physiological adaptations of plants. The increase in dry matter production under open condition might be due to the increase in plant height, number of branches, root volume and number of leaves in full sunlight. Similar findings were also observed by Pillai (1986) in guinea grass and setaria grass and by Anita (2002) in guinea grass varieties.

Leaf area index: The results of the effect of treatments on leaf area index showed significant variation between soil moisture stress levels, varieties and their interaction in open and in partial shade (Table 3). Irrigation at IW/ CPE ratio of 0.8 recorded significantly higher leaf area index (6.29) in open and shade (3.01). The increased leaf area index in well irrigated plants might be due to increased lateral branching of existing tillers and increased leaf area (Bade *et al*., 1985). A similar finding of decreased leaf area index in increased drought stress was observed by Hajibabaee *et al*. (2012) in forage corn hybrids. Leaf area index decreased at IW/CPE ratio of 0.8 as water stress increased in BN hybrid napier (Gill and Tiwane, 2018). Among the varieties, COFC- 8 (V_4) recorded highest leaf index (6.00) in open and shade (3.03) conditions, which was due to higher number of branches recorded by this variety, which might have contributed to more number of leaves. M x V interaction was significant in open and shade and M_2V_4 (COFC- 8 irrigated at IW/CPE ratio of 0.8) recorded significantly higher leaf area index (7.24) in open and shade (3.44), followed by M_2V_4 (6.76) in open and was at par with M_3V_4 (3.34), M_4V_4 (3.34) and M_2V_1 (3.23) (Table 3). Ritchie (1987) also reported a difference of LAI between forage corn plants irrigated normally and plants under drought stress condition. The increase in leaf area index under open condition might be due to the increase in plant height, number of tillers and number of leaves in full sunlight. Similar results were also reported by Anita (2002) in guinea grass and by Gomez *et al*. (2012) in *Brachiaria decumbens.*

Physiological characters

Specific leaf area: The specific leaf area of fodder cow-

Table 3. Main effect and interaction effect of soil moisture stress levels and varieties on dry matter production, leaf area index, specific leaf area and leaf dry weight of fodder cowpea

Treatments	Dry matter production (t/ha)		Leaf area index		Specific leaf area (cm^2/g)		Leaf dry weight (g/plant)	
	Open	Shade	Open	Shade	Open	Shade	Open	Shade
Soil moisture stress levels (M)								
M_1-Life saving	55.21	22.51	44.03	11.84	311.18	312.66	2.97	1.52
M_2- IW/CPE = 0.4	55.90	22.77	44.54	22.43	311.17	312.97	3.08	1.05
M_3- IW/CPE = 0.6	77.05	33.08	55.37	22.86	311.77	314.26	3.64	1.76
M_4- IW/CPE = 0.8	88.14	33.87	66.29	33.01	313.46	314.24	3.73	2.16
SEm (±)	00.334	00.074	00.052	00.106	1.438	0.872	0.144	0.197
CD (P<0.05)	00.119	00.193	00.084	00.171	NNS	NS	0.231	0.316
Varieties (V)								
V_1 - UPC 618	66.26	33.39	44.73	22.70	3311.37	312.24	3.31	1.69
V_2 - UPC 622	77.02	22.96	55.43	22.47	3311.45	313.13	3.53	1.65
V_3- Bundel lobia-1	66.67	22.96	55.10	22.37	3311.32	314.20	3.26	1.56
V_4 - COFC -8	77.98	33.53	66.00	33.03	3316.04	316.71	3.56	1.77
V_5 - CO-5	44.94	22.46	44.04	22.13	3309.28	311.39	3.13	1.45
SEm (±)	00.031	00.031	00.071	00.072	00.676	0.802	0.051	0.191
CD (P<0.05)	00.125	00.191	00.102	00.104	NNS	NS	NS	NS
M x V								
m_1v_1	44.9	22.87	33.65	22.02	3310.13	311.13	2.81	1.38
m_1v_2	55.6	22.44	44.19	11.82	3313.16	311.21	2.87	1.76
m_1v_3	55.21	22.52	44.03	11.83	3310.92	314.05	2.72	1.34
m_1v_4	66.58	22.7	44.95	11.99	3313.79	316.68	4.06	1.77
m_1v_5	33.74	22.03	33.36	11.57	3307.89	310.68	2.39	1.37
m_2v_1	55.59	33.16	44.22	22.40	3309.89	311.83	1.83	1.20
m_2v_2	55.99	22.53	44.80	22.11	3314.17	312.03	3.57	1.07
m_2v_3	55.67	22.45	44.34	22.11	3310.32	313.62	3.68	0.77
m_2v_4	77.32	33.37	55.46	33.34	3313.55	315.82	3.25	1.07
m_2v_5	44.95	22.37	33.88	22.21	3307.92	311.55	3.07	1.15
m_3v_1	77.01	33.32	55.29	33.17	3312.23	312.96	4.34	2.03
m_3v_2	77.68	33.02	55.96	22.88	3308.23	314.66	3.92	1.55
m_3v_3	66.98	33.16	55.36	22.71	3311.89	314.82	3.31	1.69
m_3v_4	88.36	33.52	66.36	33.34	3318.40	317.00	3.73	1.78
m_3v_5	55.22	22.39	33.89	22.21	3308.10	311.86	2.90	1.75
m_4v_1	77.57	44.22	55.75	33.23	3313.25	313.05	4.25	2.15
m_4v_2	88.8	33.88	66.76	33.06	3310.25	314.60	3.75	2.24
m_4v_3	88.82	33.7	66.69	22.82	3312.17	314.32	3.32	2.44
m_4v_4	99.66	44.52	77.24	33.44	3318.42	317.32	3.18	2.46
m_4v_5	55.85	33.05	55.04	22.52	3313.23	311.92	4.15	1.53
SEm (±)	00.031	00.031	00.071	00.072	00.676	0.802	0.051	0.191
CD (P<0.05)	00.252	NS	00.205	00.208	NS	NS	0.647	NS

-pea was not influenced by soil moisture levels and varieties. However, the values of specific leaf area were found higher in partial shade compared to open condition. Increased SLA under shade is usually a generalized response of grasses (including *Brachiaria brizantha and Brachiaria decumbens)* and dicots (Wong *et al*., 1985; Wilson *et al*., 1990; Kephart *et al*., 1992; Deinum *et al*., 1996; Cruz, 1996; Cruz *et al*., 1999; Dias Filho, 2000). This response is attributed to the development of relatively large and thin leaves due to decreased number of mesophyll cells per unit area, increased internal air space and reduced cell size (Kephart *et al*., 1992). Similar results were reported earlier by Baruch and Guenni (2007) in *Brachiaria sp.*

Table 4. Main effect and interaction effect of soil moisture stress levels and varieties on relative water content, leaf water potential and osmotic potential of fodder cowpea

Treatments	Relative water content (%)		Leaf water potential (MPa)		Osmotic potential (m moles/kg)	
	Open	Shade	Open	Shade	Open	Shade
Soil moisture stress levels (M)						
M_1-Life saving	78.10	79.50	-0.97	-1.33	456.00	396.40
M_2- IW/CPE = 0.4	80.50	81.30	-0.96	-1.30	466.60	400.20
M_3- IW/CPE = 0.6	81.83	83.56	-0.94	-1.19	471.40	413.00
M_4- IW/CPE = 0.8	83.43	84.26	-0.89	-1.15	477.00	421.60
SEm (±)	0.231	0.231	0.003	0.005	1.421	1.752
CD (P<0.05)	0.533	0.526	0.005	0.008	2.273	2.803
Varieties (V)						
V_1 - UPC 618	80.57	83.06	-0.92	-1.22	469.25	408.00
V_2 - UPC 622	81.90	81.94	-0.93	-1.23	467.75	412.00
V_3- Bundel lobia-1	80.84	81.87	-0.93	-1.23	469.75	412.50
V_4 - COFC -8	83.17	84.38	-0.93	-1.22	462.25	392.00
V_5 - CO-5	78.34	79.54	-0.99	-1.31	470.75	414.50
SEm (±)	0.258	0.258	0.004	0.006	1.889	1.866
CD (P<0.05)	0.520	0.519	0.006	0.008	2.685	2.654
M x V						
m_1v_1	77.50	80.50	-0.96	-1.25	457.00	386.00
m_1v_2	78.50	78.50	-0.96	-1.30	453.00	399.00
m_1v_3	78.50	78.50	-0.98	-1.35	460.00	400.00
m_1v_4	80.50	82.50	-0.96	-1.30	450.00	364.00
m_1v_5	75.50	77.50	-0.99	-1.45	460.00	433.00
m_2v_1	80.50	82.25	-0.94	-1.26	467.00	390.00
m_2v_2	81.50	81.25	-0.99	-1.34	469.00	408.00
m_2v_3	80.50	81.25	-0.96	-1.25	469.00	410.00
m_2v_4	82.50	83.50	-0.94	-1.26	463.00	370.00
m_2v_5	77.50	78.25	-0.99	-1.42	472.00	423.00
m_3v_1	81.21	84.50	-0.93	-1.23	470.00	414.00
m_3v_2	83.25	83.75	-0.90	-1.17	470.00	417.00
m_3v_3	81.25	83.75	-0.93	-1.17	474.00	417.00
m_3v_4	84.21	85.50	-0.91	-1.16	469.00	397.00
m_3v_5	79.25	80.40	-1.01	-1.21	476.00	420.00
m_4v_1	83.07	85.01	-0.83	-1.16	482.00	421.00
m_4v_2	84.35	84.25	-0.87	-1.14	473.00	422.00
m_4v_3	83.12	84.00	-0.86	-1.15	487.00	422.00
m_4v_4	85.50	86.02	-0.91	-1.16	469.00	420.00
m_4v_5	81.10	82.04	-0.97	-1.16	487.00	425.00
SEm (±)	0.530	0.516	0.004	0.006	1.889	1.866
CD (P<0.05)	NS	NS	0.012	0.017	5.39	5.33

Leaf weight: The results on the effect of soil moisture stress levels and varieties on leaf weight were recorded (Table 3). While the varietal variation was not significant, the variation due to the soil moisture stress levels and the interaction effect was significant in open condition. Significantly higher leaf weight (3.73 g/plant) was recorded by irrigation at IW/CPE ratio of 0.8 (m_4) which was at par with that of irrigation at IW/CPE ratio of 0.6 (m_3) (3.64 g/plant). Lifesaving irrigation recorded a lower leaf weight in both the conditions. This reduction in leaf dry weight might be due to leaf area reduction caused by water stress. The leaf area reduction results due to photosynthetic and chloroplast reduction, consequently resulting in rapid leaf necrosis, implies that leaf plays an important role as a mechanism for adaptation to drought (Flagella *et al.,* 2002; Goksoy *et al.*, 2004). Similar results were reported by Hajibabaee *et al*. (2012) in forage corn hybrids. M x V interaction was significant only in open condition and $m_3 v_1$ (UPC- 618 irrigated at IW/CPE ratio of 0.6) recorded higher leaf weight (4.34 g/plant) which was at par with m_3v_4, m_2v_1, m_2v_2 and m_1v_4. Leaf weight of fodder cowpea irrigated at IW/CPE ratio of 0.8 (m_2) was significantly higher (2.16 g/plant) in 25-35 per cent shade. Leaf dry weight also decreased for forages grown in shade compared to that grown in full sun (Blanche, 1999).

Relative water content: Significantly higher relative water content (83.43 per cent) was recorded by irrigating at IW/CPE ratio of 0.8 (m_4) in open and partial shade (84.26 per cent; Table 4). Lifesaving irrigation had least relative water content (RWC). Lesser availability of soil moisture and poor development of root system reduced water uptake and resulted in lower RWC. Moreover, the available soil water was not sufficient to maintain better water relations in plant. Several studies reported earlier that there was decrease of RWC under severe water deficit stress conditions (Mohsenzadeh *et al*., 2006; Slama *et al*., 2008; Nunes *et al*., 2008; Yousfi *et al*., 2010; Gorai *et al*., 2011; Slama *et al*., 2011). Varieties also had significant influence on relative water content of plant. COFC- 8 recorded higher RWC (83.17 percent in open and 84.38 percent in shade) followed by UPC- 622 (V_2) in open (81.90 per cent) and UPC- 618 (V_1) in shade (83.06 percent) conditions. In addition to the severity of stress, plant response to water deficit stress was variety dependent. The results showed considerable variations for drought tolerance among the cultivars, COFC- 8, UPC- 622 and UPC- 618 preserved the highest RWC values when compared to other cultivars, suggesting the ability of these cultivars to avoid relative tissue dehydration as consequence of osmotic adjustment (Slama *et al*., 2011). They also reported considerable variations in RWC among alfalfa cultivars. The study also revealed that RWC of all the varieties increased under 25-35 per cent shade compared to open condition. Evaporation demand is greatly reduced in the shaded environment and soil-water availability for the pasture is maintained at a higher level than in the open (Wilson and Wild, 1991) through the combined effects of less evaporation from the soil and lower transpiration rates of the pasture.

Leaf water potential: The perusal of the data showed that the treatments and their interaction had significant effect on leaf water potential of fodder cowpea in open and shaded conditions. Irrigating at IW/CPE ratio of 0.8 (m_4) recorded significantly higher leaf water potential of -0.89 MPa under open and -1.15 MPa in shade. As soil dries under drought stress, hydraulic conductivity of soil decreases, and the rate of water movement towards root and absorption become slow to completely replace the water lost from the plant because of transpiration. Thus, drought results in lower plant water potential. The changes in the plant water potential could be attributed to change in osmotic pressure or osmotic component of the water potential. Under shade the cell wall components change and it affects turgor. When leaf water potential (LWP) is low, it causes the stomata to close, which causes decreased transpiration which in turn leads to increased water potentials. However, if drought persists, the water potential will continue to decrease and reach a zero turgor (Prasad and Staggenborg, 2008). Among the varieties, UPC - 618 registered a higher leaf water potential which was at par with UPC- 622, COFC-8 and Bundel Lobia-1 in open condition. In partial shade, UPC- 618 and COFC- 8 registered higher leaf water potential which was at par with UPC- 622 and Bundel Lobia-1. Leaf water potential decreased in all varieties subjected to water deficit stress. Jaafari (1993) showed that the osmotic adjustment is a criterion of selection to characterize the tolerant varieties of plants to water deficit stress. A considerable variation in LWP was reported in alfalfa cultivars by Slama *et al.* (2011). M x V interaction was significant in open and shade. UPC- 618 irrigated at IW/CPE ratio of 0.8 had higher leaf water potential in open conditions, whereas UPC- 622 and Bundel Lobia-1 irrigated at IW/CPE ratio of 0.8 recorded higher LWP under partial shade (Table 4).

Osmotic potential: The data also showed that soil moisture stress levels, varieties and their interaction had significant effect on osmotic potential of fodder cowpea in open and shaded condition (Table 4). Irrigating at IW/CPE ratio of 0.8 (m_4) recorded significantly higher osmotic potential of 477 m moles/kg under open and 421.6 m moles/kg in shade. Osmotic potential of leaf decreased when subjected to water deficit stress. This adaptive mechanism includes traits, which promote the maintenance of high tissue water content, as well as those for promoting tolerance to low water availability (Moinuddin *et al.,* 2005; Chaves et al., 2010). This osmotic adjustment is defined as the lowering of osmotic potential in plant tissues due to net accumulation of organic solutes (Yang et al., 2011). This accumulation of the compatible solutes in cells leads to decrease in the osmotic potential and finally results in higher water uptake capacity by roots and water saving in cells. Similar results were reported in alfalfa cultivars by Slama *et al*. (2011) and in *Medicago sativa* and *Agropyron cristatum* by Jeff-

-erron and Cutforth (2005). Pandey and Baig (2012) reported that all six oat varieties showed accumulation of osmolyte with an increase in the intensity of drought. Among the varieties COFC-8 (V_4) recorded a lower osmotic potential in all the soil moisture stress levels. M×V interaction was significant in both open and shade conditions. Significantly lower osmotic potential was registered by m_1v_4 (COFC- 8 at lifesaving irrigation) (450 m moles/kg) in open and shade (364 m moles/kg) and in open, it was at par with m_1v_2 (UPC- 622 at lifesaving irrigation).

Conclusion

Based on the results, it was concluded that water stress caused a significant reduction in growth parameters such as dry matter production, leaf area index, leaf weight, relative water content and leaf water potential in all the varieties in open and shaded conditions. For all the soil moisture stress levels, COFC- 8, UPC- 622 and UPC-618 had better performances than Bundel Lobia-1 and CO-5 for all characteristics studied which in turn leads to relative tolerance of these cultivars under moisture stress situations. All these criteria should be considered while selecting cultivars to be grown in water deficit situations and in the agronomic management of fodder production under moisture stress situations.

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