Study of some morphological traits and selection of drought-resistant alfalfa cultivars (*Medicago sativa* L.) in Jiroft, Iran

G. Afsharmanesh

Faculty member, Agricultural Research Station of Jiroft & Kahnouj, Kerman, Iran.

Abstract

In order to determine the effects of water deficit stress on some morphological traits of alfalfa cultivars in Jiroft, Iran, an experiment was conducted in the fields of Agricultural Research Center of Jiroft in 2005-2006. It was a split-plot experiment based on a Randomized Complete Block Design with three replications, in which water deficit stress at three levels [including severe stress (irrigation when soil moisture was 25% of field capacity), moderate stress (irrigation when soil moisture was 50% of field capacity) and mild stress (irrigation when soil moisture was 75% of field capacity)] made the main plot and alfalfa cultivars at five levels (Yazdi, Nikshahri, Ranger, Bami and Baghdadi) made the sub-plot. The results of six sequential cuttings showed that water deficit stress significantly affected all morphological traits except internode length. The effect of cultivar was significant at 1% level on all traits except leaf/stem ratio and node number. With the increase in the intensity of drought stress, fresh forage yield, dry forage yield, stem length, stem number/unit area, leaf area index, internode length and internode number decreased but leaf/stem ratio increased. Dry forage had the highest correlation with plant height, stem number/unit area and leaf area index. Leaf/stem ratio had a negative correlation with forage yield. Finally, the cultivars Nikshahri and Bami were selected as drought-resistant cultivars, Baghdadi and Yazdi were selected as semi-drought-resistant cultivars and Ranger was selected as drought-sensitive cultivar in the region.

Keywords: alfalfa cultivars; water deficit; morphological traits; fresh forage; dry forage.

Introduction

Abiotic stresses are the prime cause of yield decrease throughout the world and on average, are responsible for 50% of the decrease in main agricultural products (Valiy and Nguyen, 2006).

In the U.S., as a result of the limited water resources and the decrease in soil water due to the urbanization as well as the repetition of drought periods, the reduction of water use in agriculture section has been considered (Lindenmayer et al., 2007). Water deficit stress is usually regarded as a physical limiting factor of forage production, which affects both forage yield and quality, growth and development; for example, it causes 49% decrease in forage and 18% increase in leaf/stem ratio (Buxton, 2004).

Rastgar (2005) reported that alfalfa has deep vertical roots, which can extract moisture from depths of soil and can resist drought and heat for a longer time. Lindenmayer et al. (2007) mentioned alfalfa as an important drought-tolerant crop for arid regions with the ability of surviving in dry months. Bauchan and Greene (2000) reported that the produced dry matter of alfalfa under drought and low-irrigation conditions was 22 t/ha. McCallum et al. (2001) and Erice et al. (2006) found alfalfa as drought-resistant crop with the ability of producing high-quality yield. Alfalfa is called the queen of crops and is cultivated as the fourth main crop in the U.S. Its dry forage is used in feeding dairy cattle, livestock, fowls and other domestic and field animals and is known as one of the most...
important crops because of its following abilities:
1. High adaptation and acclimation to climate;
2. Annual fixation of 200 kg N/acre (560 kg/ha);
3. High annual dry forage yield (22 t/ha in low-irrigation conditions and 24 t/ha in irrigated conditions);
4. Consuming low energy and growing in some years without replanting and N fertilizer application (up to 5 years in temperate regions) (Brown et al., 2005);
5. Producing good nutrients with 15-22% protein content and high vitamin and mineral contents (Wu, 2004);
6. Attracting insects by its sweat nectar for honey production;
7. Acting like a barrier and stopping the spread of pests and diseases to the subsequent crops in rotation;
8. Mitigating soil erosion (alfalfa prevents erosion by 89% and water flow by 94% compared to other crops) (Liu, 1992); and
9. Improving soil structure by penetrating its vertical roots which increases its permeability (Bauchan and Greene, 2000).

Peter et al. (1988) and Smith and Hamel (2005) believe that alfalfa forage yield depends upon three factors including plant number/unit area, stem number/plant and single-stem yield. But Sengul (2002) considered plant height, stem number/plant and single-stem yield as the forage yield components.

Volence and Cherney (1990) regarded single-stem yield as the main alfalfa yield component whereas Hart et al. (1988) mentioned mean stem number/unit area as the most effective morphological trait on alfalfa yield and reported that 63% of all changes were associated with this component.

By regression analysis of over 30 morphological and physiological traits of alfalfa, Foutz et al. (1976) showed that four components including leaf area, leaf/stem ratio, peduncle weight and number/plant were responsible for over 95% of yield variations in alfalfa clones. It shows that morphological traits are more reliable in determining alfalfa yield than physiological ones.

By comparing some perennial forage species, Bell et al. (2007) reported that alfalfa morphological traits were more adapted to drought conditions.

Butler (2006) reported alfalfa dry forage yield as 20.18 t/ha/yr in Mexican plain under water deficiency conditions and recommended cultivars with spring dormancy of 7-8 days. He mentioned dormancy of alfalfa under drought stress per unit decrease in autumn dormancy and determined its yield decrease as 630 kg/ha.

Pataki et al. (2003) reported total dry matter yield of alfalfa as 23000 kg/ha/yr in 5 cuttings under optimum irrigation and 17590 kg/ha under water stress conditions.

Saeed and Nadi (1997) reported that as water deficit stress increased, stem length, stem density, leaf area index and total biomass of alfalfa decreased and its total yield in six cuttings was 15.3, 12.9 and 11.2 t/ha for the treatments of 65 mm irrigation once seven days, 80 mm irrigation once ten days and 104 mm irrigation once thirteen days, respectively. The yield decreased as irrigation intervals were prolonged.

The increase in alfalfa quality, i.e. the increase in leaf/stem ratio under water deficit stress has been reported by Buxton (2004), Martens (2007) and Bonner (1997). Petil et al. (1992) reported that alfalfa leaf/stem ratio increased by 20% under water deficit stress compared with well-irrigated plants, being due to the decrease in stem growth rate.

Carter and Sheaffer (1983) reported that alfalfa leaf area and internode length decreased by 39% and 48%, respectively under drought stressed compared with well-irrigated plants. In the current study, the most resistant cultivar to drought in region was determined and recommended. In addition, yield-related morphological traits under water deficit stress conditions were studied.

Materials and Methods

In order to study the effects of low-irrigation on alfalfa morphology through applying water deficit stress, a split-plot experiment was conducted based on a Randomized Complete Block Design with three replications in Jiroft Research Station, Iran in 2005-2006. Jiroft has a hot arid climate with a mean precipitation of 140 mm and annual evaporation rate of 3000 mm. The main factor was water deficit stress at three levels including (a1) irrigation when soil moisture reached 25% of field capacity (severe stress), (a2) irrigation when soil moisture reached 50% of field capacity (moderate stress), and (a3) irrigation when soil moisture reached 75% of field capacity (mild stress). The sub-plot was alfalfa cultivar at five levels including Yazdi (b1), Nikshahri (b2), Ranger (b3), Bami (b4) and
Baghdadi (b).

Soil preparation operation included plowing and two vertical discs. In order to control and precisely measure the water use, drop irrigation method was used and the water used for each treatment was measured by installing volume counters beside the central counter. Each treatment was composed of four rows of 6 m length and 1.6 m width (with in-row spacing of 40 cm). The space between main plots and also between replications was 2 m and the space between sub-plots was 0.5 m. Based on the results of soil analysis and recommendations of Soil and Water Research Center, 30 kg N/ha from urea source, 200 kg P/ha as P₂O₅ from triple superphosphate source and 100 kg K/ha as K₂O from potassium sulfate source was applied. The seeds were planted at early March and after emergence and establishment, the plants were thinned at three to four-leaf stage so that the within-row spacing was adjusted as about 5-7 cm (with a plant density of about 40 plants/m²). The weeds were manually uprooted. The traits which were measured included fresh weight, dry weight, stem number/m², leaf number/plant, stem number/plant, leaf area, height, leaf/stem weight ratio, internode length and internode number. For uniformity, all treatments were harvested two months after planting and then the treatments were irrigated. Since then, the irrigation time and quantity was measured according to the soil moisture and evaporation from Class A pan. Therefore, when soil moisture reached 75% of field capacity, the applied irrigation water was calculated on the basis of the equation of class A evaporation pan (Et₀ = KP × EPan) and plant base evapotranspiration (Et₀) was then multiplied by crop factor (Kc):

\[ \text{Etc} = \text{Kc} \times \text{Et₀} \]

where, Et₀ was evapotranspiration of control plant (mm), KP was evaporation rate from pan (mm), EPan was pan coefficient, Etc was the evapotranspiration of given plant (alfalfa), and Kc was crop factor (Alizadeh, 2001). Pan coefficient depended on its location and arrangement and varied in the range of 0.5-0.85. It is considered as 0.66 for practical purposes. Kc is considered as 0.45 at early growth stage of alfalfa, 1.20 at mid-growth stage, 1.15 at late growth stage, being 0.92 on average (FAO, 2002).

Soil moisture and daily evaporation were measured by moisture meter. In total, six cuttings were harvested and weighed and a one-kilogram sample was sent to the laboratory for determining dry forage, which was oven-dried at 70°C for 24 hours. Then, their moisture percentage and dry matter were measured.

For measuring morphological traits, in each cutting, 20 stems were randomly selected and such traits as plant height, node number/stem, internode length and leaf number were measured. Then, the average was considered as the criterion and basis for measuring the traits.

To determine stem number/unit area, the number of stems in 0.5-m length of the two middle rows at three spots of the plot was counted and then, averaged. To measure the forage fresh weight in each cutting, when the plot was at 10% flowering stage, two middle rows were harvested in which the upper and lower 0.5 m was eliminated. Then, the plants were weighed and the fresh forage yield (t/ha) was determined. In order to determine dry forage, about 1 kg of fresh forage was selected and air-dried (up to 12% moisture content). It was then weighed and the dry forage weight was determined. To measure the leaf/stem ratio, the leaf and stem dry weights of 20 stems was taken as the basis of measurements. To measure the leaf area index, a leaf area meter (Delta T, the U.K.) was used.

Results and Discussion

The summary of the results of variance analysis of the effects of water deficit stress on morphological traits of alfalfa cultivars (Table 1) showed that the effect of cutting on fresh forage yield and internode length was significant at 5% probability level and its effect on stem number/m², plant height, leaf area index, leaf number/stem and node number/stem was significant at 1% probability level. But its effect on dry forage and leaf/stem ratio was not significant. The effect of water deficit stress on fresh and dry forage, stem number, plant height, leaf area index, leaf number/stem and node number was very significant at 1% probability level and its effect on leaf/stem ratio was significant at 5% probability level. But it did not significantly affect internode length. The effect of cultivar was very significant on all morphological traits at 1% probability level except for the node number which was significant at 5% probability level. In addition, the cultivars did not have significant differences regarding the leaf/stem ratio. The interaction between water deficit stress and cultivar was significant at 1% probability.
level for fresh forage yield, dry forage and stem number/m² but not significant for such traits as plant height, leaf area index, leaf number/stem, leaf/stem ratio, internode length and node number.

The means comparison of the effect of cutting on fresh forage yield (Table 2) showed that the sixth cutting had the highest forage yield (9.85 t/ha) whereas the first and second cuttings had the lowest one (6.57 and 7.63 t/ha, respectively). In one hand, the plants were thinned out in March and all treatments were cut during April-May for making them uniform. On the other hand, the plants were thinned during early-April for adjusting within-row spacing. Therefore, the yield decreased because of the low stem number. Then the yield gradually increased up to the third cutting and started to decrease from third cutting until fifth cutting because of the hot weather of summer. At mid-September (sixth cutting), the temperature was moderate and so, the fresh forage yield increased. Therefore, an increasing trend was observed up to the third cutting which, with the increase in plants age, led to the increase

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>df</th>
<th>Means of squares</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fresh forage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry forage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stem no.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf area</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf no./stem</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leaf/stem ratio</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internode length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Internode no.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replication</td>
<td>2</td>
<td>30.03** 2.755**</td>
</tr>
<tr>
<td>Water deficit stress</td>
<td>2</td>
<td>419.90** 18.30**</td>
</tr>
<tr>
<td>Cultivar</td>
<td>11</td>
<td>797.640 39.30**</td>
</tr>
<tr>
<td>Cultivar × stress</td>
<td>8</td>
<td>37.480 1.752**</td>
</tr>
<tr>
<td>Error a</td>
<td>4</td>
<td>5.325 5.114 16.99</td>
</tr>
<tr>
<td>Cultivar × cutting</td>
<td>20</td>
<td>21.271 0.871**</td>
</tr>
<tr>
<td>Cultivar × stress × cutting</td>
<td>40</td>
<td>3.015** 0.190**</td>
</tr>
<tr>
<td>Error c1</td>
<td>30</td>
<td>6.485 0.696 26.96</td>
</tr>
<tr>
<td>Cultivar × cutting</td>
<td>120</td>
<td>1.59 0.109 23.57</td>
</tr>
<tr>
<td>Error c2</td>
<td>150</td>
<td>2.570 0.226 253.84</td>
</tr>
</tbody>
</table>

* ** and *** show significance at 1% and 5% probability levels and non-significance, respectively.

Table 2. Means comparison of the effects of cutting, water deficit stress and cultivar on alfalfa morphological traits

<table>
<thead>
<tr>
<th>Factor</th>
<th>Fresh forage (t/ha)</th>
<th>Dry forage (t/ha)</th>
<th>Stem no./m²</th>
<th>Height (cm)</th>
<th>Leaf area index</th>
<th>Leaf no./stem</th>
<th>Leaf/stem ratio</th>
<th>Internode length (cm)</th>
<th>Node no.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First cutting</td>
<td>6.57 b</td>
<td>1.43 b</td>
<td>257.3 b</td>
<td>46.6 a</td>
<td>3.07 a</td>
<td>21.3 a</td>
<td>1.34 a</td>
<td>6.7 a</td>
<td>6.3 b</td>
</tr>
<tr>
<td>Second cutting</td>
<td>7.63 b</td>
<td>1.77 b</td>
<td>279.1 b</td>
<td>45.8 a</td>
<td>2.65 b</td>
<td>13.5 b</td>
<td>1.26 a</td>
<td>6.4 a</td>
<td>7.1 b</td>
</tr>
<tr>
<td>Third cutting</td>
<td>8.24 ab</td>
<td>1.88 ab</td>
<td>332.7 a</td>
<td>44.3 ab</td>
<td>2.68 b</td>
<td>13.7 b</td>
<td>1.23 a</td>
<td>6.7 a</td>
<td>6.8 b</td>
</tr>
<tr>
<td>Fourth cutting</td>
<td>8.01 ab</td>
<td>1.87 ab</td>
<td>327.2 a</td>
<td>44.6 ab</td>
<td>2.02 c</td>
<td>10.6 c</td>
<td>1.29 a</td>
<td>5.9 ab</td>
<td>7.5 ab</td>
</tr>
<tr>
<td>Fifth cutting</td>
<td>7.93 ab</td>
<td>2.02 a</td>
<td>331.2 a</td>
<td>38.31 c</td>
<td>1.88 c</td>
<td>9.5 c</td>
<td>1.24 a</td>
<td>6.8 a</td>
<td>6.4 b</td>
</tr>
<tr>
<td>Sixth cutting</td>
<td>9.85 a</td>
<td>1.95 a</td>
<td>251.5 b</td>
<td>41.24 bc</td>
<td>3.07 a</td>
<td>19.6 a</td>
<td>1.37 a</td>
<td>5.2 b</td>
<td>8.9 a</td>
</tr>
<tr>
<td>Water deficit stress</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe stress</td>
<td>6.33 c</td>
<td>1.46 c</td>
<td>269.7 c</td>
<td>39.8 c</td>
<td>2.06 c</td>
<td>13.1 c</td>
<td>1.33 a</td>
<td>6.3 a</td>
<td>6.6 b</td>
</tr>
<tr>
<td>Moderate stress</td>
<td>7.32 b</td>
<td>1.67 b</td>
<td>294.6 b</td>
<td>43.3 b</td>
<td>2.46 b</td>
<td>15.2 b</td>
<td>1.29 ab</td>
<td>6.2 a</td>
<td>7.1 ab</td>
</tr>
<tr>
<td>Mild stress</td>
<td>10.47 a</td>
<td>2.33 a</td>
<td>325.2 a</td>
<td>47.3 a</td>
<td>3.16 a</td>
<td>15.9 a</td>
<td>1.25 b</td>
<td>6.4 a</td>
<td>7.7 a</td>
</tr>
<tr>
<td>Cultivar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yazdi</td>
<td>5.32 c</td>
<td>1.22 c</td>
<td>263.0 b</td>
<td>39.8 b</td>
<td>1.88 b</td>
<td>14.2 b</td>
<td>1.29 a</td>
<td>5.7 b</td>
<td>7.4 a</td>
</tr>
<tr>
<td>Nikshahri</td>
<td>11.46 a</td>
<td>2.56 a</td>
<td>330.8 a</td>
<td>48.8 a</td>
<td>3.13 a</td>
<td>15.1 b</td>
<td>1.25 a</td>
<td>6.8 a</td>
<td>7.3 a</td>
</tr>
<tr>
<td>Ranger</td>
<td>2.81 d</td>
<td>0.67 d</td>
<td>243.6 b</td>
<td>30.9 c</td>
<td>1.67 b</td>
<td>13.3 b</td>
<td>1.34 a</td>
<td>5.0 b</td>
<td>6.6 b</td>
</tr>
<tr>
<td>Bamri</td>
<td>11.40 a</td>
<td>2.61 a</td>
<td>334.4 a</td>
<td>50.0 a</td>
<td>2.96 a</td>
<td>14.7 b</td>
<td>1.24 a</td>
<td>7.3 a</td>
<td>7.3 a</td>
</tr>
<tr>
<td>Baghdadi</td>
<td>9.21 b</td>
<td>2.04 b</td>
<td>310.7 a</td>
<td>47.8 a</td>
<td>3.16 a</td>
<td>16.1 a</td>
<td>1.33 a</td>
<td>6.8 a</td>
<td>7.3 a</td>
</tr>
</tbody>
</table>

Means with the same letter(s) in each column are not significant at 5% level.
in alfalfa yield due to the increase in stem number (as a yield component). At sixth cutting, the increase in leaf area (as the photosynthesizing organ) and leaf number/stem increased forage yield. The result of Sengul (2002) about the increase in stem number in alfalfa due to the aging confirms the current study.

With the increase in the intensity of water deficit stress from mild stress (irrigation when soil moisture reached 75% of field capacity) up to severe stress (irrigation when soil moisture reached 25% of field capacity), fresh forage yield significantly increased. Mild water deficit stress had the highest fresh forage yield (10.47 t/ha) and severe water deficit stress had the lowest one (6.33 t/ha). Martens (2007) recognized the decrease in stem number/plant and plant height as the reason for forage decrease and also recognized stomatal closure and the decrease in nitrogen fixation due to the drought stress as the reason for the decrease in photosynthesis.

Different alfalfa cultivars had different forage yields, so that the cultivars Nikshahri and Bami had the highest fresh forage yield (six cuttings on average) (11.46 and 11.40 t/ha, respectively) and Ranger had the lowest one (2.81 t/ha). The cultivars Baghdadi and Yazdi had moderate yields. The cultivars Bami and Nikshahri had higher yield than the other cultivars likely due to having higher yield components (stem number/m² and length). The cultivars Bami and Nikshahri had greater stem number/m² as well as higher stem length and leaf area index than the other cultivars which led to the increase in their yields.

The dry forage yield was lower in the first cutting than in the second cutting. Then, an increasing trend was observed in dry yield up to the fourth cutting and afterwards, it started to decrease. This was consistent with Lloveras (2001) who reported the increase in alfalfa dry forage yield from the first cutting (2.77 t/ha) to the second cutting (3.52 t/ha).

With the increase in the intensity of water deficit stress, dry forage yield decreased so that mild stress had the highest dry forage yield (on average 2.33 t/ha in each cutting) and severe stress had the lowest one (1.46 t/ha). It seems that the increase in stress intensity decreased yield components including stem number/m², stem length and leaf area which explains the lower yield under severe water deficit stress than mild stress. Saeed and Nadi (1997) reported that the decrease in alfalfa dry forage yield with the increase in drought stress intensity was due to the decrease in stem density, stem length and leaf area. They applied water deficit stress with increasing irrigation interval under which total dry forage yield at sixth cutting was 15.3, 12.9 and 11.2 t/ha in treatments of 65 mm irrigation once every seven days, 89 mm irrigation once every ten days and 104 mm once every thirteen days, respectively. Aranjuelo et al. (2001) reported that with the increase in temperature and water deficit stress, alfalfa dry forage yield decreased due to the decrease in photosynthesis which resulted from the decrease in leaf area and reduction of RUBISCO enzyme activity.

In a study on the comparison of five alfalfa cultivars under drought stress and no-stress conditions, Pataki et al. (2003) reported the decrease in dry forage yield from 23000 kg/ha (total of five cuttings) under no-stress conditions to 17590 kg/ha under drought stress conditions which is consistent with the results of the current study.

Alfalfa cultivars had significantly different forage yield, so that the cultivars Bami and Nikshahri, which were more adapted to the region, produced the highest dry forage (2.61 and 2.56 t/ha in each cutting, respectively) and the cultivar Ranger produced the lowest one (0.67 t/ha). The superiority of Bami and Nikshahri was because of its higher stem length and number/unit area as well as its greater leaf area.

The effect of cutting was significant on stem number/m², so that stem number in the first cutting increased from 257.3 plants/m² to 332.7 plants/m² in the third cutting and then started to decrease in the fourth, fifth and sixth cuttings. The reason for the increase in the second and third cuttings compared with the first cutting could be related to the filling of the empty space allocated to the plants at early growth stage by stems because the planting was carried out in spring and thinning operation was conducted at early-April and a spacing of 5-7 cm was left between plants. The sixth cutting had the lowest stem number/m² (251.5).

Sengul (2002) reported an increase in stem number with the aging of plants. In summer cuttings, stem number decreases because of hot weather. The effect of drought stress on stem number/m² was significant, so that with the increase in the intensity of stress, stem number/m² started to decrease. Mild water deficit stress had the highest stem number (325.2) and severe stress had the lowest one (269.7). The
decrease in alfalfa stem number under water deficit conditions has been reported by Martens (2007) and Saeed and Nadi (1997), too. The decrease in stem number is a likely strategy of the plants in reducing their transpiring area so as to decrease water loss. The effect of cultivar on stem number was significant so that the local cultivars of Nikshahi and Bami and partly Baghdadi had higher stem number/m² than Yazdi and Ranger. Bami had the highest stem number (334.4 stems/m²) and Ranger had the lowest one (243 stems/m²). Cultivars had different ability in producing stem. In a study on comparing alfalfa cultivars, Sengul (2002) found that the mean stem number of ecotypes was 37.5 and observed significant differences in this regard. The alfalfa ecotype Kasimoyiu had the highest stem number and the ecotypes Alakoy and Cayirbasi had the lowest one. By sowing 10 kg seeds/ha, Lloveras (2001) found mean stem number/m² as 492 and dry matter yield as 20.5 t/ha/year while by sowing 50 kg seeds/ha, the plants produced 526 stems/m² and 20.4 t dry forage/ha/year.

The effect of plant height was different in different cuttings, so that the first and fifth cuttings had the highest (46.6 cm) and lowest (38.31 cm) plant heights, respectively. It seems that the first cutting, which coincided with spring, experienced more desirable weather conditions regarding temperature and relative humidity and therefore, had higher stem length. But in the fifth cutting, which coincided with the peak temperature and relative humidity, alfalfa stem length decreased. Aranjuelo et al. (2001) reported that a 3°C increase in temperature from 25 to 28°C decreased RUBISCO enzyme activity, photosynthesis and nitrogen fixation by rhizobium. Thus, less cell wall material was built and stem length decreased.

With the increase in the intensity of water deficit stress, alfalfa stem length decreased, so that mild water deficit stress had the highest stem length (47.3 cm) and severe stress had the lowest one (39.8 cm). The decrease in stem growth under drought stress has been reported by Buxton (2004), too. The decrease in stem growth which in turn decreases stem diameter and internode length has been reported by Petil et al. (1992), Bonner (1997), Martens (2007) and Saeed and Nadi (1997), too.

Different cultivars had different stem length, so that Bami had the highest stem length (50.0 cm), which had no significant difference with Niknami and Baghdadi (with stem lengths of 48.8 and 47.8 cm, respectively), but it was superior to Ranger and Yazdi. In a study on forage yield and morphology of indigenous varieties of alfalfa, Sengul (2002) reported that the studied ecotypes had significantly different stem lengths. Mahmudiye had the highest stem length (94.1 cm) and Ercis-3 had the lowest one (62.4 cm). The stem length of the other ecotypes was in the range of 68.2-88.1 cm. When selecting and breeding alfalfa cultivars (Rotili et al. 2001), selected a cultivar with the stem length of 86.47 cm, stem diameter of 2.87 mm, internode length of 4.97 and leaf/stem ratio of 0.85-1.0. The reason for the lower heights of alfalfa in Jiroft was the high temperature during the harvest times, but instead the interval between subsequent cuttings is shortened, so that the cutting in this region amounts to 12-14 cuttings per year.

Different cuttings had different leaf area, so that the first and sixth cuttings had the highest leaf area index (3.07). Leaf area of alfalfa is composed of two components: stem number/unit area and leaf number. As can be seen in Table 2, higher leaf number increased leaf area index in the first and sixth cuttings which could be related to the desirable environmental conditions during late-May (the first cutting) and mid-September (the sixth cutting). Leaf area index of alfalfa in different cuttings varied from 2.68 to 1.88. The lowest leaf area was in the fifth cutting coinciding with high periphery temperature. Aranjuelo et al. (2001) reported the decrease in leaf area due to the rise of temperature too, whereas Brown et al. (2005) reported alfalfa leaf area in re-growth during spring as 170 mm² and during summer as 400 mm² in temperate regions.

With the increase in water deficit stress intensity, leaf area index decreased. Mild water deficit stress had the highest leaf area index (3.16) and severe stress had the lowest one (2.06). The decrease in alfalfa leaf area under drought stress has been reported in other studies (e.g. Aranjuelo et al., 2001; Saeed and Nadi, 1997; Freyer et al., 2005).

Carter and Sheaffer (1983) reported 39% decrease in alfalfa leaf area under water deficit stress compared with well-irrigated plants. Taiz and Zeiger (2005) reported that one of the main effects of water deficit was the decrease in leaf expansion. Although leaf area plays an important role in photosynthesis, high leaf expansion rate can adversely affect plant usable water. At the commencement of water stress, cell
growth inhibition decreases leaf expansion. Lower leaf area leads to absorption of less water from soil and the decrease in transpiration. Therefore, with the decrease in leaf area, the plant constructs its first defense system against drought.

Alfalfa cultivars exhibited significant differences in their leaf area index, so that the cultivars Nikshahri, Baghdadi and Bami were categorized in one group and the cultivars Yazdi and Ranger were categorized in another group. Baghdad had the highest (3.16) and Ranger had the lowest leaf area index (1.67). As a result of non-uniform utilization of ecological factors, cultivars had different morphologies, which is inconsistent with Yazdi Samadi (1994).

Water deficit stress had significant effects on leaf/stem ratio, so that the increase in water deficit stress intensity led to the increase in leaf/stem ratio as one of the qualitative factors. Leaf/stem ratio increased from 1.25 under mild water deficit stress to 1.43 under severe stress. The increase in leaf/stem ratio has been reported by Saeed and Nadi (1997) and Martens (2007), too.

Petil et al. (1992) and Bonner (1997) regarded the further decrease in stem growth as the main reason for the 20% increase in alfalfa leaf/stem ratio under the increased intensity of drought stress.

Buxton (2004) reported that alfalfa leaf/stem ratio increased by 19% under drought stress conditions which supports the results of the current study.

Cultivars did not show significant differences in their leaf/stem ratio. It seems that this ratio mostly depended upon cutting time. Ranger had the highest (1.34) and Nikshahri had the lowest leaf/stem ratio (1.24). In a study in Qom province, Iran, Zamaniyan et al. (2004) found that the mean leaf/stem ratio of the cultivars Yazdi, Bami and Baghdadi in two subsequent years was 1.28, 1.21 and 1.20, respectively in one field and 1.39, 1.50 and 1.34, respectively in another field.

Pataki et al. (2003) reported the highest leaf dry weight as 721 g/kg and the lowest one at flowering stage as 424 g/kg. And Sheaffer et al. (2000) reported leaf yield as 5.6, 4.5 and 4.5 t/ha and stem yield as 3.9, 5.3 and 5.8 t/ha at early flowering, late flowering and blooming stages.

The results of the effects of cutting on internode length showed that the fifth cutting had the highest internode length (6.8 cm) but it had no significant difference with other cuttings except the sixth cutting. Zamaniyan et al. (2000) reported the same result. They found that the effect of internode length was non-significant in three subsequent cuttings for the cultivars Hamadani, Yazdi, Ghare-Yonkjah, Bami, livoor, Pires and Pioneer-58.

The effect of water deficit stress on internode length was not significant, but it started to decrease as the stress increased. Mild water deficit stress had the highest internode length (6.4 cm) and moderate stress had the lowest one (6.2 cm). However, Carter and Sheaffer (1983) reported 48% decrease in internode length under drought stress. Sengul (2002) reported the decrease in internode length with the increase in moisture stress.

Alfalfa cultivars had different internode lengths. Bami had the longest internode (7.3 cm) followed by Nikshahri and Baghdad (6.8 cm). They were superior to the other cultivars. In a study on quality and morphology of alfalfa indigenous cultivars, Sengul (2002) reported that the ecotype Hidirhoy-2 had the longest (5.71 cm) and ecotype Gulgoren had the shortest internode length (2.71 cm). Zamaniyan et al. (2000) reported mean internode length of Bami as 4.65 cm and that of Yazdi as 4.52 cm for three cuttings in Karaj, Iran.

Rotili et al. (2001) reported the internode length of alfalfa bred cultivar as 4.97 cm. The effect of water deficit stress on node number was significant. Mild stress had the greatest node number (7.7) which did not show significant difference with moderate stress (7.1) but it had significant difference with severe stress. The severe stress produced the lowest number of nodes (6.2).

Rostami and Yazdi Samadi (1989) reported the decrease in node number in whole plant. They reported that with 100% of field capacity irrigation, alfalfa plants produced 128 nodes but with 50% of field capacity irrigation, they produced 88 nodes.

The cultivars Bami, Nikshahri, Baghdadi and Yazdi produced approximately same number of nodes, so that their node number varied in the range of 7.3-7.4, but they were superior to Ranger. This result is consistent with the results of Zamaniyan et al. (2004). They reported node number for the cultivars Yazdi, Bami and Baghdadi as 8.18, 8.46 and 7.63 nodes field, respectively.

According to means comparison (Table 3), the
interactions between water deficit stress and alfalfa cultivars for the measured traits. The findings about the effect of water deficit stress and cultivar did not make any significant difference in leaf/stem ratio; in other words, all cultivars followed nearly a same pattern in their leaf/stem ratio increase as the intensity of water deficit stress increased. Ranger had the highest leaf/stem ratio (1.37) under severe water deficit stress. Lower stem diameter, shorter plant height and finally, lower yield of this cultivar were the likely causes of the increase in its leaf/stem ratio.

The interaction between water deficit stress and cultivar did not make any significant difference in leaf/stem ratio; in other words, all cultivars followed nearly a same pattern in their leaf/stem ratio increase as the intensity of water deficit stress increased. Ranger had the highest leaf/stem ratio (1.37) under severe water deficit stress. Lower stem diameter, shorter plant height and finally, lower yield of this cultivar were the likely causes of the increase in its leaf/stem ratio.

The interaction between water deficit stress and cultivar did not make any significant difference in leaf/stem ratio; in other words, all cultivars followed nearly a same pattern in their leaf/stem ratio increase as the intensity of water deficit stress increased. Ranger had the highest leaf/stem ratio (1.37) under severe water deficit stress. Lower stem diameter, shorter plant height and finally, lower yield of this cultivar were the likely causes of the increase in its leaf/stem ratio.

The interaction between water deficit stress and cultivar did not make any significant difference in leaf/stem ratio; in other words, all cultivars followed nearly a same pattern in their leaf/stem ratio increase as the intensity of water deficit stress increased. Ranger had the highest leaf/stem ratio (1.37) under severe water deficit stress. Lower stem diameter, shorter plant height and finally, lower yield of this cultivar were the likely causes of the increase in its leaf/stem ratio.

Table 4 shows the fresh forage yield and drought-tolerance index of alfalfa cultivars under severe water deficit stress. According to this table, the cultivars Nikshahri and Bami had the highest drought-tolerance index under severe water deficit stress (1.23 and 1.22, respectively) and the cultivar Range had the lowest one (0.06). Stress-tolerance index is one of the most important criteria for selecting cultivars with yield stability under stress conditions. Selection on the basis of stress-tolerance index leads to the selection of cultivars which have high yield both under desirable and undesirable conditions. This index has been introduced by Fernandez (1992).
Finally, considering all the measured parameters, the alfalfa cultivars Nikshahri and Bami were recommended as drought-resistant cultivars for Jiroft region, Iran.

Acknowledgement

I am so grateful for Reza Moghabeli-Damaneh, Hossein Mashayekhi and Ali Behrooj for their assistance in measuring morphological traits.

References

Buxton, D.R. 2004. Growing quality forages under variable environmental conditions, USDA, Iowa State University, USA.