Surfactant effect on forage yield and water use efficiency for berseem clover and basil in intercropping and limited irrigation treatments

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\textbf{A B S T R A C T}

Quantifying crop response to irrigation is important for establishing effective irrigation management strategies. The present study was conducted to evaluate the response of berseem clover and basil to limited irrigation in an additive intercropping system using a surfactant. The experimental treatments were carried out in split–split plots based on a completely randomized block design with three replications. The limited irrigation treatments comprised of replenishment of I\textsubscript{100} full irrigation, I\textsubscript{50} = 25% limited and I\textsubscript{50} = 50% limited weekly evaporation and plant water requirements which were assigned to the main plots. The planting systems of sole berseem clover and sole basil culture along with additive intercropping of berseem clover + 50% basil were assigned to the subplots. Water treatments of control (water alone) and water + surfactant were assigned to the sub-subplots. Results show that severely limited irrigation (I\textsubscript{50}) dramatically reduced the forage yield of berseem clover and basil by 19.5% compared with the control (I\textsubscript{100}). The severity of the adverse effects of limited irrigation stress decreased by the surfactant application in irrigation by water + surfactant (9.5% decrement compared to full irrigation). The highest irrigation water use efficiency (2.7 kg m\textsuperscript{-3}) was achieved in I\textsubscript{50} treatment with an added surfactant. The highest total dry matter yield (berseem clover + basil dry matter) (9257.9 kg ha\textsuperscript{-1}) was obtained from additive intercropping of berseem clover 100% + basil 50% while irrigated by water + surfactant.

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1. Introduction

Irrigation water use efficiency (IWUE), defined as the amount of biomass or grain produced per unit volume of applied water, provides a quick and simple measure of how well the available water can be converted into grain and thereby is the basic indicator of measuring the effectiveness of water-saving in agriculture (Sekhon et al., 2010). When water resource in a crop production is a limiting factor, a proper irrigation treatment is needed to enable maximum production per unit irrigation water volume. Deficit irrigation is one way of maximizing the IWUE (Bekele and Tilahun, 2007). The main objective of deficit irrigation is to increase the IWUE of crops by reducing the amount of water in irrigation or by reducing the number of irrigation events (Kirda, 2002). In recent years, the focus is shifting towards increasing productivity efficiency within the constraints of available limited water resources. As such, deficit irrigation is becoming a possible option, i.e., in irrigating crops, reducing water requirements while minimizing the adverse effects of extreme water stress on crop yield (Garg and Dadhich, 2014). In addition, water loss by evapotranspiration is very high during the growing season in semi-arid regions. Forage crops in these environments are often subjected to the detrimental effects of high temperatures and water deficits during the spring-summer period that seriously reduce the herbage and seed production. Therefore, it is necessary to know the allowable level of transpiration deficiency without significant reduction in crop yield. The monetary loss due to deficit irrigation yield reduction should be smaller than the benefits gained from the saved water which in turn could be normally used for other crops under traditional irrigation practices (Kirda, 2002).

Surfactant (wetting agent) application in the irrigation water increases moisture retention in soil (Leinauer, 2002). The increase in water retention under deficit irrigation treatments due to the application of surfactants can be explained by the mechanism in which the surfactant is applied. Surfactants reduce the surface...
tension of water and help water infiltrate into the pore spaces of soil. These pore spaces are not generally accessible to water without the surfactants (Leinauer, 2002). Surfactants also help maintain a uniform distribution of soil moisture and root zone moisture holding capacity and as a consequence improve crop yield under water deficit conditions (Wolkowski et al., 1985). Where the soil wettability is less than optimal, the use of surfactant in combination with appropriate irrigation and soil cultivation practices, improves the soil hydrological behavior resulting in an improved irrigation efficiency and water conservation (Kostka et al., 2007). By surfactant application in limited irrigation treatments, higher yields are produced. Economical evaluation has shown that using surfactants increases yield production cost in water repellent and wettable soils, however, the yield increment can compensate for the cost of surfactant and consequently a higher profit can be achieved (Chaichi et al., 2015). Therefore, by evaluating the effects of surfactant on forage and grain production of corn (Chaichi et al., 2015), fruits (McMillan et al., 2010) and potato (Oostindie et al., 2010) in different conditions, this study identifies the extent for the first time to which the water conservation in combination with surfactant utilization can be practiced based on yield data in an intercropping system.

Food strategies must not merely be directed at ensuring food security for all, but must also achieve the consumption of adequate quantities of safe and good quality foods that together make up a healthy diet. In this regard, cultivation and producing forage crops play key roles. However, the importance of these crops in producing protein and supporting food security have not been yet well appreciated. Berseem clover (Trifolium alexandrinum L.) is one of the best forage sources for feeding livestock. This plant is capable of producing 3.75 tons of dry forage and fix 100–200 kg of nitrogen/ha per year. Sweet basil (Ocimum basilicum L.) from the Lamiaceae family is a medicinal plant which is mostly used as an anti-spasm medicine for stomach gases, it is also appetizing, diuretic and adaptogenic and anti-inflammation.

Intercropping is a way to increase diversity in an agricultural ecosystem. In addition, by using the intercropping system, the ecological balance, a better utilization of resources, higher quantity and quality of products, and less damage by pests and diseases are well achieved. Those systems, which are often without synthetic input and are based on an integrated management of local natural resources, theoretically offer numerous ecological advantages. Additionally, medicinal forage (intercropping of forage and medicinal crops) is considered as alternative forage sources to prevent contamination from diseases and improve growth and development in livestock.

Drought is known as one of the main natural hazards especially in arid and semiarid regions where there are considerable issues in regard to water resource management. In arid and semi-arid regions like Iran, less precipitation and high evaporation rates are the most important problems that are caused by high temperatures and low humidity of the air mass over the land. Because of this, we found that there is a necessary need to identify a good water management and good sowing pattern to catch the efficient IWUE for such a region. The specific objectives of the current study were: (1) to measure the effectiveness of water-saving in agriculture with considering the maximum production per unit irrigation water volume, (2) to evaluate the effects of wetting agents (surfactant) on total dry matter (berseem clover + basil) dry matter yield under limited irrigation systems, (3) To determine the result of interaction between three factors (limited irrigation treatments, cropping patterns and water treatment) on total dry matter yield, forage yield and IWUE of medicinal forage (berseem clover + basil). In short, the best intercropping patterns, the amount of required irrigation water and the best rate of surfactant were determined.

2. Materials and methods

2.1. Experimental site and climatic data

A series of 2-year (2013 and 2014) experiments was conducted at the Research Farm of the College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran (N 35° 56’, E 50° 58’). The climate of this site is considered as arid to semiarid with a long-term (50-year) mean air temperature of 13.5 °C, soil temperature of 14.5 °C, and 262 mm of annual rainfall. The weather conditions at the experimental site during the two growing seasons are shown in Table 1.

2.2. Soil characteristics

The soil type at the site is classified as a Typic Haplocambid (Mirkhani et al., 2010) according to the United States Department of Agriculture classification (USDA, Soil Survey Staff, 1999). Prior to planting, soil samples were taken from 0 to 30 cm depth and analyzed for selected physical and chemical properties, including soil texture, soil acidity (pH), electrical conductivity (EC), total nitrogen (N), available phosphorus (P), and available potassium (K). Soil texture was determined using the hydrometer method. The soil pH and EC were measured by a pH-meter and EC-meter, respectively in 1:2.5 soil–water suspensions (Rhoades, 1996). Nitrogen content was measured by the Kjeldahl method (Bremner and Mulvaney, 1982). Available P was measured by the method of Olsen et al. (1954) and available K was determined by a flame photometer. The soil characteristics of the experimental site were performed before planting. The results of two years indicated: soil pH 8.79, EC = 1.86/1.96 (ds m−1), total nitrogen (N) = 0.09/0.07 (%), available phosphorus (P) = 8.87/9.0 (mg kg−1), available potassium (K) = 225/202 (mg kg−1), and the soil texture was clay loam for the whole period of 2013/2014, respectively.

2.3. Experimental Setup

The statistical design of the experiments was split–split plot based on a randomized complete block (RCB) design with three replications. The experimental treatments comprised of three levels of irrigation treatments, three sowing patterns and two types of water treatments. Different irrigation treatments were applied on the main plots as: the normal irrigation I100 (replenishment of 100% of weekly evaporation and plant water requirements), limited irrigations including I75 (replenishment of 75% of weekly evaporation and plant water requirements), and I50 (replenishment of 50% of weekly evaporation and plant water requirements). The sub-plots consisted of three sowing patterns including sole berseem clover, sole basil culture, and additive intercropping of berseem clover + 50% basil (Safikhani et al., 2013). The sub-subplots were assigned to two types of water treatments of control (water only) and water + surfactant (1 ppm) irrigation. The study was performed in plot sizes of 4 × 2 = 8 m2, which comprised of four rows of cropping 50 cm apart. The sole berseem clover and basil were sown at the rates of 30 kg and 5 kg per hectare (ha), respectively. In the additive intercropping treatment, basil was sown at 50% density of its normal sowing rate (2.5 kg ha−1) with berseem clover at its normal rate of (30 kg/ha) on the same rows corresponding to the experimental plots. In additive intercropping system, the main crop (berseem clover) was sown at its normal density on rows of 50 cm apart. Then the second crop (basil) was sown at 50% of its normal density on rows 25 cm apart from the main crop (Safikhani et al., 2013).
and IE is the irrigation efficiency. Where $I$ is the constant coefficient, $A$ is the canopy area (sq. ft.), $K_c$ is the crop coefficient, $E_{T0}$ is the weekly potential evapotranspiration (inches) and $IE$ is the irrigation efficiency. $E_{T0}$ was calculated using daily data from Karaj synoptic weather station in mm per unit time converted to inches. $K_c$ is defined as the ratio of the crop evapotranspiration rate to the reference evapotranspiration rate. The $K_c$ value of the mid-season stage of berseem clover was 0.9 in this experiment which was retrieved from FAO reports (FAO, 2012). The water requirement for each treatment was measured in gallons per week converted to liters per week. A counter meter was used for accurate water measurement and control. The total amount of irrigation water used during the plant life cycle was as follows: $I_{100} = 4895.8 \text{ m}^3 \text{ ha}^{-1}$, $I_{75} = 3671.9 \text{ m}^3 \text{ ha}^{-1}$ and $I_{50} = 2447.9 \text{ m}^3 \text{ ha}^{-1}$ during the first year, and $I_{100} = 7497.15 \text{ m}^3 \text{ ha}^{-1}$, $I_{75} = 5622.8 \text{ m}^3 \text{ ha}^{-1}$ and $I_{50} = 3748.57 \text{ m}^3 \text{ ha}^{-1}$ during the second year for normal, moderate and severely limited irrigation regimes, respectively. To reach physiological maturity the different irrigation regimes continued until 2nd September in 2013 and 15th in September 2014, respectively.

In this study the surfactant (provided by Aquatrols Corporation, USA, with active ingredient: 10% alkoxylated polyols, 7% glucoethers, inter ingredient 83% water) was applied at a rate of 1 ppm in irrigation water in corresponding water treatment at all irrigation intervals (Mitra et al., 2006; Karcher and Landreth, 2003). $IWUE$ was calculated using Eq. (2):

$$IWUE = \frac{TDM}{In} \times 100 \tag{2}$$

Where, $IWUE$ is the irrigation water use efficiency (kg ha$^{-1}$ mm$^{-1}$), $TDM$ is the total dry matter (berseem clover + basil matter) (kg ha$^{-1}$) yield and $In$ is the amount of irrigation water applied (m$^3$).

### Table 1

<table>
<thead>
<tr>
<th>Month</th>
<th>Relative Humidity (%)</th>
<th>Evaporation (mm)</th>
<th>Precipitation (mm)</th>
<th>Mean Air Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>45.3</td>
<td>37.9</td>
<td>7.8</td>
<td>10</td>
</tr>
<tr>
<td>June</td>
<td>38.2</td>
<td>30.7</td>
<td>13.2</td>
<td>13</td>
</tr>
<tr>
<td>July</td>
<td>39.5</td>
<td>30.9</td>
<td>14.0</td>
<td>14</td>
</tr>
<tr>
<td>August</td>
<td>42.2</td>
<td>27.0</td>
<td>9.9</td>
<td>12</td>
</tr>
<tr>
<td>September</td>
<td>32.7</td>
<td>33.7</td>
<td>9.9</td>
<td>11</td>
</tr>
</tbody>
</table>

### 2.4. Sowing and fertilization

To prepare a suitable seedbed, the land was cultivated by a deep plough in autumn and a light one in the spring of each year. The final preparation was achieved after applying two vertical and horizontal disks. Seedbed preparation was accomplished on 1st May, 2013 and 3rd May, 2014 for the first and second experimental periods. Before cultivating the land, vermi-compost (2 tons ha$^{-1}$) fertilizer was added to the soil. All seeds were inoculated by a biological fertilizer (a mixture of different probiotic bacteria) before sowing as a 20cc bacterial solution per 1 kg seed (Somasegaran and Hoben, 1994). The major components of biological fertilizer comprised of Azotobacter + Azospirilium + Mycorrhiza + Bacillus and Rhizobium bacteria which were provided by the soil microbiology lab of the Department of Soil Science, College of Agriculture, University of Tehran.

### 2.5. Irrigation

In both years, all experimental plots were irrigated normally until the plants reached their full establishments (3–4 leaf stage). Times of irrigation were scheduled based on the common practice of the area, which consisted of irrigating at seven-day intervals. Before triggering the second step of irrigation (limited irrigation), all experimental plots were protected by a pile of soil to preserve water during the irrigation throughout the season. Likewise, the schedule of the irrigation treatments ($I_{100}$, $I_{75}$ and $I_{50}$) was once a week starting on 22nd July in both years, when the plants reached the 4 to 6-leaf growth stage. The amount of required irrigation water was calculated using the following equation (Howell, 2003; Vafabakhsh et al., 2008):

$$I_n = \frac{0.623 \times A \times K_c \times E_{T0}}{IE} \tag{1}$$

Where $I_n$ is the volume of irrigation water (gallons), 0.623 is a constant coefficient, $A$ is the canopy area (sq. ft.), $K_c$ is the crop coefficient, $E_{T0}$ is the weekly potential evapotranspiration (inches) and $IE$ is the irrigation efficiency. $E_{T0}$ was calculated using daily data from Karaj synoptic weather station in mm per unit time converted to inches. $K_c$ is defined as the ratio of the crop evapotranspiration rate to the reference evapotranspiration rate. The $K_c$ value of the mid-season stage of berseem clover was 0.9 in this experiment which was retrieved from FAO reports (FAO, 2012). The water requirement for each treatment was measured in gallons per week converted to liters per week. A counter meter was used for accurate water measurement and control. The total amount of irrigation water used during the plant life cycle was as follows: $I_{100} = 4895.8 \text{ m}^3 \text{ ha}^{-1}$, $I_{75} = 3671.9 \text{ m}^3 \text{ ha}^{-1}$ and $I_{50} = 2447.9 \text{ m}^3 \text{ ha}^{-1}$ during the first year, and $I_{100} = 7497.15 \text{ m}^3 \text{ ha}^{-1}$, $I_{75} = 5622.8 \text{ m}^3 \text{ ha}^{-1}$ and $I_{50} = 3748.57 \text{ m}^3 \text{ ha}^{-1}$ during the second year for normal, moderate and severely limited irrigation regimes, respectively. To reach physiological maturity the different irrigation regimes continued until 2nd September in 2013 and 15th in September 2014, respectively.

### 3.1. Measurements

The quantitative forage characteristics of berseem clover and basil were recorded at the 10% flowering stage. The seed yield of berseem clover and basil were measured after the plants reached the full physiological maturity stage. The IWUE for total dry matter yield (kg dry forage/m$^3$) and seed yield (kg seed/m$^3$) was calculated by dividing the yield (kg ha$^{-1}$) by the volume of irrigation water used (m$^3$ ha$^{-1}$). Harvest Index (HI) was calculated as the ratio of seed yield (kg ha$^{-1}$) to total aboveground biomass (kg ha$^{-1}$).

### 3.2. Statistical Analysis

For statistical analysis an ANOVA technique for split-split-plot design was carried out using Proc GLM procedure of SAS (SAS Institute, 1999). Mean comparison was implemented using Duncan’s test at the 95% level of probability. All the differences among the treatments were tested at 0.05 probability level unless otherwise stated.

### 4. Results and discussions

### 4.1. Forage yield and components

The response of forage yield components of both berseem clover and basil, including plant height (H), leaf/stem ratio (L/S), forage yield were different depending on the irrigation treatments, sowing patterns and water treatments in both 2013 and 2014 (Tables 2 and 3). All the differences among the treatments were tested at 0.05 probability level unless otherwise stated.
The adverse effects of deficit irrigation on basil dry matter were greater than for berseem clover and reduced by 25.1% and 10.26% at I50 in comparison with I100, respectively (Tables 2 and 3). It is assumed that when the soil water content is not enough to facilitate the nutrient uptake by roots, plants face difficulties in absorbing the essential nutrients such as nitrogen and phosphorus which results in a yield reduction (Jahanzad et al., 2013). Results clearly showed that, under severe deficit irrigation, plants with higher tillering potential have a higher tolerance to reduce the adverse effects and catch the economical yield.

The surfactant treatments resulted in significant differences in all parameters except for berseem clover L/S ratio. By using surfactant, forage yield increased by 14.91% in berseem clover compared with untreated plots (Table 2). Using surfactant improved forage yield by 8.8% in basil (Table 3). This is possible because of the ability of the crops to explore a wider soil profile as well as more efficient use of resources (e.g., light) when the surfactant is added to the system. In summary, the dry matter yield was preserved under deficit irrigation through the surfactant treatment (Tables 2 and 3).

### 4.2. Effect of irrigation treatments and surfactant on total dry matter (berseem clover + basil dry matter) yield

Wolkowski et al. (1985) asserted that wetting agents have no significant effects on yield; however, the results of our two-year experiment indicate that in all surfactant treatments across different irrigation regimes the forage yield was higher than the control (no surfactant application) (Table 4).

#### Table 2

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (H) cm</th>
<th>Leaf/stem (L/S)</th>
<th>Forage Yield kg ha⁻¹</th>
<th>Seed Yield (SY) kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation systems 100%</td>
<td>2013</td>
<td>2014</td>
<td>Mean</td>
<td>2013</td>
</tr>
<tr>
<td>75%</td>
<td>32.4 b</td>
<td>34.7 a</td>
<td>33.44 a</td>
<td>0.42 a</td>
</tr>
<tr>
<td>50%</td>
<td>30.6 b</td>
<td>27.02</td>
<td>28.81 b</td>
<td>0.53 a</td>
</tr>
<tr>
<td>Sowing patterns</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clover 100%</td>
<td>46.89 a</td>
<td>47.75 a</td>
<td>47.31 a</td>
<td>0.73 a</td>
</tr>
<tr>
<td>basil 100%</td>
<td>51.21 a</td>
<td>43.61 b</td>
<td>47.41 a</td>
<td>0.75 a</td>
</tr>
<tr>
<td>clover 100% + basil 50%</td>
<td>30.59 a</td>
<td>31.62 a</td>
<td>31.1 a</td>
<td>0.52 a</td>
</tr>
<tr>
<td>Water treatments</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>32.35 b</td>
<td>28.72 b</td>
<td>30.53 a</td>
<td>0.48 a</td>
</tr>
<tr>
<td>water + surfactant</td>
<td>33.04 a</td>
<td>32.18 a</td>
<td>32.61 a</td>
<td>0.5 a</td>
</tr>
</tbody>
</table>

It is worthwhile to mention that berseem clover and basil seed yields are also influenced by other environmental factors, e.g., sowing pattern. In brief, surfactant application has a significant positive effect on all measured traits in both berseem clover (Table 2) and basil (Table 3).

#### Table 3

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Plant height (H) cm</th>
<th>Leaf/stem (L/S)</th>
<th>Forage Yield kg ha⁻¹</th>
<th>Seed Yield (SY) kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation systems 100%</td>
<td>2013</td>
<td>2014</td>
<td>Mean</td>
<td>2013</td>
</tr>
<tr>
<td>75%</td>
<td>77.36 a</td>
<td>76.2 a</td>
<td>76.78 a</td>
<td>16.2 a</td>
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<tr>
<td>50%</td>
<td>51.6 c</td>
<td>50 c</td>
<td>50.80 c</td>
<td>10.96 b</td>
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<tr>
<td>clover 100%</td>
<td>72.82 a</td>
<td>71.96 a</td>
<td>72.39 a</td>
<td>15.62 a</td>
</tr>
<tr>
<td>basil 100%</td>
<td>58.8 b</td>
<td>59 b</td>
<td>58.9 b</td>
<td>15.7 a</td>
</tr>
<tr>
<td>clover 100% + basil 50%</td>
<td>51.07 b</td>
<td>44.02 b</td>
<td>47.31 b</td>
<td>0.73 b</td>
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<td>Water treatments</td>
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</tr>
<tr>
<td>Water</td>
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<td>28.72 b</td>
<td>30.53 a</td>
<td>0.48 a</td>
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<tr>
<td>water + surfactant</td>
<td>33.04 a</td>
<td>32.18 a</td>
<td>32.61 a</td>
<td>0.5 a</td>
</tr>
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Table 4
IWUE and TDM as influenced by irrigation systems, sowing patterns and water treatments.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>2013</th>
<th>2014</th>
<th>mean</th>
<th>2013</th>
<th>2014</th>
<th>mean</th>
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<td></td>
</tr>
<tr>
<td>100%</td>
<td>1.66 c</td>
<td>1.17 c</td>
<td>1.41 c</td>
<td>8127.83 a</td>
<td>8524.09 a</td>
<td>8325.96 a</td>
</tr>
<tr>
<td>75%</td>
<td>2.55 b</td>
<td>1.34 b</td>
<td>1.94 b</td>
<td>7543.97 a</td>
<td>7443.68 b</td>
<td>7493.82 b</td>
</tr>
<tr>
<td>50%</td>
<td>3.16 a</td>
<td>1.80 a</td>
<td>2.48 a</td>
<td>7415.05 a</td>
<td>6670.63 c</td>
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<td><strong>Sowing patterns</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clover 100%</td>
<td>2.43 b</td>
<td>1.44 b</td>
<td>1.93 b</td>
<td>7267.8 b</td>
<td>7612.6 b</td>
<td>7440.2 b</td>
</tr>
<tr>
<td>basil 100%</td>
<td>2.02 c</td>
<td>1.25 c</td>
<td>1.63 c</td>
<td>6407.68 c</td>
<td>6760.26 c</td>
<td>6583.97 c</td>
</tr>
<tr>
<td>clover 100% + basil 50%</td>
<td>2.92 a</td>
<td>1.62 a</td>
<td>2.27 a</td>
<td>9411.37 a</td>
<td>8474.54 a</td>
<td>8942.95 a</td>
</tr>
<tr>
<td><strong>Water treatments</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>2.28 b</td>
<td>1.30 b</td>
<td>1.79 b</td>
<td>7388.84 b</td>
<td>6897.51 b</td>
<td>7143.17 b</td>
</tr>
<tr>
<td>water + surfactant</td>
<td>2.63 a</td>
<td>1.58 a</td>
<td>2.1 a</td>
<td>8002.39 a</td>
<td>8334.10 a</td>
<td>8168.24 a</td>
</tr>
</tbody>
</table>

Fig. 1. Berseem clover (Terifolium alexandrinum) root (a and b) and forage growth (c and d) under severe limited irrigation conditions (I50 = 50%) under two water treatments of control (water) and water + surfactant assigned to the sub-subplots.

Fig. 2. Interaction between irrigation treatments and water treatments (with and without surfactant) on the forage dry matter yield of berseem clover (Terifolium alexandrinum) and basil (Ocimum basilicum) (mean 2013 and 2014).

Fig. 3. The interaction of sowing patterns and water treatments (with and without surfactant) on the forage dry matter of berseem clover (Terifolium alexandrinum) and basil (Ocimum basilicum) (mean 2013 and 2014).
4.3. Effect of sowing patterns and surfactant on total dry matter (berseem clover + basil dry matter) yield

Sowing patterns and water treatments significantly influenced the aboveground dry biomass of berseem clover and basil (Table 4). The highest total dry matter yield (mean for two years) of 9257.9 kg ha$^{-1}$ was gained from intercropping of berseem clover + 50% basil with surfactant application, supported by a report from Wang et al. (2014). The results indicate that interaction between planting pattern and surfactant application has a significant effect on yield (Fig. 3). Interspecific belowground interactions and rhizosphere effects between intercropped species played an important role in the yield advantage of intercropping. Due to the application of surfactants along with intercropping efficiency, the total dry matter yield increased compared with sole berseem clover and sole basil culture for both water treatments (with/without surfactant) at the end of the growing seasons (2013 and 2014, Fig. 3). These results support the idea that intercropping along with surfactant can bring the sustainability in cropping systems in arid and semiarid regions.

4.4. Seed Yield (SY)

In berseem clover the seed yield (SY) followed a similar trend as forage yield, the minimum and maximum SY were recorded at I50 and I100, respectively (Tables 2 and 3). Berseem clover SY was significantly reduced in treatments with severely limited irrigation. The water stress at I75 and I50 caused a berseem clover SY reduction of 4.96% and 15.66% compared with I100, respectively (Table 2). Likewise, the water stress at I75 and I50 caused a basil SY reduction of 8.10% and 10.40% compared with I100, respectively (Table 3). Results support the idea that reduced transpiration due to insufficient water in the soil can also intensify disruption of nutrient uptake by roots and ion transportation from roots to shoots (Jahanzad et al., 2013) which caused the reduction in seed yield component of both berseem clover and basil under severity of deficit irrigation.

The surfactant treatments resulted in differences in SY of berseem clover. By using surfactant, SY increased by 7.32% in berseem clover compared with untreated plots (Table 2). Using surfactant improved SY by 3.4% in basil (Table 3).

4.5. Effect of irrigation treatments and surfactant on IWUE in dry matter yield

In the second year, evapotranspiration was significantly higher than the first year due to a higher wind velocity, more windy days, more sunny days, and higher mean temperatures (Table 1). In addition, the relative humidity was lower in the second year due to the higher temperature compared with the first year. Therefore, the proportion and percentage of water vapor in the air decreased and the water loss through evapotranspiration increased. Despite the higher evapotranspiration in the second year, the yield was not affected significantly compared with the first year results. As such, the average forage yield in 2013 across all treatments with no surfactant was 7462.9 kg ha$^{-1}$ and that with surfactant was 8447.6 kg ha$^{-1}$ (11% increases). The average yield in 2014 across all treatments with no surfactant was 6897.5 kg ha$^{-1}$ and that with a surfactant was 8334.1 kg ha$^{-1}$ (17% increases). Here, the IWUE mean values were calculated as the ratio of produced TDM over the total water consumed. IWUE was significantly affected by the irrigation and water treatment (Table 4) and increased with decreasing plant water consumption in both years. The highest IWUE (2.7 kg m$^{-3}$) was achieved in the I50 + surfactant treatment. As expected, the lowest IWUE (1.38 kg m$^{-3}$) was recorded for irrigation I100 without surfactant. Surfactant treatment increased the total forage yield in full irrigation (I100) but had no significant influence on IWUE accordingly (Fig. 4). The results clearly show that, although surfactants increased the total yield when adequate amounts of water were applied to plants (I100), it had no significant influence on forage yield per 1 m$^3$ of water used by the crops. These results are supported by the previous reports by Zegada-Lizarazu and Iijima (2005), Nagaz et al. (2009) and Chaichi et al. (2015). They theorized that the higher IWUE can be explained by better water distribution uniformity in the soil and reducing evaporation.

4.6. Effect of sowing patterns and surfactant on IWUE

Sowing pattern and water treatment significantly affected the IWUE of berseem clover and basil (Table 4). The total dry matter yield in intercropping system was higher with a surfactant in 2014 as: 7820.6 kg ha$^{-1}$ with no surfactant, and 9128.4 kg ha$^{-1}$ for berseem clover + 50% basil + surfactant, while it was approximately the same in both water treatments in 2013 as: 9335.4 kg ha$^{-1}$ with no surfactant, and 9487.3 kg ha$^{-1}$ for berseem clover + 50% basil + surfactant. Nevertheless, IWUE was not affected by the surfactant application in intercropping systems. The highest value for IWUE (mean of two years) was 2.33 kg m$^{-3}$ recorded for intercropping of berseem clover + 50% basil along with surfactant application (Fig. 5). Whereas, it is well established that crop growth and yield decrease with increasing water stress (Chaves et al., 2003), the intercropping system dramatically reduced the adverse effects of deficit irrigations. Results support the idea that the agronomic association among legumes and grasses forage crops favours genotypic
interaction in a plant mixture whose root systems leave biochemi-
ical compounds in the soil which is desirable for a qualitative
and quantitative biomass production (Martiniello and Teixeira da
Silva, 2011). Nevertheless, DaCosta and Huang (2006) reported that
water use characteristics vary with species, irrigation regime, and
climatic conditions. Importantly, the efficiency of using an inter-
cropping system across surfactant in arid and semi-arid regions
was improved during the warm season when soil water availability
decreases due to the high temperature and low precipitation.

5. Conclusion

Introducing practical methods for improving the yield of for-
gage and promoting the efficient use of limited available water for
irrigation in arid and semi-arid areas can enhance the sustainability
of feed production in these areas. In this study, deficit irrigation was
applied based on berseem clover and basil weekly water require-
ments due to the prevailing environmental conditions in arid and
semi-arid regions. As the severity of the limited irrigation increased
(I50), all the growth and development traits of crops in sole berseem
clover, sole basil culture and intercropping systems followed a
decreasing trend, while the seed yield decreased by 10.40% and
15.66% in basil and berseem clover, respectively. Intercropping
and surfactant application significantly improved all vegetative and
genерative traits of berseem clover and basil. It was concluded that
the application of surfactant in limited irrigation treatments not
only modified the adverse effects of drought stress on growth and
development of crops, but also increased irrigation water use effi-
ciency in forage yield (I50 + with surfactant) by 48.9% compared with
I100 without surfactant. Application of surfactants in a medicinal
forage system (berseem clover and basil intercropping) is beneficial
and efficient in dry regions.

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