RESPONSE OF SORGHUM (Sorghum bicolor M.) TO THREE IRRIGATION SYSTEMS UNDER TREATED WASTE WATER AND FRESH WATER IRRIGATIONS SYSTEM

Saif A. Al-Khamisi*1, Nadiya M. Al-Jabri2, Saleem K Nadaf3, Abdulaziz. S. Al-Harthy4

1*Head of Field Crops Research Department, PO Box 50; PC 121Seeb, Sultanate of Oman.
2Field Crops Researcher, Sultanate of Oman.
3Plant Genetic Resources Expert, Directorate General of Agricultural and Livestock Research, Ministry of Agriculture & Fisheries, Sultanate of Oman.
4Director of Research Administration, the Research Council, Sultanate of Oman.

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ABSTRACT

The treated wastewater is highly used as an alternate source of water for growing crops like sorghum for forage/fodder to livestock in Arabian Peninsula water deficit countries including Oman. In present study, high forage yielding sorghum variety, Superdan was investigated under three irrigation systems (Surface, Sub-surface and Drips) at Agriculture Research Station, Rumais, Oman, for its response to treated wastewater and fresh water irrigation conditions with respect to forage productivity. Study was conducted over continuous 11 forage harvests which started from summer season (April, 2013) and completed in mid-winter season (March, 2015). The results of study revealed that both mean green and dry matter yields/ cut and their total yield over 680 days were significantly higher under drip irrigation and it was followed by sub-surface and surface irrigation systems in both treated and freshwater irrigations. Water use efficiency (WUE) of sorghum was significantly higher under drip irrigation than under other irrigation systems not only with treated wastewater (2.54) but also with freshwater irrigation (2.49). The concentrations of heavy elements were either very low, low or in trace amount under the limits of toxicity threshold in both plant samples and soil samples. The present study demonstrated that forage sorghum can last till 11 cut-harvests spanning 680 days providing total green and dry matter yields of 508.30 t/ha and 143.88 t/ha respectively under treated wastewater irrigation compared to total green and dry matter yields of 498.26 t/ha and 144.58 t/ha, respectively under freshwater irrigation.
1 Introduction

The treated wastewater is nowadays used for growing crops for forage or fodder to livestock and helps in decreasing the pressure of normal water use in the countries of the Arabian Peninsula including Oman that face water scarcity. However, its application requires effective treatment to safeguard public health and environment at economic cost (Anderson et al., 2001; Agunwamba, 2001; Sipala et al., 2003; Ling et al., 2011; Khan et al., 2012).

The problem of fresh water scarcity exists in all the arid and semi-arid areas of the world. The problem assumes grave in the countries, which are largely dependent on agriculture. Application of treated wastewater for irrigation in many countries has been considered in practice as an alternative to available water to irrigate crops to address the problem of water scarcity (Al-Rashed & Sherif, 2000; Aghtape et al., 2011; Khan et al., 2012).

Sorghum (Sorghum bicolor Moench.) is the most important drought tolerant forage crop in summer season in semi-arid tropic regions of the world like Oman (Akhtar & Nadaf, 2002). In most of the countries, sorghum is mainly used as green fodder. However, in India and Africa it is grown as a cereal grain food crop (Khan et al., 2010). It has the ability to tolerate water stress and survive even under sub-marginal conditions (Duarte et al., 2000; Khan et al., 2010).

The treated wastewater is found to provide a good source of N, P and K for better growth of fodder crops like sorghum, pearl millet, maize, etc. under treated wastewater (Khan et al., 2010; Al-Khamisi et al., 2011). However, very few studies investigated for appropriate irrigation system under arid conditions especially for cultivation of sorghum forage. Among these, Adams & Stevenson (1990), El-Aref et al. (2005) and Sakellariou-Makrantonaki et al. (2007) found drip irrigation system to be efficient for crop growth as it delivers continuous and adequate water supply into plant root zone among other irrigation systems studied.

In view of the above, the present study was undertaken to explore the potential of three irrigation systems using treated wastewater available from STPs (Sewage Treatment Plant) in the country for the growth of forage sorghum variety, Superdan in producing higher yield of fodder in comparison with that by use of fresh available water with no deleterious elements in fodder.

2 Materials and Methods

The present experiment was undertaken from April 2013 to March 2015 under split-plot arrangement in RCBD. In this experiment water type was main factor viz. fresh water and Treated wastewater and irrigation system was the sub factor viz. surface, sub-surface and drip irrigation. Seeds of forage sorghum variety from Australia namely Superdan were planted in plots consisting of four 3m rows at 25 cm between rows in plots of 3m x 4m and 15 cm between plants in each irrigation system under each water type during April, 2013. The first harvest of crop was taken-up for fodder during first week of July, 2013 when the crop showed 25-50% flowering. The crop was subsequently harvested for green forage ten times till the last cut-harvest made during March 2015. The experimental period lasted almost 680 days. Plots were irrigated half hour three times every week and fertilized with 100:50:50 kg NPK/ha as per national recommendations (Akhtar & Nadaf, 2002). At each fodder harvest, plant height (cm) and green matter weight (kg/m²) were recorded. The water applied up to each harvest was recorded from water meters fixed for each irrigation system. The fresh random samples of harvest were taken for each genotype for the determination of dry matter content (AOAC, 1984). The water-use efficiency (WUE) was computed using the value of quantity water applied for every cut-harvest. SPAD values of leaf samples were also measured during each harvest period using SPAD-502 meter. These values are proportional to the amount of chlorophyll present in the leaf chlorophyll content (Ling et al., 2011). The experimental data were subjected to analysis of variance according to Gomez and Gomez using M-Stat-C software.

3 Results and Discussion

Results presented in tables 1 to 5 revealed means plant height (cm), chlorophyll (SPAD values), green and dry matter yield (t/ha), and water-use efficiency (WUE) over 11 cut-harvests of forage sorghum hybrid, Superdan used for investigation.

3.1 Plant height

With respect the plant height, effects of water type, irrigation system and cut-harvests were found significant (p<0.05) while all the interaction were found not significant (p>0.05) (Table 1). The plant height under treated wastewater was significantly higher (164.66 cm) than the freshwater. Similar improvement in plant height under treated wastewater conditions was also previously reported in pearl millet (Khan et al., 2012), maize, sorghum and other cereal fodder crops (Agunwamba, 2001; Khan et al., 2010; Al-Khamisi et al., 2011). Vegetative characters like plant height are influenced by NPK and organic matter, which are abundantly found in treated wastewater in improving the plant growth. In present experiment also higher concentration N and K were found in treated wastewater (N = 28.7 mg/l and K = 22.93 mg/l) than the freshwater irrigation ((N = 0.463 mg/l and K = 17.83 mg/l) (Table 8). In the samples of both the water types, P was found undetected. Among the irrigation systems, sorghum responded significantly superior in terms of plant height under drip irrigation than under other irrigation systems (Table 1) not only with treated wastewater.
wastewater (172.30 cm) but also with freshwater irrigation. This was also observed in sorghum by El-Aref et al. (2015).

### 3.2 Leaf Chlorophyll Content

It is well known that leaf color shows the amount and proportion of chlorophyll in leaves that make plant nutrient status. Hence, leaf colour, as a function of chlorophyll content, could be used as an index to diagnose nutrient status. In the present study, SPAD values recorded for chlorophyll were used to indicate plant nutrient status for interpretation of results. In respect of chlorophyll, only the main effect of cut-harvests and interaction effect of water type and cut-harvest were found significant (p<0.05) while all the other effects were not significant (p>0.05) (Table 2). There were no significant differences in SPAD values (p>0.05) obtained in the plant samples under use of either treated wastewater or freshwater in all the irrigation systems. However, these values were significantly different between the samples taken in the periods of different cut-harvests which is attributed to differential conditions of growth prevailed during different cut-harvests.

### 3.3 Green and dry matter yields (t/ha)

With respect of green matter yield, only the main effects of irrigation system and cut-harvests were highly significant (p<0.05) whereas the interaction effects of water type x irrigation system and that of irrigation system x cuts were found significant (p<0.05). However, other interaction effects were not found significant (p>0.05) (Table 3). In respect of dry matter yield all the effects were significant (p<0.05) to highly significant (p<0.01) except the main effect of water type and that of three-factor interaction, which were non-significant (p>0.05). Both green and dry matter yields were significantly superior under drip irrigation system than under sub-surface and surface irrigation systems not only in terms of mean yields but also total yield over cuts for the experimental period (680 days) in both treated and freshwater irrigations (Tables 3 and 4). The over-all mean and total green matter yield of 48.74 t/ha and 584.90 t/ha were obtained under drip irrigation system as compared to 42.76 t/ha and 513.14 t/ha under surface irrigation and 35.57 t/ha and 426.87 t/ha under sub-surface irrigation systems with the use of treated wastewater. However, in case of freshwater irrigation, the over-all mean and total green matter

| Cuts   | Treated wastewater | Fresh water |
|--------|--------------------|-------------|
|        | Drip   | Surface | Sub surface | Mean | Drip | Surface | Sub surface | Mean |
| Cut-1  | 242.00 | 230.50  | 207.50      | 226.67 | 205.00 | 229.75  | 194.50      | 209.75 |
| Cut-2  | 174.75 | 165.25  | 162.25      | 167.42 | 165.25 | 149.50  | 160.75      | 158.50 |
| Cut-3  | 196.25 | 192.25  | 158.75      | 182.42 | 202.50 | 173.25  | 188.25      | 188.00 |
| Cut-4  | 172.75 | 174.00  | 168.75      | 171.83 | 173.00 | 168.00  | 179.75      | 173.58 |
| Cut-5  | 144.30 | 131.75  | 135.70      | 137.25 | 131.20 | 137.80  | 123.40      | 130.80 |
| Cut-6  | 144.00 | 145.00  | 126.75      | 138.58 | 141.50 | 150.00  | 138.75      | 143.42 |
| Cut-7  | 105.00 | 106.00  | 109.25      | 106.75 | 97.00  | 89.00   | 82.75       | 89.58  |
| Cut-8  | 184.50 | 173.75  | 165.50      | 174.58 | 157.25 | 160.50  | 141.25      | 153.00 |
| Cut-9  | 208.50 | 194.25  | 196.00      | 199.58 | 193.00 | 195.50  | 177.25      | 188.58 |
| Cut-10 | 169.00 | 171.25  | 167.75      | 169.33 | 164.00 | 166.25  | 158.50      | 162.92 |
| Cut-11 | 154.25 | 137.00  | 119.25      | 136.83 | 142.75 | 141.75  | 135.25      | 139.92 |
| Mean   | 172.30 | 165.55  | 156.13      | 164.66 | 161.13 | 160.12  | 152.76      | 158.00 |

| Statistical parameters | F-test | LSD (5%) |
|------------------------|--------|----------|
| Water type             | **     | 4.85     |
| Irrigation system      | **     | 5.83     |
| Cuts                   | **     | 11.36    |
| Water type x Irrigation system | NS | -        |
| Water type x Cuts      | NS     | -        |
| Irrigation system x Cuts | NS    | -        |
| Water type x Irrigation system x Cuts | NS | -        |
| C. V. (%)              |        | 12.4     |

Table 1: Means of plant height (cm) in sorghum under treated wastewater and freshwater in three irrigation systems
yield of 44.89 t/ha and 538.60 t/ha were obtained under drip irrigation system as compared to 38.63 t/ha and 463.60 t/ha under surface irrigation and 41.04 t/ha and 492.53 t/ha under sub-surface irrigation systems. Similar trends were observed in dry matter yields under irrigation systems and water types. In general, the forage yield levels under treated wastewater were found to be higher than under freshwater. Jun-feng et al. (2007), Khan et al., (2010), Al-Khamisi et al. (2011) and Khan et al. (2012) also found treated wastewater improving the forage yield the crops.

### 3.4 Water-Use Efficiency (WUE)

In respect of WUE, only the main effect of cut-harvests was found highly significant (p<0.01) and interaction effect of water type and irrigation system was significant (p<0.05) while all other effects were not found significant (p>0.05) (Table 5). The mean WUE with use of treated wastewater (2.33) was similar to that with freshwater (2.36). Among the irrigation systems, WUE of sorghum was significantly higher under drip irrigation than the

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**Table 2** Means of chlorophyll (SPAD values) in sorghum under treated wastewater and freshwater in three irrigation systems

| Cuts | Treated wastewater | Fresh water | Mean |
|------|--------------------|-------------|------|
|      | Drip | Surface | Sub surface | Mean | Drip | Surface | Sub surface | Mean |
| Cut-1 | 45.00 | 46.00 | 44.75 | 45.25 | 45.25 | 42.50 | 38.75 | 42.17 |
| Cut-2 | 38.00 | 34.75 | 30.75 | 34.50 | 41.75 | 36.00 | 42.00 | 39.92 |
| Cut-3 | 43.05 | 40.43 | 38.33 | 40.60 | 42.98 | 42.63 | 39.78 | 41.79 |
| Cut-4 | 48.50 | 45.75 | 39.00 | 44.42 | 40.50 | 41.00 | 37.75 | 39.75 |
| Cut-5 | 34.63 | 36.40 | 37.80 | 36.28 | 29.63 | 34.15 | 33.48 | 32.42 |
| Cut-6 | 38.80 | 43.23 | 42.08 | 41.37 | 38.10 | 39.63 | 39.08 | 38.93 |
| Cut-7 | 36.25 | 36.25 | 41.25 | 37.92 | 46.25 | 42.25 | 43.25 | 43.92 |
| Cut-8 | 40.03 | 40.95 | 40.83 | 40.60 | 43.58 | 43.23 | 42.53 | 43.11 |
| Cut-9 | 43.85 | 42.93 | 40.80 | 42.53 | 44.68 | 43.58 | 41.20 | 43.15 |
| Cut-10 | 40.00 | 42.00 | 41.75 | 41.25 | 42.00 | 41.50 | 41.50 | 41.67 |
| Cut-11 | 43.00 | 41.75 | 39.75 | 41.50 | 40.00 | 41.50 | 40.50 | 40.67 |
| Mean | 41.01 | 40.95 | 39.73 | 40.56 | 41.34 | 40.72 | 39.98 | 40.68 |

**Table 3** Means of green matter yield (t/ha) in sorghum under treated wastewater and freshwater in three irrigation systems

| Cuts | Treated wastewater | Fresh water | Mean |
|------|--------------------|-------------|------|
|      | Drip | Surface | Sub surface | Mean | Drip | Surface | Sub surface | Mean |
| Cut-1 | 40.56 | 40.60 | 37.92 | 44.42 | 78.23 | 80.93 | 47.52 | 68.89 |
| Cut-2 | 63.50 | 59.14 | 47.31 | 56.65 | 61.01 | 53.74 | 49.59 | 54.78 |
| Cut-3 | 86.88 | 73.08 | 59.88 | 73.28 | 83.40 | 73.93 | 79.20 | 78.84 |
| Cut-4 | 47.65 | 52.10 | 45.05 | 48.27 | 44.83 | 36.15 | 42.45 | 41.14 |
| Cut-5 | 20.70 | 21.15 | 26.43 | 22.76 | 13.23 | 16.80 | 20.25 | 16.76 |
| Cut-6 | 25.95 | 17.40 | 20.20 | 21.18 | 23.40 | 18.78 | 22.88 | 21.68 |
| Cut-7 | 20.98 | 25.15 | 15.55 | 20.56 | 15.80 | 8.40 | 11.60 | 11.93 |
| Cut-8 | 46.00 | 42.38 | 40.13 | 42.83 | 34.75 | 29.63 | 34.50 | 32.96 |
| Cut-9 | 61.00 | 51.00 | 43.38 | 51.79 | 75.13 | 46.50 | 64.63 | 62.08 |
| Cut-10 | 61.00 | 51.00 | 43.38 | 51.79 | 50.13 | 46.50 | 64.63 | 53.75 |
| Cut-11 | 18.00 | 13.88 | 11.00 | 14.29 | 13.88 | 13.63 | 14.25 | 13.92 |
| Mean | 48.74 | 42.76 | 35.57 | 42.36 | 44.89 | 38.63 | 41.04 | 41.52 |

**Statistical Parameters**

| Parameter | F-test | LSD (5%) |
|-----------|--------|----------|
| Water type | NS | - |
| Irrigation system | NS | - |
| Cuts | ** | 3.12 |
| Water type × Irrigation system | NS | - |
| Water type × Cuts | ** | 4.41 |
| Irrigation system × Cuts | NS | - |
| Water type × Irrigation system × Cuts | NS | - |
| C. V. (%) | 13.5 | - |
other irrigation systems (Table 5) not only with treated wastewater (2.54) but also with freshwater irrigation (2.49) as compared to surface and sub-surface irrigations. Similarly, higher values of water-use efficiencies N level under drip irrigation system in the studies of El-Aref et al. (2005). Several authors have investigated the response of annual forages under treated wastewater conditions in comparison with freshwater conditions without involving irrigation system. In the earlier studies conducted using treated wastewater, the higher magnitudes of element contents in treated wastewater were
attributed to their higher yields of forage. The forage samples had either low or under the limits of contents of heavy elements that are otherwise deleterious to livestock health and in turn in its products for human use (Jun-feng et al., 2007; Aghtape et al., 2011; Khan et al., 2012). In the present study also, plant samples were analyzed for certain heavy and macro elements studied such as Mn, Fe, Zn, P, Al, Ba, Cr, Co, Pb and Ti. The results of statistical analysis indicated that there were no significant effects of either water type or irrigation system or their interaction on any of the macro and heavy elements studied. The concentrations of

| Irrigation system | Mn   | Fe   | Zn   |
|------------------|------|------|------|
|                  | FW   | TW   | Mean | FW   | TW   | Mean | FW   | TW   | Mean |
| Drip             | 0.170| 0.195| 0.183| 1.065| 1.274| 1.170| 0.149| 0.192| 0.171|
| Surface          | 0.178| 0.167| 0.173| 1.189| 1.305| 1.247| 0.144| 0.123| 0.134|
| Sub-surface      | 0.219| 0.177| 0.198| 1.441| 0.979| 1.210| 0.207| 0.208| 0.208|
| Mean             | 0.189| 0.180| 1.232| 1.186| 0.167| 0.174|

### Table 6 (b) Means concentrations (ppm) of P, Al and Ba in sorghum plant samples from the plots irrigated by treated wastewater and freshwater under three irrigation systems

| Irrigation system | P   | Al  | Ba  |
|------------------|-----|-----|-----|
|                  | FW  | TW  | Mean| FW  | TW  | Mean| FW  | TW  | Mean |
| Drip             | 3.729| 3.834| 3.782| 0.455| 0.427| 0.441| 0.087| 0.090| 0.088|
| Surface          | 3.621| 4.689| 4.155| 0.491| 0.454| 0.473| 0.083| 0.101| 0.092|
| Sub-surface      | 3.235| 5.357| 4.296| 0.529| 0.437| 0.483| 0.089| 0.084| 0.087|
| Mean             | 3.528| 4.627| 4.092| 0.492| 0.39| 0.086| 0.092|

### Table 6 (c) Means concentrations (ppm) of Cr, Co, Pb and Ti in sorghum plant samples from the plots irrigated by treated wastewater and freshwater under three irrigation systems

| Irrigation system | Cr  | Co  | Pb  | Ti  |
|------------------|-----|-----|-----|-----|
|                  | FW  | TW  | Mean| FW  | TW  | Mean| FW  | TW  | Mean |
| Drip             | 0.065| 0.071| 0.068| 0.065| 0.065| 0.065| 0.173| 0.185| 0.179| 0.031| 0.037| 0.034|
| Surface          | 0.066| 0.064| 0.065| 0.066| 0.064| 0.065| 0.207| 0.181| 0.194| 0.033| 0.038| 0.035|
| Sub-surface      | 0.067| 0.062| 0.065| 0.065| 0.063| 0.064| 0.173| 0.184| 0.179| 0.036| 0.022| 0.034|
| Mean             | 0.066| 0.066| 0.065| 0.064| 0.184| 0.183| 0.033| 0.032|

Statistical analysis:

- **Water type**: NS - NS - NS -
- **Water quantity**: NS - NS - NS -
- **Water type × Water quantity**: NS - NS - NS -
- **C.V.**: 42.3 17.9 14.9

For more details, refer to the original source:

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Table 7 Values of macro-elements and heavy elements found in soil samples taken after harvest

| Element (mg/kg) | Fresh water 0-15 cm | Fresh water 15-30 cm | Fresh water 30-60 cm | Mean | Treated wastewater 0-15 cm | Treated wastewater 15-30 cm | Treated wastewater 30-60 cm | Mean |
|----------------|----------------------|-----------------------|----------------------|------|---------------------------|-----------------------------|-----------------------------|------|
| Mn             | 0.393                | 0.401                 | 0.377                | 0.390| 0.363                     | 0.332                       | 0.351                       | 0.349|
| Cd             | nd                   | nd                    | nd                   | nd   | nd                        | nd                          | nd                          | nd   |
| Cu             | 0.035                | nd                    | nd                   | 0.035| nd                        | nd                          | nd                          | nd   |
| Fe             | 1.309                | 1.355                 | 1.305                | 1.323| 1.194                     | 1.311                       | 1.269                       | 1.258|
| Zn             | 0.070                | 0.086                 | 0.111                | 0.089| 0.046                     | 0.050                       | 0.024                       | 0.040|
| B              | 0.011                | 0.056                 | 0.025                | 0.031| 0.037                     | 0.008                       | 0.024                       | 0.023|
| P              | 0.316                | 0.036                 | nd                   | 0.176| 0.017                     | nd                          | nd                          | 0.017|
| Al             | 0.039                | 0.016                 | 0.019                | 0.025| 0.006                     | 0.006                       | 0.002                       | 0.005|
| Ba             | 0.136                | 0.136                 | 0.134                | 0.135| 0.124                     | 0.138                       | 0.143                       | 0.135|
| Cr             | 0.045                | 0.046                 | 0.041                | 0.044| 0.040                     | 0.047                       | 0.040                       | 0.042|
| Co             | 0.080                | 0.084                 | 0.089                | 0.084| 0.077                     | 0.078                       | 0.069                       | 0.075|
| Pb             | 0.352                | 0.291                 | 0.255                | 0.299| 0.241                     | 0.200                       | 0.232                       | 0.224|
| Ni             | 0.154                | 0.177                 | 0.157                | 0.163| 0.128                     | 0.116                       | 0.135                       | 0.126|
| Ti             | 0.006                | 0.007                 | 0.004                | 0.006| 0.003                     | 0.002                       | 0.002                       | 0.002|

nd= not detected

Table 8 Mean chemical contents of water samples from treated wastewater and freshwater irrigations taken during experimental period

| Parameter            | Unit | Treated wastewater | Fresh water |
|----------------------|------|--------------------|-------------|
| ECw                  | dS/m | 0.88               | 1.06        |
| pH                   | -    | 7.7                | 7.5         |
| Nitrogen N-NO₃ (nitrate) | mg/l | 28.7              | 0.463       |
| Potassium K+         | mg/l | 22.93              | 17.83       |
| Sulfate SO₄²⁻        | mg/l | 81.17              | 39.87       |
| Bicarbonate HCO₃⁻     | mg/l | 107.99             | 152.53      |
| Carbonate CO₃⁻       | mg/l | Trace              | Trace       |
| Calcium Ca²⁺         | mg/l | 58.21              | 38.91       |
| Magnesium Mg²⁺       | mg/l | 20.29              | 30.01       |
| Sodium Na⁺           | mg/l | 94.07              | 140.07      |
| Chloride Cl⁻         | mg/l | 140.02             | 276.49      |
| Manganese Mn²⁺       | mg/l | 0.028              | 0.018       |
| Cadmium Cd²⁺         | mg/l | Nd                 | Nd*         |
| Copper Cu¹⁺          | mg/l | Nd                 | Nd*         |
| Fe                   | mg/l | 0.365              | 0.337       |
| Zinc Zn²⁺            | mg/l | nd                 | nd          |
| Boron B              | mg/l | nd                 | nd          |
| P                    | mg/l | nd                 | nd          |
| Aluminum Al³⁺        | mg/l | 0.013              | 0.011       |
| Barium Ba³⁺          | mg/l | 0.056              | 0.054       |
| Chromium Cr³⁺        | mg/l | 0.047              | 0.044       |
| Cobalt Co²⁺          | mg/l | 0.062              | 0.057       |
| Lead Pb⁴⁺            | mg/l | 0.211              | 0.185       |
| Nickel Ni            | mg/l | nd                 | nd          |
| Ti                   | mg/l | 0.001              | nd          |

*nd-not detected

Heavy elements were either very low, low or in trace amount under the limits of toxicity threshold in both plant samples (Tables 6 (a-c)) and soil samples (Table 7) taken after experimentation. Irrigation with treated wastewater has shown increase in concentrations of only three among the elements studied such as in P (4.627 ppm in treated wastewater vs 3.528 in freshwater), Zn (0.174 ppm in treated wastewater vs 0.167 in freshwater) and Ba (0.092 ppm in treated wastewater vs 0.167 in freshwater). This was also found in the recent study of Galavi et al. (2010) where concentrations of Cu and Fe were found increased with irrigation of wastewater and in general concentrations of all elements in plant samples were lower than toxicity threshold.

Present study revealed that forage sorghum can last till 11 cut-harvests spanning 680 days giving total green and dry matter yields of 508.30 t/ha and 143.88 t/ha respectively under treated wastewater irrigation as compared to total green and dry matter yields of 498.26 t/ha and 144.58 t/ha respectively under freshwater irrigation (Tables 3 and 4; Figure 1). The sorghum crop appeared to respond favorably under summer conditions >27° C as compared to its response in winter as evidenced by higher green and dry matter yields obtained in cut-harvests, 1, 2 and 3 taken during 2013 to the extent of 65.72 t/ha @938.84 kg/ha/day, 55.71 t/ha @1295.67 kg/ha/day and 76.06 t/ha @2001.53 kg/ha/day, respectively. Similar trend was observed in cut-harvests 8, 9 and 10 taken during 2014 which were out of growth and development due to high temperatures prevailed during the period (Table 9). However, the forage yields were of lower magnitude due older age of crop stand. Summer conditions
Table 9 Means of per day green and dry matter yields in different cut harvests in sorghum during experimental period

| Cuts      | Harvesting date | Cut duration (days) | Green yield (kg/ha/day) | Dry yield (kg/ha/day) |
|-----------|-----------------|---------------------|-------------------------|-----------------------|
| Cut-1     | 1-Jul-2013      | 70                  | 938.84                  | 275.27                |
| Cut-2     | 13-Aug-2013     | 43                  | 1295.67                 | 362.60                |
| Cut-3     | 21-Sep-2013     | 38                  | 2001.53                 | 522.66                |
| Cut-4     | 23-Dec-2013     | 93                  | 480.69                  | 138.48                |
| Cut-5     | 1-Mar-2014      | 66                  | 299.36                  | 89.42                 |
| Cut-6     | 27-Apr-2014     | 57                  | 376.02                  | 106.68                |
| Cut-7     | 11-Jun-2014     | 44                  | 369.23                  | 98.68                 |
| Cut-8     | 13-Aug-2014     | 62                  | 611.23                  | 170.45                |
| Cut-9     | 16-Oct-2014     | 63                  | 903.78                  | 274.17                |
| Cut-10    | 8-Dec-2014      | 51                  | 1034.73                 | 316.18                |
| Cut-11    | 16-Mar-2015     | 97                  | 145.40                  | 44.51                 |

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

References

Adams SS, Stevenson WR (1990) Water management, disease development and potato development. American Potato Journal 67:3-11.

Aghtape A, Ghanbari A, Sioursmehr A, Siahsar B, Asgharipour M, Tavssoli A (2011) Effect of irrigation with wastewater and foliar fertilizer application on some forage characteristics of foxtail millet (Setaria italica). International Journal of Plant Physiology and Biochemistry 3: 34-42.

Agunwamba JC (2001) Analysis of socioeconomic and environmental impacts of waste stabilization and unrestricted wastewater irrigation. Interface with maintenance. Environmental Management 27: 463-476.

Akhtar M, Nadaf SK (2002) Consolidated Results of the Experiments in Field Crops (1971-2000), Directorate General of Agriculture, Ministry of Agriculture and Fisheries, Sultanate of Oman.

Al-Khamisi SA, Abdalrahman HA, Ahmad M, Goosen MFA (2011) Assessment of Reclaimed Water Irrigation on Growth, Yield and Water-use Efficiency of Forage Crops. Applied Water Science 1: 57-65.

Al-Rashed MF, Sherif MM (2000) Water resources in the GCC countries: An over view. Water Resource Management 14: 42-48.

Anderson I, Adin A, Crook J, Davis C, Holtquist R, Jimenez-Cisneros B, Kennedy W, Sheikh B, Vander Merwe B (2001) Climbing the ladder: A step-by-step approach to international guidelines for water recycling. Water Science and Technology 43 : 1-8.

AOAC (1984) Official methods of analysis. 14th Ed. Association of Official Analytical Chemists. Washington, D.C. USA.

Duarte MP, Fermando AL, Guimaraes H, Amparo,V, Alves L, Santos-Oliveira JF (2000) Study of sweet and fiber sorghum in Portugal. Effect of climatic conditions and sowing date on the final productivity and on the quality of biomass. In: Proceedings of the First World Conference on the biomass for Energy and Industry Sevella, Spain, 5-9, June, 361-364.

El-Aref KAO, Abdel Mawly SE, Abo-Elhamid AS (2005) Improving yield and water-use efficiencies of two sorghum cultivars irrigated by surface and drip irrigation systems and fertilized by nitrogen. Assiut University bulletin for environmental researches 8: 67-73.

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were in general found to advance crop growth towards flowering earlier than winter conditions in case of monocot-forage crops like sorghum. This phenomenon is common in all grass species as was also found in Rhodes grass species in various cuts year round by Nadaf et al., 2009a and Nadaf et al., 2009b.
Galavi M, Jalali A, Ramroodi M, Mousavi SR, Galavi H (2010) Effects of treated municipal wastewater on soil chemical properties and heavy metal uptake by sorghum (Sorghum bicolor L). Journal of Agricultural Sciences 2:235-241.

Jun-feng W, Gen-Xu W, Hua W (2007) Treated wastewater irrigation effect on soil, crop and environment: Wastewater recycling in the loess area of China. Journal of Environmental Sciences 19: 1093-1099.

Khan M, Shaukat SS, Shahzad A, Arif H (2012) Growth and yield responses of pearl millet (Pennisetum glaucum [L.] r.br.) irrigated with treated effluent from waste stabilization ponds. Pakistan Journal of Botany 44 : 905-910.

Khan MA, Shaukat SS, Hany O, Jabeen S (2010) Irrigation of sorghum crop with waste stabilization pond effluent: growth and yield responses. Pakistan Journal of Botany 42 : 1665-1674.

Ling Q, Huang W, Jarvis P (2011) Use of a SPAD-502 meter to measure leaf chlorophyll concentration in Arabidopsis thaliana. Photosynthesis Research 107 : 209-214.

Sakellariou-Makrantonaki S, Papalexes D, Nakos N, Kalavrouziotis IK (2007) Effect of modern irrigation methods on growth and energy production of sweet sorghum (var. Keller) on a dry year in Central Greece. Agriculture Water Management 90: 181-189.

Nadaf SK, Al-Farsi SM, Al-Hinai SA, Al-Harthi AAS, Al-Bakri AN (2009a) Effect of Spacing on Seed Yield of Indigenous Rangeland and Forage Grass Species Grown under Drip Irrigation. Agricultural & Marine Sciences 14: 1-8.

Nadaf SK, Al-Farsi SM, Al-Hinai SA, Al-Adawy MH, Al-Hinai RS, Al-Bakri AN (2009b) Effect of harvesting time on seed weight per se and seed quality in indigenous rangeland and forage species. Karnataka Journal of Agricultural Sciences 22: 955-964.

Sipala S, Mancini G, Vagliasindi FGA (2003) Development of web-based tool for the calculation of costs of different wastewater treatment and reuse scenarios. Water Science and Technology 3: 89-96.