Chapter 4

Grasses in Arid and Semi-Arid Lands: The Multi-Benefits of the Indigenous Grasses

Suzan Shahin and Mohammed Salem

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.79151

Abstract

Drought regions are the most critical areas of the world. The challenging environmental conditions create severe concerns in arid and semi-arid lands. Consequently, the management task is crucial to face the proposed complicated ecological conditions. The main objective of this chapter is to focus on the vital roles of the indigenous grasses in drought areas and how the same could be a perfect solution in the urban planning of such places sustainably. Examples of the indigenous grasses of arid and semi-arid regions from the Poaceae family will be illustrated along their multi-economic values. In addition, promising innovative approaches required to face the demanding future of the agricultural sector will be presented and discussed.

Keywords: arid and semi-arid regions, economic value, global concerns, indigenous grasses, innovative technologies, morphophysiological characteristics, sustainability, water scarcity

1. Introduction

Arid and semi-arid lands are regions of the world that have harsh environmental conditions, including high temperatures, high evapotranspiration rates, low precipitation rates, and scarcity of freshwater resources. Consequently, the management task of such regions is a challenging mission, especially with the growing concerns of climate change, population explosion, and food security.

This chapter provides insights into how the indigenous grasses can be a perfect candidate to rescue the future of the agricultural sector in arid and semi-arid regions sustainably, focusing on the major role of grasses in urban planning. In addition, examples of predominant grass communities that have multi-economic benefits of add value in arid and semi-arid areas will be discussed. In addition, the chapter offers promising innovative approaches in such drought regions.

2. Drought regions

Tropical desert (TBWh) is the global ecological zone (GEZ) that is characterized by severe ecological conditions including high summer temperatures, high evapotranspiration (ET), and low and irregular precipitation [1]. The sandy soil texture is predominant with high porosity, high water permeability, low water holding capacity, poor nutrient content, and thus low fertility [2–6].

Under such conditions certain vegetation can adapt and survive [5–7]. Such flora was for centuries a free resource that provides free ecological services including shelter, food, and medication [5].

3. Global concerns and the demanding future

Currently, there are major concerns threatening the future of the agricultural sector in many regions around the world, particularly in arid and semi-arid areas. Concerns are associated with the sharp global population growth, depletion of natural resources (e.g., fresh water), pollution (e.g., air, water, and soil), and climate change and global warming [8, 9]. Since 1960, global population is dramatically increasing, reaching 7.442 billion in 2016 with sharp growth projections [10], which are expected to reach over 9 billion by 2050. More people means more natural resources required to cover the basic life requirements, such as water, food, medication, and accommodation [8, 9].

The concerns are more serious in the era of climate change, where regions with scarcity in freshwater resources are subjected to worse drought conditions, associated with extreme ecological events of severe implications on the limited available natural resources and thus on food productivity. Particularly, the same synchronized with the sharp expansion in industrial activities, urbanization, and population. Consequently, it could be highly expected that the drought regions could be much more susceptible and sensitive to any further environmental challenges [2].

The situation is more critical in developing countries, which have limitations on the environmental resources (e.g., water, land, and energy) and thus have high risks of hunger and poverty. Based on the Food and Agriculture Organization of the United Nations (FAO), the global demand for cereals will increase by 70% in 2050 compared to the current rates and would be doubled in many low-income nations [11]. Also, the demand for food will sharply grow in high-income countries, which have high per capita food consumption rates [12].

http://dx.doi.org/10.5772/intechopen.79151

4. Indigenous grasses of drought regions

The indigenous plants including the indigenous grasses can play a significant role in mitigating the demanding future of arid and semi-arid lands. Special attention should be given to the industrial gasses that can bring extra economic value by each water drop to the drought regions [8, 13]. Such plants can provide maximum benefits with minimal inputs, as illustrated in **Figure 1**.

There are many desert grasses that have the capability of producing expensive secondary metabolites (e.g., terpenes) as their defense phytochemicals. Such natural compounds have many therapeutic applications in the traditional herbal practices [13].

For example, *Cyperus rotundus* L. (English name: Coco grass) from Cyperaceae (Sedges family) is a perennial grass that is widespread in sandy and saline soils, like in the central areas of Tunisia, northern parts of the United Arab Emirates, Southern Africa, and Northern India. This grass is not used as a forage grass only, but it is also eaten to treat worm infections and regulate menstruation. Its seeds are heated with oil and used as ear drops to soften earwax. Besides, this grass is an ingredient in tooth powder to whiten teeth. Moreover, *C. rotundus* is used by Greek as a diuretic, to break up stones, and to treat uterine disorders. The herbal extract of *C. rotundus*

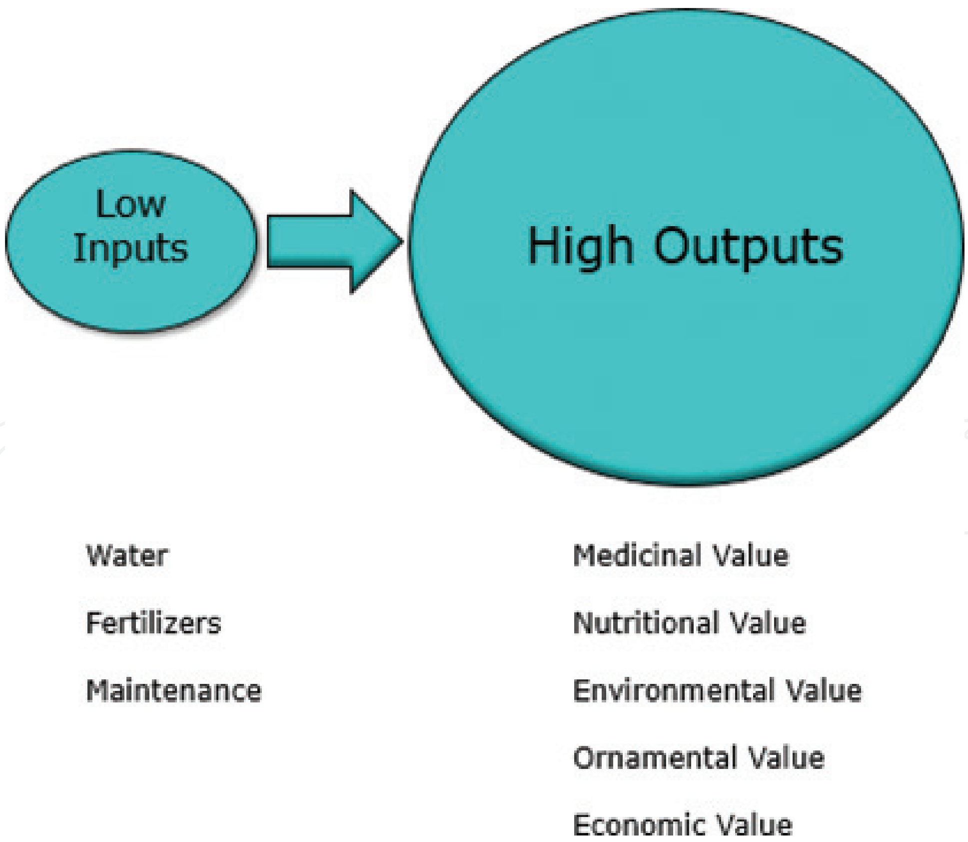

Figure 1. The Add value of the indigenous grasses in the drought regions.

rhizomes is found to be rich in sesquiterpenes and monoterpenes and proven to be a rich source of antioxidants and antibacterial bioactive compounds [14, 15].

Besides the healing benefits, there are many grass species that have excellent landscaping and urbanization potentials. The same is due to their unique shapes, textures, and colors which is totally opposite of the general concept of the desert plants by the public community. For example, *Cyperus arenarius* Retz. (English name: Dwarf sedge), which is a perennial grass of the Cyperaceae family, has high value as a landscaping grass in the urbanization activities of sandy and coastal saline habitats [16, 17].

Consequently, while the indigenous grasses of the arid and semi-arid regions can be cultivated to provide various therapeutic, nutraceutical, and health-care applications, they also could be employed to sustain the landscaping beauty and to conserve a balanced ecosystem. Examples of potential grasses from the Poaceae family are provided in **Table 1**.

On the other hand, cultivating exotic grasses, which are originally from other regions (e.g., temperate region), requires enormous amounts of inputs (e.g., water and soil nutrients) to survive and grow [32]. Even with the application of the modern irrigation technologies, which save 60% of the watering amounts [11], most of these grasses have high watering requirements, lack adaptation mechanisms, and disturb the natural balance of the desert ecosystem. In additional, to the high irrigation requirements, exotic grasses are labor intensive (e.g., adding fertilizers and maintenance) leading to expensive environmental and economic costs. Due to these, the cultivation of exotic grasses is restricted or even banned in some areas [32].

Similarly, some indigenous grasses in the drought regions that consume high amount of water should be cultivated wisely. For example, Rhodes grass (*Chloris gayana* Knuth.), which is a

No.	Botanical name (common name)	Characteristics	Economic value	References
1	*Cynodon dactylon* L. (Bermudagrass)	Halophyte	Medicinal, landscaping, forage	[18–21]
2	*Paspalum vaginatum* Sw. (Paspalum)	Halophyte, xerophyte	Landscaping	[22, 23].
3	*Cenchrus ciliaris* L. (Buffel grass)	Halophyte, xerophyte	Medicinal, forage	[19, 24, 25]
4	*Pennisetum setaceum* (Forssk.) Chiov. (Fountain grass)	Halophyte, xerophyte	Landscaping	[26, 18]
5	*Desmostachya bipinnata* L. (Halfa grass)	Halophyte, xerophyte	Medicinal, religious	[19, 27].
6	*Cymbopogon commutatus* (Steud.) Stapf. (Incense grass)	Halophyte	Medicinal, landscaping, forage, insecticidal, aromatic	[19]
7	*Cymbopogon schoenanthus* L. (Camel grass)	Xerophyte	Medicinal, landscaping, insecticidal, aromatic	[28, 29]
8	*Cymbopogon jwarancusa* (Jones) Schult. (Oil grass)	Halophyte	Medicinal, forage, aromatic	[30, 31]

Table 1. Economic value of common perennial grasses of Poaceae family in drought regions.

http://dx.doi.org/10.5772/intechopen.79151

perennial grass from the Poaceae family, has high value as a forage grass in warm regions. However, since it is a water-intensive grass, growing it as a forage grass has been banned in many countries (e.g., in United Arab Emirates) [32].

4.1. Morphophysiological characteristics

Cultivating the indigenous grasses could greatly mitigate the water scarcity situation with robust adaptation strategies to survive the drought conditions. Over the time, these desert grasses have developed diverse morphophysiological mechanisms to adapt to arid environmental conditions, as illustrated in **Table 2** [4, 13]. These environmental conditions include high intensity of sunlight, high wind speed, rapid loss of water through evaporation or evapotranspiration, low amount of precipitation, low soil moisture content, low soil water-holding capacity, high rate of water permeability, high level of soil salinity, and deficiency in soil nutrients [33, 34].

Many indigenous grasses of the drought regions belong to the xerophytes and/or halophytes as indicated in **Table 1**, which are adapted to water scarcity and soil salinity, respectively [33, 34].

In addition, the following morphological properties enable desert plants to adapt to the prevailing harsh environmental condition: seeds dormancy, long root system, light green color, small leaf area, succulent plant parts, presence of hairy surface and thorns, short growth rate, and short life cycle (ephemerals) [33, 34].

Physiological adaptation of grasses in drought regions is another adaptation mechanism that enables the plant either to reduce the amount of water loss, "transpiration," or increase the ability of the grass to uptake more water. The same is achieved by different physiological and biochemical modifications [19].

For example, some grasses have the ability to control stomatal opening during the day, thus controlling transpiration rates and reducing water loss. Also, controlling the osmotic pressure of plant cells in drought and saline habitats is another important physiological adaptation mechanism that reduces the osmotic potential of plant cell solutes to lower levels compared to the water potential of the surrounding environment, which enables the roots to uptake more water and enhances plant water-use efficiency. Proline accumulation is another adaptation mechanism to survive stress factors, like water limitation. The accumulation of such organic compounds inside plant cells helps in reducing the osmotic potential, thus enhancing soil-water uptake. Besides, the capability of plant cell components to have higher rates of water bound plays a major role in reducing water loss during transpiration [19].

Photosynthesis carbon fixation pathways of C4 and CAM plants are vital mechanisms to adapt to hot and arid environments. Such pathways are associated with higher rates of water-use efficiency, thus a better water conservation strategy. Most indigenous grasses from drought regions are following these carbon fixation pathways [19]. Examples of such grasses that are following the C4 pathway are illustrated in **Table 1**, that include *Cynodon dactylon* L., *Paspalum vaginatum* Sw., *Cenchrus ciliaris* L., *Pennisetum setaceum* (Forssk.) Chiov, *Desmostachya bipinnata* L., *Cymbopogon schoenanthus* L., and *Cymbopogon jwarancusa* (Jones) Schult.

No.	Botanical name (Common name)	Plant photo and identification	Adaptation characteristics	References
1	*Cymbopogon commutatus* (Steud.) Stapf. (Incense grass)	 Dr. Mohamed Taher Mousa	Narrow pointed leaves and hairy basal sheaths, moderate salt tolerant	[19]
2	*Cenchrus ciliaris* L. (Buffel grass)	 Prof. Ali El-Keblawy	Narrow pointed leaves, C4-plant, highly salt tolerant, drought tolerant grass	[19, 24, 25]

No.	Botanical name (Common name)	Plant photo and identification	Adaptation characteristics	References
3	*Pennisetum setaceum* (Forssk.) Chiov. (Fountain grass)	 Dr. Shyam Kurup	Mound of narrow leaves, C4-plant, salt and drought tolerant grass	[26, 18]

Note: Plant photos are taken by authors of this work.

Table 2. Adaptation characteristics of common perennial grasses from Poaceae family.

4.2. Sustainable value

Grasses are the most plentiful species in the plant kingdom with enormous socio-economic potentials. Growing the indigenous grasses in drought regions can provide the community with great sustainable values, including the cultural, environmental, and economic values as discussed below:

4.2.1. Cultural benefits

There is no doubt that the indigenous grasses provide great cultural and social values for the local community. In the old times, such plants had been greatly used in traditional medicine, as the only available resources for therapeutic and medication purposes, which established a strong relationship between these plants and the Bedouin people who historically inhabited the desert regions [4, 35].

For example, Buffel grass (*Cenchrus ciliaris* L.) has been used in the Zulu traditional herbal practices as a pain reliever and to cure many diseases, such as menstrual disorders, urinary infections, kidney pain, tumors, sores, and wounds [36]. Also, oil grass (*Cymbopogon jwarancusa* (Jones) Schult.) has been used by Indians to treat blood disorders, vomiting, skin problems, unconsciousness, and abdominal tumors [37].

4.2.2. Ecological benefits

Grasses play a major role in the fight against desertification. It is a cost-effective method of soil binding and fixation to mitigate land degradation in dry lands. It is of particular interest in urban planning to cultivate the indigenous grasses of the drought regions, which conserve natural resources and maintain a balanced and healthy ecosystem [38]. For example, dwarf sedge (*Cyperus arenarius* Retz.) from the Cyperaceae family provides major ecological services in the sandy, saline, and coastal habitats [17].

4.2.3. Economic benefits

There are a lot of grass species in drought regions that can offer multi-economic benefits, including food and nutritional resource, medicinal, cosmetic, flavoring, and fragrance. Examples of selected grasses and their benefits are shown in **Table 1**.

4.3. Innovative technologies and approaches

Certainly, the agricultural sector in drought regions has to adopt the best agricultural practices and irrigation methods in cultivating selected indigenous grasses that can best survive the harsh conditions and at the same time provide multi-economic benefits. Such agricultural practices include deficit irrigation and irrigation scheduling, which reduce watering volumes, increase water-use efficiency and thus increase water productivity. Studies need to be done to determine an optimized amount (model) of irrigation schedule, in order to apply the minimum amount of water which returns in maximum possible yield considering the prevailing and expected change in climate [32, 39].

http://dx.doi.org/10.5772/intechopen.79151

Undoubtedly, it is very important to imitate the natural and original environment of the drought areas, through focusing on planting the indigenous grass species from the xerophytes and halophytes. Besides, the adoption of hardscaping and xeriscaping plays an essential role in reducing the heavy pressure on the limited available water resources [5, 13, 32].

On the other hand, exotic grasses have to be restricted or even banned since most of these grasses require high amounts of irrigation water and labor for maintenance and fertilization; they thus pose very expensive environmental and economic costs. It is, therefore, recommended to replace these exotic grasses with salt and drought-tolerant species, which substantially reduce water requirements and sustainably maintain a balanced and healthy ecosystem [32].

New approaches are applied to reduce water loss and enhance plant soil-water uptake. One of these approaches is the application of hydrophobic sand, which is originally beach sand coated with chemically treated pure silica. According to Salem et al. [40], mixing the hydrophobic sand with the agricultural soil improves soil and plant characteristics and conserves water use without causing any adverse effects to the cultivated plants. Successful initiatives were reported with Bermudagrass (*Cynodon dactylon* L.), showing better growth rates, while keeping the plant mineral composition (e.g., Cd, Mo, Pb, and Se) within acceptable limits [40].

5. Conclusion

It is crucially needed to use each drop of expensive freshwater resource in drought regions cautiously and wisely. This could be done through focusing on cultivating the indigenous industrial gasses that can best adapt and mitigate the harsh environmental conditions, and still produce expensive raw materials of great applications (e.g., food and pharmaceuticals), offering potential ecological and/or landscaping services sustainably. Cultivating the indigenous grasses of drought lands should be synchronized with the best agricultural practices and the most recent innovations of soil-plant water use efficiency.

The demanding future of the greenery sector in the arid and semi-arid regions does not rely on how to enlarge the available freshwater resources (which are already limited and scarce), as much as relying on how to best employ such limited resources to gain maximum economic benefits to arid and semi-arid regions sustainably.

Author details

Suzan Shahin and Mohammed Salem*

*Address all correspondence to: mohammed.s@uaeu.ac.ae

Aridland Agriculture Department, United Arab Emirates University (UAEU), Al Ain, United Arab Emirates (UAE)

References

[1] Iremonger S, Gerrand AM. Global Ecological Zones for FAO Forest Reporting, 2010. Rome: FAO; 2011. Unpublished report

[2] Ajaj R, Shahin S, Salem M. The challenges of climate change and food security in the United Arab Emirates (UAE): From deep understanding to quick actions. The Journal of Current Nutrition and Food Science. Bentham Science Publishers. 2018;**14**:1-8. DOI: 10.2174/1573401314666180326163009

[3] Ajaj R, Shahin S, Kurup S, Cheruth J, Salem M. Elemental fingerprint of agriculture soils of Eastern Region of the Arabian Desert by ICP-OES with GIS mapping. The Journal of Current Environmental Engineering. Bentham Science Publishers. 2018;**5**(1):1-23. Accepted for Publication. BMS-CEE-2018-1

[4] Shahin SM, Salem MA. Review future concerns on Irrigation requirements of date palm tree in the United Arab Emirates (UAE): Call for quick actions. In: Proceedings of the 5th International Date Palm Conference, Date Palm Improvement Section; Abu Dhabi; 16–18 March, 2014. pp. 255-262. ISBN: 978-9948-22-868-4

[5] Shahin S, Salem M. The challenges of water scarcity and the future of food security in the United Arab Emirates (UAE). Natural Resources and Conservation. 2015;**3**(1):1-6. DOI: 10.13189/nrc.2015.030101. ISSN: 2331-6365. ISSN: 2331-6373

[6] Simons H, Soto X, Zhu Z, Singh KD, Bellan MF, Iremonger S, Hirvonen H, Smith B, Watson V, Tosi J, Morales L, Shvidenko A, Bohn U, Hettwer C, Barkoudah Y, Du Z, Tickle P. Global Ecological Zoning for the Global Forest Resources Assessment 2000. Final Report. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO); 2001

[7] Shahin S, Kurup S, Cheruth J, Lennartz F, Salem M. Growth, yield, and physiological responses of *Cleome amblyocarpa* Barr. & Murb. under varied irrigation levels in sandy soils. Journal of Food, Agriculture and Environment. Publisher: WFL Publisher Ltd. JFAE. 2018;**16**(2):124-134

[8] Ajaj R, Shahin S, Salem M. The challenges of climate change and food security in the United Arab Emirates (UAE): A critical review of the influence of UV-B radiation with future research perspectives. In: Proceedings of the Third International Conference on Global Warming: Food Security. United Arab Emirates: Publisher RAK Environment Protection and Development Authority; 2015. p. 33

[9] Ajaj R, Salem M. Estimating the potential negative effects of elevated ultraviolet-B (UV-B) radiation on global agricultural sustainability: Status, challenges and recommendations. In: The Annual Meeting of the American Society of Agronomy (ASA). ACSESS Digital Library; 2015

[10] World Bank. Total Population Data. The World Bank Group. Available from: https://data.worldbank.org/indicator/SP.POP.TOTL [Accessed: April 20, 2018]

[11] Frenken K. FAO (Food and Agriculture Organization of the United Nations). Irrigation in the Middle East Region in Figures (Water Reports 34). Rome, Italy: Food and Agriculture Organization of the United Nations (FAO); 2008

[12] Shahin S, Ajaj R, Salem M. Climate change and food security: Bridging the interaction gaps for future integrity. In: Proceedings of The Transitioning Cereal Systems to Adapt to Climate Change. Minneapolis, USA; 13–14 November, 2015. p. 41

[13] Shahin S, Salem M. The innovative perspective of arid land agriculture: Essential oil-bearing plants as factories for a healthy and sustainable future. Presented in the Annual Meeting of Crop Science Society of America (CSSA), Synergy in Science: Partnering For Solutions, Minneapolis, USA; 15–18 November. ACSESS Digital Library; 2015

[14] Sonwa MM, König WA. Chemical study of the essential oil of *Cyperus rotundus*. Phytochemistry. 2001;**58**(5):799-810

[15] Yang L, Chen HX, Gao WY. Advances in studies on chemical constituents in *Euphorbia helioscopia* and their biological activities. Chinese Traditional and Herbal Drugs. 2007;**38**(10):1585

[16] Feizbakhsh A, Aghassi A, Naeemy A. Chemical constituents of the essential oils of *Cyperus difformis* L. and *Cyperus arenarius* Retz from Iran. Journal of Essential Oil-Bearing Plants. 2012;**15**(1):48-52

[17] Nassar MI, Yassine YM, Elshamy AI, El-Beih AA, El-Shazly M, Singab A. Essential oil and antimicrobial activity of aerial parts of *Cyperus leavigatus* L. (Family: Cyperaceae). Journal of Essential Oil-Bearing Plants. 2015;**18**(2):416-422

[18] Miyamoto S, Martinez I, Padilla M, Portillo A, Ornelas D. Landscape Plant Lists for Salt Tolerance Assessment. El Paso, Texas: University Agricultural Research and Extension Center; 2004

[19] Karim FM, Dakheel AJ. Salt-Tolerant Plants of the United Arab Emirates; 2006:1-161

[20] Albert-Baskar A, Ignacimuthu S. Chemopreventive effect of *Cynodon dactylon* (L.) Pers. extract against DMH-induced colon carcinogenesis in experimental animals. Experimental and Toxicologic Pathology. 2010;**62**(4):423-431

[21] Hameed M, Ashraf M, Naz N, Nawaz T, Batool R, Ahmad M, Ahmad F, Hussain M. Anatomical adaptations of *Cynodon dactylon* (L.) Pers. from the salt range (Pakistan) to salinity stress. II. Leaf anatomy. Pakistan Journal of Botany. 2013;**1**(45):133-142

[22] Huang B, Duncan RR, Carrow RN. Drought-resistance mechanisms of seven warm-season turfgrasses under surface soil drying: I. Shoot response. Crop Science. 1997;**37**(6):1858-1863

[23] Shonubi OO, Okusanya OT. The growth and physiological responses of *Paspalum vaginatum* Sw. and *Paspalum scrobiculatum* Linn. in relation to salinity. Asian Journal of Plant Sciences. 2007;**6**(6):949-956

[24] Nawazish S, Hameed M, Naurin S. Leaf anatomical adaptations of *Cenchrus ciliaris* L. from the salt range, Pakistan against drought stress. Pakistan Journal of Botany. 2006;**38**(5): 1723-1730

[25] Akram NA, Shahbaz M, Ashraf M. Nutrient acquisition in differentially adapted populations of *Cynodon dactylon* (L.) Pers. and *Cenchrus ciliaris* L. under drought stress. Pakistan Journal of Botany. 2008;**40**(4):1433-1440

[26] Goergen E, Daehler CC. Reproductive ecology of a native Hawaiian grass (*Heteropogon contortus*; Poaceae) versus its invasive alien competitor (*Pennisetum setaceum*; Poaceae). International Journal of Plant Sciences. 2001;**162**(2):317-326

[27] Shahid M, Rao NK. Saving the UAE's Halfa grass. Tribulus. 2017;**25**:69-70

[28] Hashim GM, Almasaudi SB, Azhar E, Al Jaouni SK, Harakeh S. Biological activity of *Cymbopogon schoenanthus* essential oil. Saudi Journal of Biological Sciences. 2017;**24**(7): 1458-1464

[29] Rabe A, Aliero B, Maishanu H, Maikudi H. Influence of different water frequency on the growth and yield of *Cymbopogon schoenanthus* (Camel Grass). Asian Journal of Research in Agriculture and Forestry. 2018;**1**(1):1-9

[30] Akhter R, Arshad M. Arid rangelands in the Cholistan desert (Pakistan). Science et Changements Planétaires/Sécheresse. 2006;**17**(1):210-217

[31] Naz N, Hameed M, Ashraf M, Ahmad R, Arshad M. Eco-morphic variation for salt tolerance in some grasses from Cholistan Desert. Pakistan Journal of Botany. 2009;**41**(4): 1707-1714

[32] Pitman K, McDonnell R, Dawoud M. EAD (Environmental Agency of Abu Dhabi). Abu Dhabi Water Resources Master Plan. Abu Dhabi, United Arab Emirates: Environment Agency of Abu Dhabi (EAD); 2009

[33] Jongbloed M, Feulner G, Böer B, Western AR. The Comprehensive Guide to the Wild Flowers of the United Arab Emirates. Abu Dhabi, United Arab Emirates: Environmental Research and Wildlife Development Agency; 2003

[34] Western RA. The Flora of the United Arab Emirates: An Introduction. Al Ain, United Arab Emirates: United Arab Emirates University Publications; 1989

[35] Sakkir S, Kabshawi M, Mehairbi M. Medicinal plants diversity and their conservation status in the United Arab Emirates (UAE). Journal of Medicinal Plant Research. 2012;**6**(7): 1304-1322

[36] Khan TI, Dular AK, Solomon DM. Biodiversity conservation in the Thar Desert; with emphasis on endemic and medicinal plants. The Environmentalist. 2003;**23**(2):137-144

[37] Shahi AK, Tava A. Essential oil composition of three *Cymbopogon* species of Indian Thar desert. Journal of Essential Oil Research. 1993;**5**(6):639-643

[38] Verón SR, Blanco LJ, Texeira MA, Irisarri JGN, Paruelo JM. Desertification and ecosystem services supply: The case of the Arid Chaco of South America. Journal of Arid Environments. 2017

[39] Schütze N, Kloss S, Lennartz F, Al Bakri A, Schmitz G. Optimal planning and operation of irrigation systems under water resource constraints in Oman considering climatic uncertainty. Environment and Earth Science. 2011;**65**(5):1511-1521. DOI: 10.1007/s12665-011-1135-4

[40] Salem MA, Al-Zayadneh W, Schulze HF, Cheruth AJ. Effect of nano-hydrophobic sand layer on Bermudagrass (*Cynodon* spp.) in urban landscaping. Urban Water Journal. 2014;**11**(2):167-173