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Mitigating Water Loss in Arid Lands: Buffelgrass as a Potential Replacement for Alfalfa in Livestock Feed

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Abstract: In the dry regions of the Arabian Peninsula, such as Saudi Arabia, rangeland degradation and the decline of pasture species have significantly reduced phytomass production. The scarcity of grazing pastures has led to an expansion of alfalfa-irrigated fields, exacerbating the risk of water shortages. This study is the first to systematically evaluate the adaptability and production potential of *Cenchrus ciliaris* accessions in the arid environment of Saudi Arabia. The objective of this study is to evaluate the potential of buffelgrass (*C. ciliaris*) as an alternative to alfalfa in irrigated crop systems for livestock production and to assess its suitability for reintroduction into degraded rangelands to enhance forage production. For this purpose, accessions of *C. ciliaris* were collected from five different sites in northern Saudi Arabia (Aja, Jameen, Zaitoun, Gaed, and Industrial zone) to select the most vigorous ecotypes to be introduced in the degraded lands and/or to be used as irrigated forage crop. This study shows that under full irrigation (2500-3000 mm year^{-1}), alfalfa can produce 11.9 t ha^{-1} to 22.6 t ha^{-1} with a five-year average of 17 t ha^{-1}. However, *C. ciliaris* can produce 9.3–18.4 t ha^{-1} with less water consumption than alfalfa (water supply is estimated at 400–500 mm year^{-1}). The average was about 14.1 t ha^{-1}. Our comparative study of these accessions showed that the Aja accession seemed to be the most salt tolerant, whereas the Jameen accession was the most well-developed, productive (18.4 t ha^{-1}), and overgrazing resistant accession (940.3 g plant^{-1} after 3 cuts). Therefore, the Jameen accession is recommended for rangeland rehabilitation. In terms of chemical composition, *C. ciliaris* was less protein rich than alfalfa, but this can be compensated for by its high digestibility, estimated by neutral detergent fiber (NDF of 69.6%). This study identifies the Gaed and Jameen accessions as the most productive and grazing resistant, exhibiting drought and salt tolerance, making them suitable for use in irrigated systems to produce high green- and dry-matter yields or for reintroduction to rehabilitate degraded rangelands for rehabilitation purposes.

Keywords: *Cenchrus ciliaris*; climate change; degraded rangelands; drought tolerance; forage improvement; irrigated crops; overgrazing

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1. Introduction

In the Middle East region, particularly in the Arabian Peninsula countries, the combined effects of climate change, livestock pressure, and predominant aridity have resulted in the degradation and disturbance of natural rangelands [1,2]. The limited flora and the overexploitation of natural resources have heightened the vulnerability of local populations to incidents such as drought or flooding [3]. However, in these regions, overgrazing is considered as the most impactful factor in grassland disturbance and degradation [4,5]. In Saudi Arabia, pastoralists who seasonally migrate from northern to southern areas and from wetter zones to dry steppes, manage a substantial number of livestock—including camels, sheep, goats, and cattle—estimated to be about 3.5 million head, which graze on poorly maintained dry rangelands [6]. Additionally, the long history of human settlement, irregular access to green lands, and increasing urbanization have exacerbated degradation of rangeland resources [7,8].

Saudi population growth, along with the rise of dairy industries, has led to unanticipated shortages of grass forage resources and food inefficiency for livestock production [7]. To achieve forage self-sufficiency, the Saudi government has encouraged private farmers to cultivate forage species such as alfalfa (*Medicago sativa*) and Rhodes grass (*Chloris gayana*). Incentives include arrangements for very low water and land prices for crop production. As result of this policy, many private fields were created, and alfalfa was chosen as the primary target forage crop in recent decades [9]. The total area planted with forage crops in Saudi Arabia, especially alfalfa, increased from 151,301 ha in 2007 to 187,078 ha in 2011 [10]. In 2017, the area cultivated by alfalfa was estimated at 236,800 ha, representing 28.8% of the total cultivated area [11]. However, this expansion has significantly strained water resources. The extensive use of water, particularly groundwater, has caused an alarming decline in water reserves, potentially leading to complete groundwater depletion within the next 25 years. In 2020, it was estimated that total consumed water was about 15,979 million m^3 [12], with the volume of irrigation water being 10,670 million m^3 (67%). Forage is a significant crop in Saudi Arabia, representing 42% of total biomass production and consuming 12% of water resources in 2020 [12]. Old alfalfa fields, especially in the absence of crop rotation, become highly susceptible to weed infestations [9,13] and pest attacks [14]. Nodule infections caused by bacteriophages significantly reduce nitrogen fixation, leading to notable crop yield declines [15].

Around the world, the production of staple food crops is steadily declining and becoming increasingly unpredictable due to climate change [16]. This poses a serious threat to the livelihoods of farming communities and has a negative impact on global food and nutrition security. Climate change is manifested by rising temperatures, decreasing rainfall, and prolonged droughts [2,17,18]. In Saudi Arabia, a recent study reported a 1.9 °C increase in temperature between 1967 and 2016 [19], while rainfall remained sparse and showed no significant change. The study also concluded that a 1 °C rise in temperature reduces crop yields by 7–25%. In response to the ongoing groundwater depletion crisis, the Saudi government is currently considering regulations to phase-out forage production and encourage enterprises to invest in forages with higher water use efficiency and nutritive value [20].

Buffelgrass (*Cenchrus ciliaris*), a C4 perennial grass in the Poaceae family, is an important wild forage species due to its high pastoral value [21]. This plant is cultivated in tropical and subtropical regions [22] and can grow in a diverse range of environments, including challenging deserts [23]. Buffelgrass is a drought-tolerant, fire-adapted plant with a rapid growth rate. It is also characterized by substantial root storage capacity [24–26]. These traits make it desirable for cattle pasture introductions and sustainable forage production [25,26].

Globally, buffelgrass is recognized for its high diversity [27–29] and adaptability to various environments, resistance to drought and warm climates [30], and its ability to withstand heavy grazing. In fact, under no-input production conditions, it can produce 18 t DM (dry matter)/ha/year [31] with an endogenous protein content of 6–16% [30,32]. Reported yields of buffelgrass vary across regions, with production reaching 7 t/ha in Pakistan [33], 8 t/ha in the USA [34], 12 t/ha in Kenya [35,36], and 21 t/ha in Ethiopia [37]. Thus, due to its high productivity, certain nations, including as Australia, the United States, and Pakistan, now cultivate it as a primary source of animal feed. Recently, it has been shown that silage obtained from different buffelgrass genotypes presented good to medium qualities [28]. Moreover, certain *C. ciliaris* genotypes, such as IG96-401 and IG96-96, selected from various sites in Pakistan, exhibited feeding values comparable to maize silage for parameters including nutrient utilization, intake, nutritive value, nitrogen balance, and rumen fermentation, suggesting that *C. ciliaris* genotypes could provide promising alternatives to maize silage [28]. The chemical composition of fodder is a key factor in determining its nutritional value. Some reported accessions of *C. ciliaris* exhibited a crude protein level exceeding 70.0 g kg^{-1} DM, necessary for continuous rumen microbial function [38] and for maintaining beef cattle.

Buffelgrass was first reported in restricted areas of the Hail region in northern Saudi Arabia [39], growing with *Rhus tripartita*, *Aerva javanica*, *Ephedra foliata*, and *Astragalus spinosa* in small communities in shaded areas and crevices [40]. Local shepherds in Hail province noted that *C. ciliaris* has disappeared from many rangelands, as it was one of the well-known pastoral species threatened by overgrazing [41]. Overgrazing in degraded range lands seems to be the fundamental cause of the rarity of *C. ciliaris* due to its high resistance to severe environmental and climatic conditions. Notably, during periods of severe drought, this species can persist while neighboring forage species decline [40].

Saudi Arabia is facing severe groundwater depletion due to the extent and intensity of its irrigated agriculture (cereal and vegetable crops) and especially the cultivation of alfalfa as livestock feed [42–44]. The research reported here aims to: (i) establish a sustainable development system through the use of plant species, such as buffelgrass, known for high productivity and forage quality but relatively low water consumption [45]; (ii) collect various accessions of *C. ciliaris* from the Hail region of northern Saudi Arabia and evaluate their morphological characteristics and productivity performance; and (iii) compare the nutritive value of the most vigorous accessions with that of alfalfa.

2. Materials and Methods

2.1. Alfalfa Fields

Alflafa cultivation was evaluated on 28 private fields chosen randomly in northern Saudi Arabia, all of which were managed in a similar manner by the owners, where the variety Osaila is being grown.

Studied fields lie between longitudes 41°09′ and 43°01′ E and latitudes 27°30′ and 28°07′ N. According to the records of the local metrological station (weather station: 403,940 (OEHL); Latitude: 27.43; Longitude: 41.68; Altitude: 1015 m), monthly mean temperature ranges from 10 °C to 37 °C and annual rainfall was about 200 mm during whole experimental period. Alfalfa seed sowing begins in early October, with a mean seeding rate of 30 kg ha^{-1} [46,47]. Herbicide treatment for controlling broadleaf and grassy weeds (with Clethodim and Metribuzin) and fertilizing with phosphorus, potassium, and sulfur were accomplished at the seedling stage [48,49]. Seedlings were often irrigated twice a week. Once established, fields were often irrigated twice a week in the hot season with a quantity of water estimated at 2500–3000 mm $year^{-1}$. Underground water was utilized for center-pivot irrigation.

2.2. Alfalfa Forage Yield and Interval Cutting

Crop yields were evaluated over consecutive regrowth cycles, starting from the first cut of the pasture (conducted 90 days after sowing) and for five to eight subsequent regrowth cycles, ranging from the beginning of winter to early summer. The phenological stage at cutting was at early flowering, corresponding to a plant length of 45 cm. Cuttings were conducted by machines 5 to 7 cm above ground level. The harvested biomass was typically pressed into separated bales of hay and weighed before transferring to the local market.

2.3. Germination, Yield and Overgrazing, and Diversity of *Cenchrus ciliaris*

Ten accessions were initially collected from various ecological habitats in the Hail area, with five retained for evaluation due to the short distance between some accession sites (Table 1; Figure 1). Accessions were selected based on their ecological representativeness and genetic diversity [50]. Cultivar references refer to accessions of *C. ciliaris* selected based on agronomic and pasture characteristics, which have subsequently been commercialized [51,52].

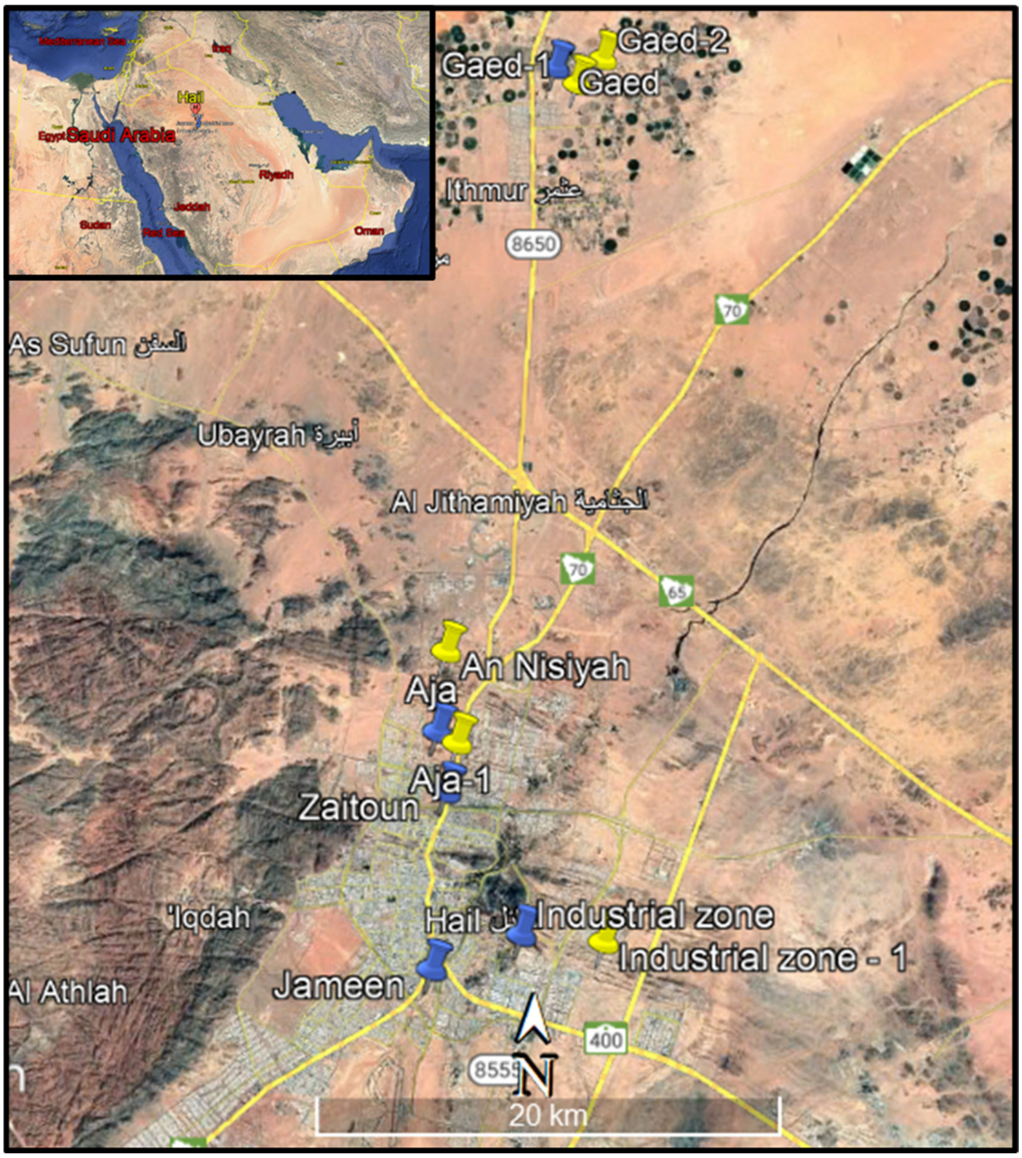

Figure 1. Localities of the accessions of *Cenchrus ciliaris* in Hail region, Saudi Arabia.

Table 1. Coordinates and elevation of collect zones of different accessions.

	Studied Accession names				
	Aja	Jameen	Zaitoun	Gaed	Industrial zone
Coordinates	27°34′30.82″N 41°41′35.69″E	27°28′56.87″N 41°41′47.35″E	27°33′5.52″N 41°41′55.08″E	27°51′27.45″N 41°43′55.26″E	27°29′47.79″N 41°44′7.04″E
Elevation (m)	981	987	980	861	981
	Discarded accession names				
	An Nisiyah	Aja-1	Gaed-1	Gaed-2	Industrial zone-1
Coordinates	27°36′27.47″N 41°41′43.62″E	27°34′15.94″N 41°42′9.51″E	27°51′2.87″N 41°44′34.58″E	27°51′43.93″N 41°45′17.19″E	27°29′41.25″N 41°46′19.29″E
Elevation (m)	986	973	854	847	996

Seed collection was conducted at the end of summer 2020, with collections made at Jameen, Aja, Zaitoun, Gaed, and The Industrial zone. Geographic coordinates were recorded using GPS. The experiment was conducted during the period 2021–2023. The region has an arid climate. The mean annual precipitation is 200 mm with a maximum temperature of 49 °C, a minimum temperature of −2 °C, and an annual average of 22.3 °C. Seed germination trials were conducted in 9-cm sterile Petri dishes lined with two Whatman No. 1 filter papers and irrigated by 10 mL of aqueous solutions, with two salt concentrations and a salt-free control (0 g/L, 2 g/L, 4 g/L) based on a preliminary test for salt tolerance. Petri dishes (in three replications) were placed in an incubator for 20 days at a constant 25 °C (optimal temperature for *C. ciliaris*), at 50% RH, and a photoperiod of 12 h light/12 h dark.

The forage productivity of *C. ciliaris* was measured at a private farm that has been used previously for cultivating alfalfa, located in the Gaed region (27°47′58.81″N; 41°45′48.96″E; Elevation of 871 m). The soil of that farm was a typical, arid soil, which has sandy texture, clay 9%, carbonate calcium 22%, low organic matter 1%, and pH 8. The field was divided into three parallel blocks in which the five accessions were laid out in a randomized complete block design. Each block consisted of a series of five accessions. Accessions were established in four consecutive rows spaced 0.25 m apart. Each row contained five seedlings spaced 0.20 m apart (twenty seedlings/m^2) [53]. Seedlings of similar size was planted at the end of the summer 2020 after lab germination. Plots were fertilized with 70 kg N ha^{-1} and 78 kg P_2O_5 ha^{-1} in March of each year. The first cut was conducted in mid-spring 2021 after the flowering stage; cuts were conducted regularly after 1 month. Overgrazing was simulated by three clipping times that corresponds to times of herbivory grazing. Irrigation (20 mm/irrigation) was conducted twice a week during summer and once a week during autumn and spring (no irrigation was conducted during the winter dormant period). A total volume of 400–500 mm of water was applied yearly (in addition to the rainfall, which averages 200 mm). This quantity is estimated to be 1/5 of that used in alfalfa irrigation.

2.4. Dry Matter, Chemical Composition and Digestibility

Both buffelgrass and alfalfa samples were analyzed for dry matter (DM), crude protein (CP), crude fat (CF), and crude fiber (CFi) by AOAC methods of analysis [54]. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were determined following [55]. Total digestible nutrients (TDN) were calculated by the equation described by Wardeh [56]. Calcium (Ca^{2+}) was estimated by incinerating the samples in a muffle oven at 55 °C for 4 h. Ashes were digested in a solution containing HCl and HNO_3 using the wet digestion technique [57] and concentrations of Ca^{2+} were estimated by using an atomic absorption spectrophotometer with an air/acetylene flame. The P content was determined using a colorimeter according to AOAC methods [54].

2.5. Statistical Analysis

Data were statistically analyzed with SPSS, version 17.0. One-way ANOVA was used to evaluate differences in yield among accessions, with a significance level set at $p < 0.05$.

3. Results

3.1. Alfalfa Crop

Alfalfa fields can be exploited for three to five years before needing to be converted to another crop as part of a crop rotation cycle. Forage yield (D.M.Y/cut) was higher during the three first years (from 2.46 ± 0.24 to 3.08 ± 0.16 t ha^{-1}) and decreased in the fourth and fifth years due to weed invasion (1.72 ± 0.34 t ha^{-1}). The average was 2.27 ± 0.52 t $ha^{-1}cut^{-1}$. Differences in dry matter yield between years were significant (F = 7.18; p-value = 0.002; $p < 0.005$). Alfalfa annual yield ranged from 11.94 to 22.66 t ha^{-1} with an average of 17 ± 5.3 t ha^{-1} after 6–7 cuts. The differences among annual yield were also highly significant (F = 38.08; $p < 0.001$). During this period of study, alfalfa density decreased significantly (F = 32.79; $p < 0.001$) from 186.8 ± 31.6 plant m^{-2} in the first year to attained 61.8 ± 27.2 plant m^{-2} in the fifth year (Table 2).

Table 2. Alfalfa density and dry matter yield (DMY), weed density, and intervals between cuts, organized to the field age, as measured on 28 fields in the Hail region, Saudi Arabia.

	1st Year		2nd, 3rd Year	4th, 5th Year	Mean
Cut number	1st cut	4–5	8–10	5–6	6–7
Time interval (days)	90	60	40	50	50
D.M.Y/cut (t ha^{-1})	3.08 ± 0.16	2.46 ± 0.24	2.34 ± 0.28	1.72 ± 0.34	2.27 ± 0.52 **
Annual yield (t ha^{-1})	16.42 ± 0.70		22.66 ± 1.1	11.94 ± 0.58	17 ± 5.3 **
Alfalfa density (plant m^{-2})	186.8 ± 31.6		171.5 ± 23.7	61.8 ± 27.2	140 ± 68 **
Income (USD/Year/ha^{-1})	3415 ± 27		4532 ± 82	2149 ± 61	3365 ± 56
Weed Control Cost (USD/Year/ha^{-1})	<50		50 < Cost < 100	100 < cost < 200	50 < cost < 200

**: $p < 0.005$.

Weed invasion also has a negative impact on annual incomes. During the first year, with proper management, revenue can reach 3415 ± 27 (USD/Year/ha^{-1}) with only a loss of 50 (USD/Year/ha^{-1}) for weed control. Incomes in the second and third years were the best, with an average of 4532 ± 82 (USD/Year/ha^{-1}) and a weed control loss <100 (USD/Year/ha^{-1}). In the fourth and fifth years, alongside the increase of herbicide use to about 200 USD/Year/ha^{-1}, incomes decreased to 2149 ± 61 USD/Year/ha^{-1}. Crop loss was also attributed to lower prices received, especially in the fourth and fifth years, because of decreased hay quality.

3.2. Germination of *Cenchrus ciliaris*

Seed germination of *C. ciliaris* of all accessions was highest in distilled water (0 g NaCl/L). During the experiment period, the survival rate presented the same behavior trend. The *C. ciliaris* seeds established well under moderate rainfall conditions, equivalent to 250 mm. The highest germination rate was observed at Aja accession with 100% of germination. The increase in salt concentration in water was followed by a decrease in germination percentage. Aja was the most salt tolerant accession, germinating fully at 2 g NaCl/L after 20 days. Jameen was the most sensitive accession to salt with 0% germination in 2 and 4 g NaCl/L (Figure 2).

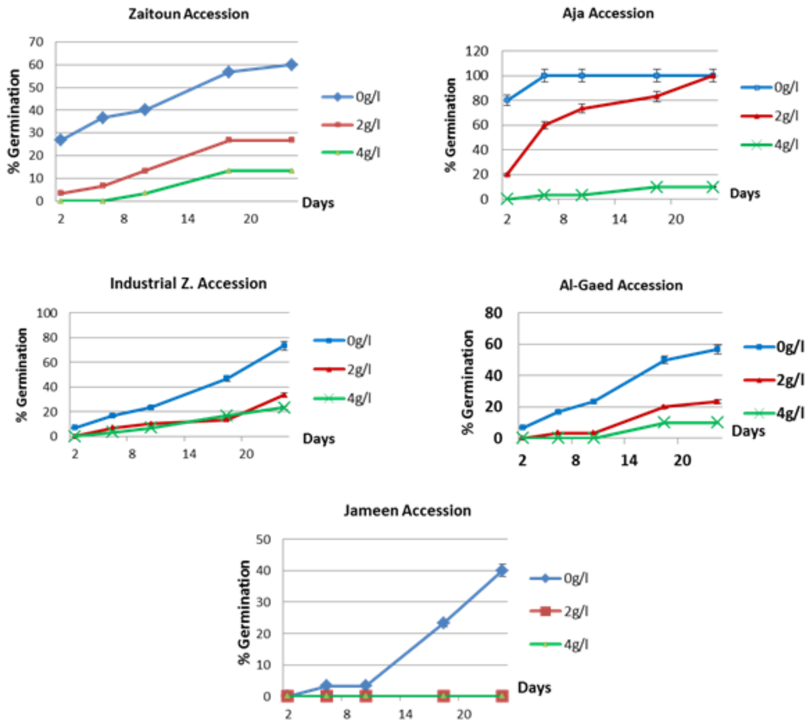

Figure 2. Effect of salt concentrations on the germination of different accessions of *Cenchrus ciliaris* in Saudi Arabia (Hail Region).

3.3. Morphological Diversity

There was considerable diversity in all measured characteristics. The averages of all morphological traits are reported in Table 3. Plant Length (PL) varied between 67 and 110 cm and plant diameter (PD) from 54 to 96.7 cm. The Jameen accession was largest, with a mean plant length of 110 cm and plant diameter of 86 cm. Dwarf tufts were observed in the Industrial zone accession, which had PL of 69.7 cm and PD of 54 cm. Leaf length (LL), as a significant forage parameter, varied from 12.3 cm in the Zaitoun accession to 34 cm in the Jameen accession, which was considered to be the best developed. Branch number (BN) ranged between 3.3 and 7 and was best developed in the Industry-zone accession. Many spikes (SP) is an undesirable forage-quality trait; it varies from 7 in the Zaitoun accession to 12.7 cm in the Aja accession (Table 3).

Table 3. Six morphological parameters of different accessions of *Cenchrus ciliaris* from Northern Saudi Arabia and a list of similar cultivars. Parameter values are means ± SE of all accession replicates. Different lower-case letters indicate a significant difference among different levels of each parameter.

Accession	PL (cm)	PD (cm)	ST (cm)	LL (cm)	BN	SP (cm)	Similar Cultivar
Indust. Z.	69.7 ± 9.1 c	54.0 ± 7.9 e	72.7 ± 7.6 c	16.0 ± 1.0 c	7.0 ± 1.0 a	10.0 ± 1.0 b	Gayndah
Gaed	105.0 ± 5.0 a	96.7 ± 2.9 a	71.7 ± 3.2 c	24.0 ± 1.0 b	5.3 ± 0.6 b	11.7 ± 0.6 a	Biloela
Jameen	110.0 ± 17.3 a	86.7 ± 11.5 b	104.0 ± 7.9 a	34.0 ± 1.0 a	4.0 ± 1.0 c	11.7 ± 2.1 a	Bergbuffel
Aja	86.7 ± 5.8 b	73.3 ± 2.9 c	78.3 ± 7.6 a	25.0 ± 2.0 b	3.3 ± 0.6 d	12.7 ± 1.2 c	Gayndah
Zaitoun	67.0 ± 2.6 c	66.0 ± 1.0 d	59.3 ± 5.1 d	12.3 ± 2.5 d	6.7 ± 1.2 a	7.0 ± 0.0 d	Gayndah
Average	87.7 ± 19.9	75.3 ± 16.5	77.2 ± 16.3	22.3 ± 8.0	5.3 ± 1.7	10.6 ± 2.3	
P	0.000	0.000	0.000	0.000	0.002	0.001	

PL: Plant length; PD: Plant diameter; ST: Stem length; LL: Leaf length; BN: Branch number; SP: Spike length.

Based on our germination and morphological measurements, the Jameen accession resembles the cultivar "Bergbuffel"; meanwhile, the Gaed accession has a closer affinity to the 'Biloela' cultivar. Accessions from the Industrial zone, Aja, and Zaitoun have more similarities with the 'Gayndah' cultivar.

3.4. Dry Matter Yield and Resistance to Overgrazing

As reported in Table 3, the Jameen accession was the most productive, with a cumulated forage dry matter (DM) of 513.3 ± 25.2 g plant^{-1}. The lowest productivity was observed at the Industrial-Zone accession with a yield of 254.7 ± 9.5 g. Based on the accumulation of dry matter after three cycles of cutting, the Al-Gaed and Jemeen accessions have shown better performances in term of resistance to overgrazing. Presenting better regrowth after each cutting, these accessions yielded 940.3 ± 37.4 g and 866.7 ± 32.5 g of accumulated dry matter, respectively (Table 4).

Table 4. Dry-matter yield and resistance to overgrazing (OVG) for different accessions. Different lower-case letters indicate a significant difference among different levels of each parameter.

Ac	Dry Matter DM (g)			Overgrazing OVG (g)			Yield (t ha^{-1})
Indust. Z.	254.7	±	9.5 ^{d}	501.7	±	25.6 ^{b}	9.3 ± 1.2 ^{c}
Gaed	492.7	±	8.0 ^{a}	866.7	±	32.5 ^{a}	16.9 ± 22.3 ^{a}
Jameen	513.3	±	25.2 ^{a}	940.3	±	37.4 ^{a}	18.4 ± 1.6 ^{a}
Aja	392.7	±	6.4 ^{a}	654.6	±	14.9 ^{b}	13.8 ± 2.1 ^{b}
Zaitoun	337.3	±	22.7 ^{bc}	580.8	±	36.4 ^{b}	12.0 ± 1.4 ^{b}
Average	398.1	±	100.8	708.8	±	29.3	14.1 ± 3.6
P		0.000			0.069		0.012

The average forage yield of *C. ciliaris* was estimated 14.1 ± 3.6 t ha^{-1}. Jameen was the most productive accession with a yield of 18.4 ± 1.6 t ha^{-1}; the Industrial zone accession was the lowest with a yield of 9.3 ± 1.2 t ha^{-1}.

The Jameen accession, followed by the one from Gaed, was the most productive for dry matter and crop yield. Their robust shoot systems, characterized by well-developed stems and leaves, along with their strong grazing resistance, make them ideal candidates for rangeland improvement and use in semi-irrigated systems.

3.5. Correlations

Dry matter (DM) yield was highly and positively correlated with plant length (PL) and plant diameter (PD), whereas a negative correlation was observed with the number of stem branches (BN) (Table 5). No significant correlation was observed between germination percentage (GER) and any morphological or yield parameters. Spike length (SP) was positively correlated with vegetative parameters (PL, ST, and LL) and showed that the most developed plants also produced the longest spike. All these parameters were also positively correlated with dry matter yield (DM).

Table 5. Correlations between the plant parameters. PL: Plant length (cm); PD: Plant diameter (cm); ST: Stem length (cm); LL: Leaf length (cm); BN: Branch number; SP: Spike length (cm); DM: Dry matter. plant^{-1} (gr); OVG: Resistance to overgrazing (gr); DEN: density (plant.m^{-2}); GER: Percentage of germination (%).

	PL	PD	ST	LL	BN	SP	DM	DEN	GER
PL	1								
PD	0.915 **	1							
ST	0.725 **	0.437	1						
LL	0.821 **	0.638 *	0.863 **	1					
BN	−0.578 *	−0.478	−0.566 *	−0.744 **	1				
SP	0.549 *	0.411	0.594 *	0.700 **	−0.568 *	1			
DM	0.892 **	0.925 **	0.565 *	0.794 **	−0.587 *	0.454	1		
DEN	−0.859 **	−0.902 **	−0.515 *	−0.633 *	0.427	−0.512	−0.783 **	1	
GER	−0.21	−0.113	−0.251	−0.194	−0.343	0.062	−0.217	0.049	1

**: Correlation is significant at the 0.01 level. *: Correlation is significant at the 0.05 level.

3.6. Comparison Between Alfalfa and Buffelgrass for Yield, Chemical Composition, and Digestibility

In our irrigated trials, forage yield of C. ciliaris ranged from 9.3 to 18.4 t ha^{-1}, not much less than yields produced by alfalfa, which varied from 11.94 to 22.66 t ha^{-1} in the same study area (Table 6). This study shows that, with about 80% reduction the water volume consumed by alfalfa, C. ciliaris could replace alfalfa as a good forage source for Saudi Arabia's arid regions. Additionally, C. ciliaris is a C4-xerophytic species, capable of surviving prolonged periods of drought. In contrast, alfalfa, a typical C3 plant, cannot withstand extended arid conditions. But what about nutrient values when comparing these two species?

Table 6. Buffelgrass (*Cenchrus ciliaris*) and alfalfa (*Medicago sativa*) crop yields in the current study and literature reports.

	Yield (t ha^{-1})	Irrigation (YES/NO)	Cuts Number/Year
1- *Medicago sativa*			
Actual study	11.94–22.66	Yes, 2500–3000 mm/year	5–10 cuts
[58]	2.21–5.33	Yes, 1140–1220 mm	
[59]	16.36	Yes	5–6 cuts
2- *Cenchrus ciliaris*			
Actual study	9.30–18.4	Yes, 400–500 mm	4
[60]	2.94–26.16	Yes, 480 mm	4 cuts (Seasonal)
[61]	0.50–3.00	No, rain 180–250 mm	3–4
[34]	2.90–9.35	No, rain 122–740 mm	3 cuts
[62]	3.36–5.84	No, rain 320–560 mm	3

Aja, Zaitoun, and the Industrial zone were similar to the Gayndah cultivar whereas Gaed was similar to the Biloela cultivar and Jameen was similar to Bergbuffel, the latter of which presented a remarkable genetic variation, found using ISSR markers [50].

Differences in chemical composition and nutrient values of alfalfa and buffelgrass are presented in Table 7. Dry matter (%) and crude fat (%) were comparable for both species, while it is clear that alfalfa, as a legume, was more protein-rich than buffelgrass and, thus, highly valued by local dairy farmers (Table 6). Buffelgrass, despite its low protein content compared to alfalfa, has higher digestibility (ADF, NDF, TDN), making it a promising replacement for alfalfa as a perennial forage crop with higher water-use efficiency. Moreover, the richness of P and Ca^{2+} in buffelgrass compared with alfalfa is an important asset for dairy industries (Table 6).

Table 7. Chemical composition and in vitro digestibility of alfalfa and buffelgrass. TDM: total dry matter production; NDF: neutral detergent fiber; ADF: acid detergent fiber, TDN: total digestible nutrients, Ca^{2+}: calcium, P: phosphorus.

Nutrient (% DW)	Alfalfa	Buffelgrass
Dry matter	90.30 ± 5.40	88.00 ± 4.70
Crude protein	20.60 ± 2.40	8.30 ± 0.10
Crude fat	2.36 ± 0.13	3.10 ± 0.17
Crude fiber	23.60 ± 1.33	29.20 ± 3.30
ADF	35.60 ± 3.40	49.90 ± 0.30
NDF	41.90 ± 2.10	69.60 ± 0.50
TDN	60.22 ± 3.70	63.20 ± 3.50
Ca^{2+}	1.23 ± 0.10	3.32 ± 0.87
P	0.25 ± 0.02	0.81 ± 0.11

4. Discussion

Water depletion is a major factor contributing to the conversion of extensively cultivated land into deserts worldwide [63,64]. The expansion of rain-fed mixed farming to uplands and the increasing pressure of livestock exacerbated by urban expansion are significant challenges faced by all countries in the Arabian Peninsula. In this work, we have reported that alfalfa culture use consumes a significant quantity of groundwater. The high-water consumption by alfalfa culture was also reported by previous studies [58,65]. To search for an alternative to alfalfa in water depletion conditions, we have shown that *C. ciliaris* in the *Poaceae* family can improve biomass production under low water irrigation. The vigor of the water use efficiency of this species makes it a good candidate for arid rangelands [66] and salty soils [67].

Worldwide, as a potential forage species, *C. ciliaris* has become very rare in its native habitats and has even disappeared in open arid rangelands [68–70].

On the other hand, in response to livestock's food needs, excessive alfalfa cultivation provokes water reserve shortages for human use. *C. ciliaris* exhibits rapid spread and remarkable adaptability to different environments; thus, it is widely planted and considered a replacement in the restoration of degraded rangelands. Various practices, such as soil moisture conservation and rainwater harvesting, could help improve grass establishment in pastures vulnerable to water loss in arid regions [71].

Crop productivity and performance are determined by genotypic expression, which is shaped by dynamic environmental interactions. Salinity and drought are the two most significant stressors that restrict forages, especially grasses, in Saudi Arabia. In water-deficient areas, certain grass species can provide high dry yields, proteins, and energy while growing under low water conditions. In this study, we selected five genetically divergent accessions (Aja, Industrial zone, Gaed, Zitoun, and Jameen) of *C. ciliaris* [50]. The Jameen accession was identified as the most productive (18.4 t ha^{-1}) and the most-resistant to grazing (944.3 g after 3 cuts) (Table 4); however, it was sensitive to salt stress, as its seeds did not germinate in 2 g/L NaCl (Figure 2). Productivity of the Jameen accession was followed by the Gaed accession, which yielded of 16.9 t ha^{-1} and accumulated dry matter of 866.7 g after the cuts. Recent work concluded that *C. ciliaris* can easily be grown in salt affected areas by providing anatomical modifications that seem to be critical for the better survival under harsh sandy and salty environmental conditions [67].

In arid and semi-arid regions, forage grasses are known to be the best feed for ruminant livestock. However, quality of forage of those grasses does vary depending on such factors as crude fiber, crude protein (CP), and ash contents [72]. Interestingly, CP is considered a vital element of animal feed that can increase milk-production [73]. In the present study, *C. ciliaris* produced high CP levels at low to medium salt concentrations (up to 200 mM) as previously shown in another study [74].

One of the motivations for our study is the significant morphological and physiological diversity of *C. ciliaris* [28], which our results confirmed for accessions from the Hail region of northern Saudi Arabia. Similarly, Visser et al. [75] and M'seddi et al. [53] found significant variations among 47 accessions of buffelgrass from southern Tunisia for 12 traits related to seeds and spikes. Recently, Negawo et al. [76] reported variations in nutritional quality and agronomic traits among different Buffelgrass accessions, suggesting a rich genetic variation in selected lines that could aid in the development of superior cultivars. Additionally, our work showed interannual differences in all traits, suggesting close ties between *C. ciliaris* performance and current environmental conditions, confirming earlier work [31,76]. High morphological diversity can be used for multiple purposes. For harvesting hay, taller and more erect plants, i.e., the Jameen accession, might be the most suitable. For use in natural resource management and for soil stabilization, *C. ciliaris* accessions which are shorter, more prostrate, and more rhizomatous, i.e., Industrial Zone accession, should be selected, as they would provide better ground cover. Types with strong rhizomes would also protect steep slopes and stream banks from erosion [77].

Different traits such as biomass yield and feed quality are crucial parameters in the improvement of forage. Comprehending the link between biomass yield and feed quality characteristics, along with the genetic foundation of this connection, is crucial for breeding initiatives. Recent studies have also reported a positive correlation between biomass yield and plant height in certain *C. ciliaris* accessions [76,78].

Spike length is an important reproductive trait. Not appreciated as an indicator of forage quality, spike traits can be helpful seed production. Except for the Zaitoun accession, which has small spikes (7 cm), all other accessions produce spikes from 10 to 12.7 cm long. At the close of our study, seed production for potential restoration initiatives took place at the Station for the Propagation of Pastoral-Plant Seeds in the Hail region. Seeds were cleaned by removing extra leaves and waste, then collected in cloth bags for storage in the station's seed bank.

For crop improvement, our *Cenchrus* plots were fertilized with 70 kg N ha^{-1} and 78 kg P_2O_5 ha^{-1}. This fertilization strategy has been shown to double buffelgrass yields or even multiply them three or four times [34,61]. However, without a good nitrogen source, Tmannetje and Davis reported that buffelgrass gradually disappeared and was replaced by unsown species [79]. The encouraging results of the current study suggest that using *C. ciliaris* in mixed cropping would be an efficient way to improve forage quality. Such an approach was proposed by Tmannetje and Jones [79], who recommended a mixed cropping of alfalfa with buffelgrass to improve forage quality with less or no N-fertilization. For instance, mixed cropping of alfalfa (*Medicago sativa*) with annual ryegrass (*Lolium rigidum*) [80] or Rhodes grass (*Chloris gayana*) [81] can improve forage production in rangeland and field conditions, since ryegrass and Rhodes consume less water while alfalfa improves the hay quality. Another rationale for replacing alfalfa with buffelgrass is its water use efficiency. In our study with limited irrigation, *C. ciliaris* yielded between 9 and 18 t ha^{-1} with only 400 to 500 mm additional water yearly. In contrast, growth parameters of alfalfa crops were significantly affected by different irrigation treatments [58]. Under normal irrigation conditions (2500–3000 mm/year), crop yields were estimated at 11 to 22 t ha^{-1}. Mean alfalfa dry forage (hay) yield ranged only from 2.21–5.33 t ha^{-1} in different irrigation treatments in the range of 1140–1220 mm [58]. Abdullah [60] recorded 26.16 t ha^{-1} while Theunissen [82] mentioned that buffelgrass can reach 30 t ha^{-1}. This finding showed that alfalfa dry hay could be severely affected under water stress irrigation management.

Salt tolerant accessions can be used in saline soil, whereas overgrazing resistant varieties should be used for regeneration of degraded natural rangelands. Such activities can be achieved by enclosure establishment on highly damaged and degraded rangelands, which accelerates the natural restoration [4]. In the same way, [78] reported that *Cenchrus biflorus* can be a potential candidate for rangeland rehabilitation purposes in arid environments. Irrigation conditions for *C. ciliaris* employed in our study are consistent with findings from other researchers, such as Rao [61], who found that crop yields under rainy conditions reached peak levels on both fertilized and non-fertilized plots at between 180 and 250 mm of growing-season rainfall, and Abu-Alrubet al. [83], who reported that under high precipitation and soil fertilization, yields of *C. ciliaris* can reach 9.5 t ha^{-1}.

Growth of *C. ciliaris* peaked when both warm temperatures and important precipitation events or sufficient soil moisture coincided; however, it can also grow at a slower rate during cooler weather than many other tropical grasses [84]. Thus, significant seasonal changes in biomass were observed in *C. ciliaris* over the course of the year. Despite this limitation, Hussey and Bashaw [85] selected a cultivar of buffelgrass, '409-704', for improved winter survival and improved yield under lower temperature conditions.

Our work also suggests that varieties of *C. ciliaris* with fewer spikes can be promising as a productive forage crop in the near future. Selecting cultivars with high vegetative growth and reduced reproductive traits or employing biotechnological methods to decrease seed production and increase forage yield could make *C. ciliaris* an even better replacement for or mixture with alfalfa. Finally, it is highly recommended to use native and local varieties of *C. ciliaris* because introducing exotic cultivars can cause a negative displacement of native species.

5. Conclusions

Selected accessions of *C. ciliaris,* particularly Gaed and Jameen, demonstrate great potential as an alternative to alfalfa for improving biomass production and feeding livestock in the arid zones of Saudi Arabia. With reduced irrigation, in both quantity and frequency, buffelgrass can yield up to 18.4 tons of high-quality forage per hectare per year. However, in natural grasslands without irrigation, it is one of the most drought- and heat-tolerant species, thriving in areas with annual rainfall as low as 200 mm. Some genotypes have also proved tolerant to grazing. Buffelgrass can be grazed directly, recovers well from heavy grazing, and can be processed into hay for use during feed shortages. Despite its moderate protein content, *C. ciliaris* is rich in total digestible nutrients (TDN), making it a valuable contributor to livestock production. These attributes make buffelgrass a valuable alternative to alfalfa for smallholder farming systems during periods of water crisis. In arid regions, such as Saudi Arabia, *C. ciliaris* can be used for initial field establishment, whether in monoculture or with alfalfa as a mixed crop. We also suggest that irrigated pastoral crops should be established by the rehabilitation of degraded rangelands via the seeding of high forage quality species such as *C. ciliaris*. Salt-tolerant selection of *C. ciliaris* and those with superior productivity should be carefully evaluated as they could be a successful resource to address the problems of feed scarcity under arid conditions.

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