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Effect of Irrigation Schemes on Forage Yield, Water Use Efficiency, and Nutrients in Artificial Grassland under Arid Conditions

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Abstract: Artificial grasslands are effective solutions to problems with grassland degradation. Water scarcity is an important limitation for grassland production in arid regions. In this study, we carried out comparison experiments to assess the impacts of irrigation schemes on forage yield, water use efficiency, and nutrients in the single and mixed sowing ways of *Medicago sativa* L. and *Agropyron cristatum* in different stages in artificial grassland. Results indicated that deficit irrigation can increase forage yields of *M. sativa* and *A. cristatum* in most growth stages and sowing treatments. Heavy deficit irrigation or even no irrigation had the greatest potential to increase forage yields of both species in the squaring stage and instantaneous water-use efficiency (WUEI) in all growth stages. They can also significantly increase the nutritional level of *M. sativa* using a mixed sowing method. In June and September, only irrigating to near field capacity (T1) can increase the long-term water-use efficiency (WUEL) of both species. We suggest irrigating with water to near field capacity in June, and applying deficit irrigation in July and August. Deficit irrigation is an effective water management technique to both save water and increase forage quality in arid areas.

Keywords: yield; water-use efficiency; nutrient elements; deficit irrigation

1. Introduction

Grasslands are an important ecosystem in the world and have great potential for carbon sequestration and other ecological functions [1]. However, as a result of widespread overgrazing and climate change, large areas of grasslands have experienced degradation, which has led to water loss and soil erosion, soil salinization, and reduction of grassland production and forage quality. The problems have combined to greatly damage the ecosystems and inhibit the development of animal husbandry. Artificial grasslands are an effective way to address the problems created by grassland degradation [2]. Artificial grasslands can supply a large quantity of high quality forage grasses, requiring less land than natural grasslands, relieving high grazing pressure, and promoting recovery of degraded natural grasslands [3].

Water scarcity is an important limitation for forage growth in grasslands in arid regions [4,5]. Studies have shown that irrigated grasslands may have higher and more stable rates of yield [6–8]. However, achieving high output yields with less irrigation in an efficient and sustainable manner is one of the key challenges in artificial grasslands in arid areas. Deficit irrigation is irrigating with limited water to obtain maximum water use efficiency and stable yields instead of obtaining maximum yields. It is believed to increase the net income of farms [9] (pp. 57–66) because of the reduced cost of irrigation and increased irrigation efficiency [10]. One effective way to solve water scarcity problems is

by optimizing plant water usage through enhancing yield, water use efficiency, and nutritional levels by applying deficit irrigation [11].

Forage nutrients such as crude protein, cellulose, and crush ash are indicators to assess forage quality and verify the effectiveness of irrigation in artificial grassland [12]. Changes of nutrient contents were consistent with vegetation stages and management measures such as irrigation [13]. Forages with high crude protein usually have high nutrient levels and have been verified to increase maximal milk and protein production of dairy cows when the content of crude protein is no more than 16.5% [14]. Forage in a given growth phases has different dry-matter digestibility, which were proven to be closely associated with changes in yield and the digestibility of the cellulose [15]. Ash content could be used to assess the mineral content level because it may vary considerably among species under different management measures even when the nutrition and climate are identical [16].

Current studies have explored the influence of deficit irrigation on yield and the quality of crops [17–19]. Lu et al. [20] assessed the influence of drip irrigation by reclaimed water on tomato yield and quality. Audrey et al. [21] analyzed the functional response of leaf- and plant-hoppers to modern fertilization and irrigation of hay meadows. However, few studies have discussed the effects of deficit irrigation on forage yield, water use efficiency, and nutrients in artificial grasslands in arid areas.

Using single and mixed sowing treatments of *Agropyron cristatum* and *Medicago sativa* L., this study compared forage yield, water use efficiency, and nutrients under different irrigation conditions. The study was designed to provide useful information for alleviating water shortages and promoting sustainable development of artificial grasslands by both increasing plant production and optimizing water use efficiency in arid areas.

2. Materials and Methods

2.1. Study Area

The study area is located in Maodeng Ranch in eastern Xilinhot, Inner Mongolia. Maodeng Ranch is the ecological experimental station of Inner Mongolia University. The area belongs to a meadow steppe–typical steppe area. As the hinterland of the Inner Mongolia Xilingol League Prairie, Xilinhot is located in the central Inner Mongolia Autonomous Region (43°02′–44°52′N, 115°13′–117°06′W). The region is characterized by a temperate arid continental monsoon climate. It experiences a cold and dry Siberian high winter and a warm and humid summer affected by monsoons. Annual average precipitation and temperature are 300 mm and 1.7 °C, respectively. Precipitation is concentrated in June to September. The average wind speed is 3.5 m/s [22]. The soil is fertile, mainly chestnut soil. The main grassland types are temperate steppe with some lowland steppe grasslands. Edificators are *Stipa grandis* and *Leymus chinensis*. The dominant plant species are *A. cristatum* and *Cleistogenes squarrosa*. Common species are *Artemisia frigida* Willd., onion plants, etc.

A short growing season due to the long winter, short summer, and irregular precipitation throughout the year results in low and unstable grass production in the study area. Furthermore, overgrazing and unreasonable utilization means that large tracts of grasslands in the region are threatened by degradation, desertification, and reduced palatability. Therefore, artificial grassland construction through manual planting and management is necessary to alleviate pressure on local grasslands. At the same time, due to low precipitation and the scarcity of water resources, irrigation is important for artificial grasslands.

2.2. Experimental Design

The experimental plots were ploughed on 12 May 2012 and sowed on 9 June 2012. Sowing treatments included single species sowing of *A. cristatum* and *M. sativa*, respectively, and the mixed species sowing of the two species. The plots were planted one by one with 0.5 m ridges around and 1 m spacing between ridges. Totally 48 plots were ploughed with three replicates for each sowing way. The size of each plot is 30 × 30 m. Plot maintenance included seeding and pest control during the

experimental period. Three key phenology phases were selected for irrigation: the re-greening stage (18 May 2013), the elongation stage (23 June 2013), and the heading stage (28 July 2013). Field capacity is the amount of soil moisture after excess water has drained away and the rate of downward movement has materially decreased. It was measured as the soil in three pots of each plot were saturated with water and excess water was drained out from the bottom holes of pots. Then the pots were covered with plastic sheet for two days to prevent evaporation and to allow downward redistribution of water. The TDR probes were then inserted vertically from the soil surface (0–20 cm) to determine field capacity. The irrigation schemes included four scenarios based on field capacity (27.29%) and with no rain shelters as mentioned by Gong et al. [23]. Treatment 1 (T1) irrigated with enough water to reach 85% of field capacity. Treatment 2 (T2) was low deficit irrigation at 65% of field capacity. Treatment 3 (T3) was high deficit irrigation at 45% of field capacity. Treatment 4 (RF) was a rain-fed control with no irrigation. Each treatment included three replicated plots. A total of 48 plots were planted. Table 1 shows information on the irrigation schemes, survey time, and irrigation amounts during the different stages.

Table 1. Irrigation schemes and amounts at different stages.

Irrigation Time	Irrigation Scheme *	% of Field Capacity	Irrigation Amount (m ³ /hm ²)	Survey Time	Precipitation (m ³ /hm ²)	Gross Irrigation Amount (m ³ /hm ²)
Seeding establishment (18 May 2013)	T1	100	142.9	Tillering stage (4 June 2013)	132.1	275
	T2	100	142.9		132.1	275
	T3	100	142.9		132.1	275
	RF	100	142.9		132.1	275
Tillering stage (23 June 2013)	T1	85	528.5	Heading and flowering stage (1 July 2013)	591.8	1263.2
	T2	65	298.9		591.8	1033.6
	T3	45	169.1		591.8	903.8
	RF	0	0		591.8	734.7
Heading and flowering stage (28 July 2013)	T1	85	324	Squaring stage (9 August 2013)	1358.9	1825.8
	T2	65	232.7		1358.9	1734.5
	T3	45	141.5		1358.9	1643.3
	RF	0	0		1358.9	1501.8

* T1: treatment 1; T2: treatment 2; T3: treatment 3; RF: rain-fed control.

2.3. Experimental Measurements

Experimental measurements were carried out on 4th June, 1st July, 9th August, and 9th September in 2013. The examined indices included biomass of grasses, soil bulking density, and moisture content. Biomass was harvested in samples of 1 × 1 m. Soil bulking density was measured with cutting ring method. Each index was measured in one sample for each plot. Additionally, we took soil samples at 0–20 cm depth and grass samples from each plot. Then, forage nutrient elements—including the contents of crude protein (CP), cellulose (CL), and crush ash (CA)—were tested in laboratory experiments (Table 2). The methods used to test CP, CL, and CA were Kjeldahl method, Weende analysis, and Burning method independently as mentioned in the reference [24]. Materials for measuring forage nutrient elements were collected in August when the plants reached the highest nutritional level. Each index was measured one time in each plot. Photosynthesis rate and transpiration rate of grass leaves were measured one time in each plot using the Li—6400 portable photosynthesis system (Li-Cor, Inc., Lincoln, NE, USA) from 6:00 a.m. to 6:00 p.m. on a day during each stage for each treatment. A stationary meteorological station was fixed to provide long-term dynamic monitoring of local meteorological conditions. Four soil moisture meters were also placed in each treatment to monitor soil moisture and temperature during the study period.

Table 2. ANOVA single factor comparison of forage yields, WUEI and WUEL in different stages and treatments ¹.

Month	T	<i>Medicago sativa</i> L. by Single Sowing			<i>Agropyron cristatum</i> by Single Sowing			Mixture Sowing					
		Yield	WUEI	WUEL	Yield	WUEI	WUEL	<i>Medicago sativa</i> L.		<i>Agropyron cristatum</i>		Yield	WUEL
								Yield	WUEI	Yield	WUEI		
June	T1	1522.58 ^{abcde}	3.50 ^{ab}	75.92 ^e	599.74 ^{ab}	3.14 ^{ab}	30.22 ^{abc}	1409.10 ^{abc}	2.90 ^{ab}	233.10 ^{ab}	3.51 ^{abc}	1642.20 ^{abc}	82.84 ^b
	T2	820.24 ^{abc}	3.70 ^{ab}	39.64 ^{bcd}	578.59 ^{ab}	2.45 ^{ab}	29.30 ^{abc}	459.82 ^a	2.45 ^a	142.49 ^a	2.74 ^{abc}	602.31 ^a	30.85 ^a
	T3	590.80 ^{abc}	2.51 ^a	26.77 ^{abc}	282.02 ^a	3.09 ^{ab}	14.10 ^a	540.63 ^{ab}	2.61 ^a	205.96 ^{ab}	6.32 ^{bc}	746.59 ^{ab}	37.17 ^a
	RF	664.92 ^{abc}	4.74 ^{abc}	33.02 ^{abcd}	357.93 ^a	3.83 ^{abc}	17.91 ^{ab}	566.14 ^{ab}	3.39 ^{abc}	427.54 ^{ab}	3.73 ^{abc}	993.69 ^{abc}	49.90 ^{ab}
July	T1	2259.68 ^{def}	3.11 ^{ab}	23.68 ^{abc}	1756.77 ^{bcde}	3.17 ^{ab}	18.39 ^{ab}	1700.53 ^{abcd}	2.08 ^a	382.90 ^{ab}	3.24 ^{abc}	2083.43 ^{abcd}	21.68 ^a
	T2	1774.66 ^{bcde}	2.27 ^a	24.49 ^{abc}	2168.29 ^{de}	2.30 ^a	29.84 ^{abc}	2090.82 ^{bcd}	1.93 ^a	316.94 ^{ab}	2.55 ^{ab}	2407.77 ^{cd}	33.28 ^a
	T3	1177.27 ^{abcde}	2.03 ^a	21.42 ^{abc}	2123.64 ^{de}	2.85 ^{ab}	35.69 ^{abc}	2077.76 ^{bcd}	2.23 ^a	473.67 ^{ab}	2.23 ^a	2551.42 ^{cd}	42.45 ^{ab}
	RF	1167.68 ^{abcd}	2.62 ^a	27.00 ^{abc}	1307.06 ^{abcd}	3.12 ^{ab}	30.20 ^{abc}	1098.07 ^{abc}	2.64 ^a	1083.44 ^b	2.97 ^{abc}	2181.51 ^{bcd}	50.50 ^{ab}
August	T1	3178.16 ^{fg}	2.47 ^a	28.33 ^{abcd}	2096.58 ^{de}	2.83 ^{ab}	18.70 ^{ab}	2403.02 ^{cd}	2.25 ^a	1073.18 ^{ab}	2.34 ^{ab}	3476.20 ^{de}	31.13 ^a
	T2	2557.80 ^{def}	2.31 ^a	24.81 ^{abc}	2050.07 ^{cde}	2.29 ^a	19.92 ^{ab}	3168.20 ^{de}	2.16 ^a	883.56 ^{ab}	1.99 ^a	4051.76 ^d	39.14 ^a
	T3	3972.73 ^g	2.70 ^a	41.96 ^{cd}	2693.76 ^e	2.39 ^{ab}	28.94 ^{abc}	3858.09 ^e	2.18 ^a	2184.78 ^b	2.84 ^{abc}	6042.87 ^e	64.65 ^{ab}
	RF	1978.20 ^{cdef}	2.41 ^a	24.94 ^{abc}	2396.02 ^{de}	2.67 ^{ab}	30.22 ^{abc}	1518.38 ^{abc}	1.78 ^a	2021.44 ^c	1.63 ^a	3539.82 ^{de}	44.63 ^{ab}
September	T1	2642.89 ^{ef}	4.97 ^{abc}	55.50 ^d	2994.60 ^e	4.55 ^{abc}	62.93 ^d	1845.51 ^{abcd}	2.61 ^a	252.62 ^{ab}	4.52 ^{abc}	2098.13 ^{abcd}	44.16 ^{ab}
	T2	662.51 ^{abc}	5.68 ^{bc}	13.93 ^{ab}	2247.31 ^{de}	4.81 ^{bc}	47.16 ^{cd}	626.27 ^{ab}	3.89 ^{abc}	475.53 ^{ab}	6.35 ^{bc}	1101.80 ^{abc}	29.76 ^a
	T3	324.80 ^a	4.86 ^{abc}	6.89 ^a	2027.82 ^{cde}	4.60 ^{abc}	42.60 ^{bcd}	958.53 ^{abc}	5.13 ^{bc}	465.27 ^{ab}	3.36 ^{abc}	1423.80 ^{abc}	29.93 ^a
	RF	359.96 ^{ab}	7.02 ^c	7.58 ^a	824.13 ^{abc}	6.06 ^c	17.29 ^{ab}	624.71 ^{ab}	5.64 ^c	1066.33 ^{ab}	6.72 ^c	1691.04 ^{abc}	35.56 ^a
² M (P)		⁴ D (0.00)	⁴ D (0.00)	⁴ D (0.00)	⁴ D (0.00)	⁴ D (0.01)	⁴ D (0.00)	⁴ D (0.00)	⁴ D (0.02)	⁴ D (0.00)	⁴ D (0.03)	⁴ D (0.00)	LSD (0.21)
³ F		6.37	2.72	4.90	4.95	2.17	3.11	4.55	2.07	5.21	1.98	9.23	1.40
⁵ DF		47	47	47	47	47	47	47	47	47	47	47	47

¹ The upper letters display whether the values significantly differ from others. They were calculated by ANOVA single factor comparison in SPSS 13.0. Each treatment in each stage has three samples. In total, 48 samples were used for each ANOVA analysis. ² Method: testing method for multiple comparisons. The method was selected by the homogeneity test of variances, when $p \geq 0.05$, LSD was selected, or else DUNCAN was selected. ³ F: F test value. ⁴ D: DUNCAN's multiple range test; ⁵ DF: the number of degree of freedom.

2.4. Data Analysis

WUE was calculated with two indicators

$$WUEI = P_n \div T_r \quad (1)$$

where in a given growth stage, $WUEI$ is the instantaneous WUE at the leaf scale, the unit is $\text{mol}\cdot\text{CO}_2/\text{mmol}\cdot\text{H}_2\text{O}$; P_n is the photosynthetic rate ($\mu\text{mol}\cdot\text{CO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$), and T_r is the transpiration rate ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$).

$$WUEL = W_{dm} \div ET \quad (2)$$

where in a given growth stage, $WUEL$ is the long-term WUE at population and community scales, the unit is $\text{kg}/\text{mm}\cdot\text{hm}^2$; W_{dm} is the amount of dry matter of the forage per unit (kg/hm^2), ET is the evapotranspiration of the forage (mm). ET is calculated as

$$ET = P + I \pm vS \quad (3)$$

where in a given growth stage, P is the precipitation amount (mm), I is the irrigation amount (mm), vS is the difference in soil water content between the early and late growth stages (mm).

Different multivariate analyses were also performed (ANOVA single factor comparison) to compare the effects of irrigation schemes and planting treatments on forage yield, $WUEI$, $WUEL$, and nutrient elements. The differences were considered significant at $p < 0.05$. All statistical analyses were performed in version 13.0 of SPSS software (SPSS Inc., Chicago, IL, USA).

3. Results

The results of ANOVA single factor comparison of forage yields, $WUEI$, and $WUEL$ in different stages and treatments were shown in Table 2. It can be inferred from Table 3 that, compared to other sowing methods and indices, forage yields under the single sowing of *M. sativa* displayed bigger differences by stages and treatment. They were classified into seven groups. $WUEL$ under mixture sowing exhibited smaller differences by stages and treatments with only two groups distinguished.

Table 3. ANOVA single factor comparison ¹ of contents of forage nutrients in different sowing treatments.

T	Contents in MSS ²			Contents in MSM ²			Contents in ACS ²			Contents in ACM ²		
	CP	CA	CL	CP	CA	CL	CP	CA	CL	CP	CA	CL
T1	14.15 ^b	10.81 ^b	32.85 ^a	8.58 ^a	10.49 ^a	30.07 ^b	8.08 ^a	7.44 ^{ab}	31.15 ^b	8.02 ^a	6.46 ^{ab}	32.19 ^b
T2	8.08 ^a	7.44 ^a	31.15 ^a	11.74 ^b	12.97 ^b	29.14 ^b	12.22 ^a	9.29 ^b	26.45 ^a	8.27 ^a	6.84 ^b	32.85 ^b
T3	13.99 ^b	10.59 ^b	30.05 ^a	15.19 ^c	15.83 ^c	28.10 ^{ab}	8.08 ^a	6.58 ^{ab}	31.01 ^b	5.85 ^a	6.33 ^{ab}	25.90 ^a
RF	14.84 ^b	9.52 ^{ab}	27.53 ^a	15.17 ^c	12.69 ^b	23.16 ^a	8.40 ^a	4.95 ^a	27.04 ^{ab}	8.32 ^a	5.51 ^a	24.27 ^a
¹ M (P)	⁴ D 0.042	⁴ D 0.048	LSD 0.216	⁴ D 0.001	⁴ D 0.005	LSD 0.102	LSD 0.207	LSD 0.097	LSD 0.055	LSD 0.615	LSD 0.070	⁴ D 0.005
³ F	4.41	4.15	1.61	22.53	10.88	3.03	1.97	3.11	4.16	0.64	3.69	11.15
⁵ DF	11	11	11	11	11	11	11	11	11	11	11	11

¹ Method: testing method for multiple comparisons. Each treatment has three samples. In total, 12 samples were used for each ANOVA analysis. The method was selected by the homogeneity test of variances, when $p \geq 0.05$, LSD was selected, or else DUNCAN was selected; ² MSS: *M. sativa* by single sowing; MSM: *M. sativa* by mixture sowing; ACS: *A. cristatum* by single sowing; ACM: *A. cristatum* by mixture sowing; ³ F: F test value; ⁴ D: DUNCAN's multiple test. The parameters with the same letter are not significantly different at $p = 0.05$ according to the selected method; ⁵ DF: the number of degree of freedom.

3.1. Impact of Irrigation Schemes on Forage Yield

Table 2 and Figure 1 show that for both species and sowing ways, forage yields in August—especially under T3 treatment—were significantly higher than those in other stages. The values decreased in September. Furthermore, in the stages except August, T1 usually obtained insignificantly higher forage yields than most other treatments. For all stages, the irrigation treatments always have slightly higher forage yields than RF.

Figure 1. Mean values (with error bars) of forage yield in different sowing treatments (the colors of the bars represent different treatments, the grey lines above the bars mean the error bars).

3.2. Impact of Irrigation Schemes on WUE

3.2.1. WUEI

Table 2 and Figure 2 show that comparing to other stages and treatments, WUEIs were significantly higher in September especially under RF for both species and sowing ways. For *M. sativa* of both sowing ways, WUEIs were a little low in July and August under the four treatments. For *A. cristatum* of both sowing ways, WUEIs were a little low in August especially under T2.

Figure 2. Mean values (with error bars) of WUEI in different treatments by sowing treatments (the colors of the bars represent different treatments, the grey lines above the bars mean the error bars).

3.2.2. WUEL

Table 2 and Figure 3 show that comparing to most other stages and sowing ways, WUEs were significantly higher in June and September under T1 for the single sowing of *M. sativa* and the mixture sowing, and in September under T1 for the single sowing of *A. cristatum*. The differences of WUEs in most other stages and sowing methods were not significant, since they belong to the same groups.

Figure 3. Mean values with (error bars) of WUEL in different sowing treatments (the colors of the bars represent different treatments, the grey lines above the bars mean the error bars).

3.3. Impact of Irrigation on Forage Nutrient Elements

Table 3 shows the contents of forage nutrient elements in different sowing treatments. A forage with high nutritional level usually has high crude protein and low cellulose contents and ash content. Compared to RF, T1 can significantly increase the contents of CL in both species by mixture sowing, but decrease the contents of CP and CA in *M. sativa* by mixture sowing. T2 can significantly increase the contents of CL in both species by mixture sowing method and the contents of CA in *A. cristatum* by both sowing methods, but decrease the contents of CP in *M. sativa* by both sowing methods. Compared to T1 and T2, T3 and RF have significantly higher contents of CP in *M. sativa* by both sowing methods and lower contents of CL in both species by mixture sowing. RF also has insignificantly lower contents of CA in both species and sowing ways. The other comparisons were also insignificant. Thus, T3 and RF are preferable to enhance nutritional levels of both species and sowing ways.

4. Discussions and Conclusions

4.1. Impact of Irrigation on Forage Yield and Nutritional Level

Plant responses to irrigation strategies were based on the phenological stage when it was applied. Several studies have documented that water scarcity can reduce the final plant load during flowering and the initial stage of plant growth; and water scarcity negatively affected plant production during the tillage stage [11,25,26]. Our results also indicated that compared to the rain-fed control treatment, irrigation can increase forage yields of *M. sativa* and *A. cristatum* in most stages and by both sowing techniques. Since the highest yields appeared in August under all treatments and sowing techniques, we concluded that August is the optimal period to harvest the two species.

In order to enhance forage yield and save water through irrigation in arid areas with extreme water shortage, it is assumed that deficit irrigation is more effective than irrigating with sufficient water (T1). Our results also indicated that heavy deficit irrigation (T3) has the maximum potential to increase forage yields of both species in the squaring stage. A slight decrease of yield in the earlier stages could be compensated in the later stages when applying deficit irrigation, as was mentioned in other studies [27]. Heavy deficit irrigation and rain-fed control were also effective ways to improve forage nutritional levels of both species under two sowing methods.

4.2. Impact of Water Scarcity on Water-Use Efficiency

Water-use efficiency (WUE) is an indicator for assessing the validity of deficit irrigation on yield increase [28]. Our results indicated that the impacts of irrigation on WUE differed between WUEI and WUEL. Rain-fed controls were preferable for increasing WUEI for both species in September. This may be due to the adaptability of both forage species to water scarcity. In the study area, precipitation is always low in September, providing an insufficient water supply. When affected by water availability, plants tend to accumulate ingredients, such as soluble sugar and proline, to decrease in vivo osmotic pressure and sustain water uptake from outside [28]. They also close stomas to reduce transpiration under water pressure. Thus, no irrigation water can maintain high WUEI for *M. sativa* and *A. cristatum* in most stages and under both sowing techniques. Previous studies have also verified that WUEI can be increased under water scarcity because most of the applied water remains in the root zone instead of being depleted by ET [29,30]. However, in June and September, only irrigating to near field capacity (T1) can increase the WUEL of both species. The reason may be that the strong evapotranspiration that may consume a large amount of water in the plants in the study area.

4.3. Optimum Schedule to Increase Forage Quality and Save Water

In summary, deficit irrigation and even no-irrigation are effective water management techniques to both save water and increase forage-quality related factors, including forage yield, nutritional levels, and WUEI for the two species in most sowing ways. This has also been validated by previous studies [19]. Because of the sensitivity and resistance to water scarcity in different stages, the forages

displayed different adaptive strategies to water availability, which were characterized by the impacts of irrigation schemes on forage qualities. The optimum schedule is irrigating to near field capacity in June when the forage is sensitive to water scarcity and applying deficit irrigation in July and August when the forage species were more resistant to water scarcity [31,32]. For future research, we suggest focusing on optimizing irrigation amounts and timing and identifying suitable species mixtures. Reasons as to why heavy deficit irrigation could produce more biomass than T1 and T2 should also be discussed by analyzing the physiological and biochemical response of plants to irrigation schemes. More specific guidelines will help growers to maximize water use efficiency in grassland production in arid regions.

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