Siberian Wildrye Grass Yield and Water Use Response to Single Irrigation Time in Semiarid Agropastoral Ecotone of North China

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Abstract
An irrigation experiment of Siberian wildrye grass (*Elymus sibiricus* L.) was conducted in the alpine cold areas of North China during 2006 to 2008 to compare forage yield (FY) and water use efficiency (WUE) between single irrigation before winter (WI) or at the elongating stage (EI), two irrigations at these two stages (WEI), and the WI treatment combining with mulching straw before next reviving (WMI). The results showed that the FYs under EI were increased by 66, 218, and 99%, and WUE was increased by 56, 134, and 81%, respectively, compared to no irrigation treatment (NI). The FYs under WI were increased by 40, 53, and 44%, and the WUE was increased by 30, 31, and 34%, respectively. No significant FY and WUE increments under WEI were found compared with EI during 2006 to 2007. In 2008, the FY and WUE under WMI were higher than those under EI. Therefore, EI, WMI and WI are the first, second and third choice to achieve relatively high production and WUE of Siberian wildrye grass, respectively. In addition, the elongating-heading stage was the most water sensitive period with significantly larger moisture stress sensitivity index and WUE.

Key Words
Forage yield, Water use efficiency, Irrigation, Agropastoral ecotone.

Introduction
Although forage yield could be increased significantly through irrigation, frequent or large amount of irrigation would hamper the sustainability of water resources and increase related equipment and labor cost. Crop yield and WUE could be increased significantly by irrigating during the critical growth stage (Demir et al., 2006). Wang et al. (2009) concluded that single irrigation at the elongating stage can achieve relatively high production and WUE in the semiarid agropastoral ecotone of North China (APENC).
Currently, almost all the crops were irrigated from May to August in the area, resulting in deficiency in irrigation water resources in this period. Thus, the farmers are facing difficulty to meet crop water demands during the growing season. Off-season irrigation was considered an alternate to improve the crop growth (Stone et al. 2008). In the APENC, most of soil water collected during the rainy season was evaporated due to the long-term bare soil at the regrowth stage. Soil moisture reached a low point before the winter when ample irrigation water is available. In addition, soil water storage changed very little due to the extreme cold weather throughout the whole winter. Thus, we hypothesized that storing soil water before winter might improve the soil moisture condition and enhance the yield and WUE in the following year. Mulching can maintain good soil water condition by reducing the water losses from soil surface. If the irrigated water before winter can be stored in the soil until the critical growth stage combining with mulching technology, the yield increase would be more significant.

Methods
Experimental Site
The field experiment was conducted at the Yu'ershan Demonstration Pasture of National Grassland Ecosystem Station located in Bashang Plateau (116°11´ E, 41°45´ N, elevation of 1460 m) during Oct. 2005–Oct. 2008. The area has a semiarid continental monsoon climate, and the annual precipitation is 300–400 mm, and about 279 mm falls during the growing season from May to September. The soil is a typical sandy loam (coarse loamy, mixed, superactive, calcic cryi-ustic Mollisols) in 0 to 60 cm soil profile based on the diluvial deposit. The primary soil properties can be found in Wang et al. (2009). The field capacity in the 0–60 cm soil profile (FC, 133 mm) and wilting point (WP, 42 mm) were measured at -0.3 and -1.5 MPa matrix potential.
Experimental Design and Field Management
(i) NI, no irrigation was applied. (ii) WI, a single irrigation was applied before winter to bring the soil water storage (SWS) in 0 to 60 cm to field capacity (FC). (iii) EI, a single irrigation was applied at the elongating stage to bring the SWS to FC. (iv)WEI, two irrigations were applied before winter and at the elongating stage. The WEI treatment was replaced by WMI (the irrigation before winter and mulched treatment with naked oats

straw before the next reviving, 3 cm thick, 3000 kg ha^{-1}) in 2008.The grass was sown on 15 June 2005, at a seeding rate of 25 kg ha^{-1}. The plot size was 8 m wide by 20 m long. All plots were irrigated by a removable sprinkler system. The chemical fertilizers (75 kg ha^{-1} N and 20 kg ha^{-1} P) were tilled to subsoil before seeding in 2005 and applied on the soil surface every May from 2006 to 2008.

Measurements and Calculations

The 50 × 50 cm^2 aboveground biomass was collected at the end of each growing stage. The forage yield was calculated by 3 × 3 m^2 samples. The first harvest was generally in July and the second harvest was in late September with 5-cm height stubble. The biomass and yield samples were all dried at 75°C for 72 h in an oven. Soil volumetric water content was monitored by TDR. Evapotranspiration (ET) was determined from the soil water balance model, and water use efficiency (WUE) based on ET and Y was calculated.

The Jensen-model (Jensen 1968) was used to calculate the moisture stress sensitivity:

$$\frac{Y}{Y_{\mathrm{m}}} = \prod_{i=1}^{n} \left(\frac{\mathrm{ET}_{ai}}{\mathrm{ET}_{\mathrm{m}i}}\right)^{\lambda_i} \quad (1)$$

where Y is actual forage yield in kg ha^{-1}, Y_m is forage yield under non-stressed treatment in kg ha^{-1}, the maximum forage yield was used in this paper, ET_{ai} is actual crop evapotranspiration at growth stage "*i*", ET_{mi} is the crop evapotranspiration under non-stressed treatment at growth "i", the maximum value was used in this paper, λ_i is Jensen's moisture stress sensitivity index at growth stage "i", n is the number of growth stages, and Π is a multiplicative sign.

Results

Soil Moisture Condition

There was little variation in soil water storage during winter due to the long-term frozen soil (from November to next April) (Figure 1). The water storage decreased rapidly during the reviving-elongating and the regrowing stage. Late June and late October were the two driest periods in the region. The moisture condition under NI was poor except during the short-term rainy season. The water storage of 0–60 cm soil layer in WI and WEI were relatively high during the reviving stage because the irrigated water before winter could be reserved until next spring. From late October to next late April, water storage under WI and WEI decreased by 11% on the average. In 2006–2008, about 42, 71, and 59% of the irrigated water before winter under WI were still stored in the soil until the reviving period, and 60, 62, and 56% under WEI. But soil water in the WI treatment decreased quickly from the early-May to mid-June. The irrigated water before winter could be stored until 23 May 2006, 10 June 2007, and 9 July 2008, respectively. The ample soil water in EI and WEI could be held until the rainy season because of the irrigation at the elongating stage. The ineffective evaporation could be reduced under mulching condition, so the soil water under WMI treatment in 2008 maintained in high level.

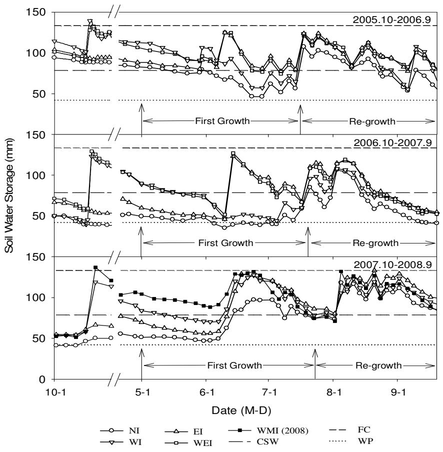

Figure 1 The dynamics of soil water storage in 0–60 cm during the 3-year (Oct. 2005-Sept. 2008). Where, NI: no irrigation; WI: irrigation before winter; EI: irrigation at the elongating stage; WEI: two irrigations before winter and at the elongating stage (Oct. 2005-Sept. 2007); WMI: irrigation before winter and mulched before the next reviving (Oct. 2007-Sept. 2008); FC: field capacity; WP: wilting point; CSW: the critical soil water storage, it was calculated by WP plus the 40% of the total available soil water storage.

Water Consumption

Significant ET difference existed among treatments (Table 1). Irrigation increased the total ET of the whole growing season considerably. Except for the dry year of 2007, no obvious difference was found among the three irrigation treatments. The ET of the first growth under NI in 2006–2008 was 146.6, 113.1, and 130.9 mm, respectively. The value under WI was increased by 15, 27, and 16% compared with NI. The ET under EI was increased by 15, 50, and 25% from NI. The ET under WEI (replaced by WMI in 2008) was increased by 27, 76, and 16% compared with NI. The average ET under the two treatments irrigated before winter (WI and WEI) was 31.9 and 38.5 mm at the reviving and tillering stages, obviously higher than 22.4 and 27.5 mm for the treatments without winter irrigation (NI and EI). The average ET under the two treatments irrigated at the elongating stage (EI and WEI) reached 72.3 and 44.0 mm at the elongating and heading stages, significantly higher than 52.3 and 32.6 mm for the two treatments without irrigation at the elongating stage (NI and WI). No obvious increase was found under WMI in 2008 except at the heading stage. There was no significant ET difference among treatments during the regrowing stage. The ET at the regrowth in 2007, with less rainfall, was lower than that in 2006 and 2008.

Table 1 Growing stages and cumulative seasonal evapotranspiration (mm).

Year	Growing Stage	Reviving	Tillering	Elongating	Heading	Re-growth	Total
2006	NI	21.3 b	28.1 b	60.8 b	36.4 b	174.6 a	321.2 b
	WI	32.4 a	39.3 a	61.0 b	35.3 b	179.3 a	347.4 ab
	EI	19.0 b	29.8 b	72.7 a	47.5 a	173.5 a	342.5 a
	WEI	27.0 a	40.3 a	74.5 a	44.8 a	170.0 a	356.6 a
2007	NI	21.9 b	29.1 b	35.9 b	26.2 b	107.6 a	220.7 d
	WI	34.7 a	38.7 a	46.8 b	22.9 b	114.4 a	257.6 c
	EI	30.9 ab	27.6 b	68.3 a	42.5 a	131.0 a	300.4 b
	WEI	37.4 a	41.9 a	78.9 a	41.3 a	130.2 a	329.7 a
2008	NI	18.9 b	19.7 b	53.7 b	38.6 b	160.0 a	290.9 b
	WI	27.7 a	32.3 a	55.4 b	36.0 b	162.1 a	313.6 a
	EI	22.2 ab	30.7 a	67.0 a	44.1 a	155.8 a	319.8 a
	WMI	24.8 ab	22.4 b	57.4 b	42.3 a	164.6 a	311.4 a

Note: values followed by the same letter within a column in the same year are not significantly different among treatments for the same growing stage at the 0.05 probability level according to the least significant difference (LSD) test.

Forage Yield and Water Use Efficiency

Irrigation, especially at the elongating stage, played the most important role in yield increase. In 2006–2008, the total forage yield under EI achieved 6381, 6883, and 5763 kg ha^{-1}, increased by 66, 218, and 99% comparing with the NI. The WI increased the forage yield by 40, 53, and 44% comparing with NI. The WEI had the same effect on the total yield with the EI treatment. The first growth of Siberian wildrye grass resulted in the highest forage yield due to the poor ability of regrowth (Table 2). In the 3 yr, the forage yield of the first harvest under NI was 2250, 1085, and 2004 kg ha^{-1}, and that of the second harvest was 1595, 1076, and 896 kg ha^{-1}, respectively. Compared with NI, the yield of the first harvest under WI was increased by 53, 87, and 50%, and that of the second harvest was increased by 23, 20, and 33%. The first harvest of EI was increased by 104, 391, and 117%, and that of the second harvest was increased by 12, 44, and 57%. No obvious difference was found between WEI and EI in 2006 and 2007. Although the effect of yield increase at the first harvest under WMI was similar to EI, there was significant increase over EI yield (161% of EI yield) in the second harvest and the total yield was 6703 kg ha^{-1} in 2008. In addition, the forage yields of the first harvest under NI and WI in 2007 were decreased by 52% and 41% comparing to that of 2006 because of the dry year in 2007, whereas the yield of the EI treatment in 2007 increased. Clearly, the irrigation at the elongating stage was important in keeping the high and stable forage yield, while the forage yield of NI and WI fluctuated with rainfall. The forage yields of the first harvest under NI and WI in the wet year of 2008 increased slightly comparing to those of 2007, but were lower than that of 2006 due to the degradation of Siberian wildrye grass at its fourth growth year. As shown in Table 2, the WUE values during the 2006, 2007, and 2008 growing seasons under EI were 1.9, 2.3, and 1.8 kg m^{-3}, and were higher than 1.2, 1.0, and 1.0 kg m^{-3} under NI, and 1.6, 1.3, and 1.3 kg m^{-3} under WI. There was no difference between EI and WEI. The WMI treatment in 2008 increased WUE to 2.2 kg m^{-3} comparing to 1.8 kg m^{-3} under EI. The WUE at the first growth stage was much higher than that at re-growth stage. The NI in the first growth reached WUE of 1.5, 1.0, and 1.5 kg m^{-3}, respectively, in 2006, 2007, and 2008. The value under WI was increased by 34, 47, and 30% compared to that under NI. The WUE under EI treatment was increased by 77, 228, and 76% compared to under NI. No obvious difference was found between WEI and EI. The mulching treatment not only increased the first growth WUE, but the value at the regrowth stage was also improved. The WUE of WMI in 2008 was 3.0 and 1.4 kg m^{-3} in the first growth and regrowth stages, significantly higher than other irrigation treatments. In addition, the first growth WUE under the elongating stage irrigation treatments (EI and WEI) had less variation among years with coefficient of variation (COV) of 8.2% and 7.1% under EI and WEI, while the WUE under NI and WI fluctuated greatly among years (COV=21.7% under NI and 19.2% under WI).

Water Sensitivity and Production Function

We further calculated the water stress sensitivity index of each stage during the first growth using the Jensen model (1968).

$$\frac{Y}{Y_m} = \left(\frac{ET}{ET_m}\right)^{0.07}_{Reviving} * \left(\frac{ET}{ET_m}\right)^{0.20}_{Tillering} * \left(\frac{ET}{ET_m}\right)^{1.08}_{Elongating} * \left(\frac{ET}{ET_m}\right)^{0.96}_{Heading} \quad (2)$$

Where ET_m is the crop evapotranspiration under non-stressed treatment at each growth stage, the maximum value was used here. The water stress sensitivity indexes at the elongating and heading stage were 1.08 and 0.96, significantly larger than 0.20 at the tillering stage and 0.07 at the reviving stage.

Table 2. Forage yield and water use efficiency.

Year	Treatment	First growth		Re-growth		Whole season	
		Yield (kg ha^{-1})	WUE (kg m^{-3})	Yield (kg ha^{-1})	WUE (kg m^{-3})	Yield (kg ha^{-1})	WUE (kg m^{-3})
2006	NI†	2250 c‡	1.5 c	1595 a	0.9 a	3845 c	1.2 c
	WI	3443 b	2.0 b	1955 a	1.1 a	5398 b	1.6 b
	EI	4591 a	2.7 a	1790 a	1.0 a	6381 ab	1.9 a
	WEI	4909 a	2.6 a	1796 a	1.1 a	6705 a	1.9 a
2007	NI	1085 c	1.0 c	1076 c	1.0 c	2162 c	1.0 c
	WI	2025 b	1.4 b	1288 b	1.1 b	3313 b	1.3 b
	EI	5328 a	3.1 a	1555 a	1.2 ab	6883 a	2.3 a
	WEI	5649 a	2.8 a	1629 a	1.3 a	7278 a	2.2 a
2008	NI	2004 c	1.5 d	896 c	0.6 c	2900 d	1.0 d
	WI	3001 b	2.0 c	1189 bc	0.7 c	4190 c	1.3 c
	EI	4354 a	2.7 b	1409 b	0.9 b	5763 b	1.8 b
	WMI	4428 a	3.0 a	2275 a	1.4 a	6703 a	2.2 a

Note: values followed by the same letter within a column in the same year are not significantly different among treatments at 0.05 probability level according to the least significant difference (LSD) test.

Conclusion

Irrigation before winter improved the seasonal ET and the growth at the reviving-tillering stage. The yield under WI was increased by 40, 53, and 44% compared to NI in the 3 yr of study. Irrigation at the elongating stage improved the seasonal ET and the growth at the elongating-heading stage. The yield under EI was increased by 66, 218, and 99% over the NI treatment. There was no significant difference between WEI and EI in 2006 and 2007. The yield increase under WMI in 2008 was similar to EI at the first harvest, but the yield and WUE of the regrowth was increased by 61% and 53% compared to EI. Therefore, single irrigation at the elongating stage is the first choice to achieve relatively high production and WUE of Siberian wildrye grass, followed by a single irrigation before winter combining with mulching straw, and a single irrigation before winter. The water stress sensitivity indexes at the elongating and heading stages were 1.08 and 0.96, much higher than at other stages.

References

Demir AO, Goksoy AT, Buyukcangaz H, Turan ZM, Koksal ES (2006) Deficit irrigation of sunflower (*Helianthus annuus* L.) in a sub-humid climate. *Irrigation Science* **24**, 279-289.

Jensen ME (1968) Water consumption by agricultural plants. In ‘Water deficits and plant growth. Vol. Ⅱ’. (Ed. TT Kozlowski) pp. 1-22. (Academic Press: New York).

Stone LR, Lamm FR, Schlegel AJ, Klocke NL (2008) Storage efficiency of off-season irrigation. *Agronomy Journal* **100**, 1185-1192.

Wang H, Li Z, Gong Y, Wang Z, Huang D (2009) Single irrigation can achieve relatively high production and water use efficiency of Siberian wildrye grass in the semiarid agropastoral ecotone of North China. *Agronomy Journal* 101, 996-1002.