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DIURNAL AND SEASONAL VARIATIONS IN PHOTOSYNTHESIS, LEAF WATER POTENTIAL AND SOIL WATER CONTENT OF SIX ALFALFA CULTIVARS ON THE SEMIARID LOESS PLATEAU

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Abstract

Leaf photosynthesis, leaf water potential and soil water content were compared among six commonly used alfalfa cultivars (*i.e.* Polaris, Alfalfaqueen, Algonquin, Sanditi, Ningxia, and Xinjiang Daye) in a semiarid region on the Loess Plateau from May to September 2014. Daily leaf water potential (ψ_L) was monitored at four-hour intervals at 6:00, 10:00, 14:00 and 18:00. Leaf net photosynthetic rate (P_N) and transpiration rate (E) were measured at two-hour intervals on the same day from 6:00 to 18:00. The variation trend and difference of ψ_L, P_N and E were analyzed among the six alfalfa cultivars. Cv. Polaris had significantly lower instantaneous and daily mean value in May, and there were no significant differences in other five cultivars and in other three months. Cvs. Ningxia and Xinjiang Daye had relatively lower daily mean P_N value among the six cultivars in each month. Cv. Algonquin showed lower water potential gradient between ψ_{ML} and ψ_{SL} in each month among the six cultivars. Our results suggest that introduced cultivars of alfalfa have similar fluctuations in photosynthesis and leaf water status as domestic cultivars, while they have relatively higher P_N and water use efficiency (WUE), which is favorable for them to quickly adapt to the environment.

Key words: Gas exchange; Leaf water potential; Sol water content; Water use efficiency.

Introduction

Alfalfa (*Medicago sativa* L.) is a worldwide-grown forage crop with high yield and nutrition value, which the economic value ranks only after corn, soybean and wheat around the world (Thacker & Haq, 2008; Xu *et al*., 2010; Chen *et al*., 2015). Alfalfa has been used as feed for livestock and cultivated in pasture/crop rotation systems for almost 2000 years in China, besides that it is also grown for reducing soil erosion and improving soil quality on the Loess Plateau (Li & Huang, 2008; Zhang *et al*., 2015).Alfalfa is a water spender although it has powerful root systems in dry regions, and water deficit is the main factor limiting its quality and production (Bai, 2002; Xu *et al*., 2006; Shan & Xu 2009; Şakiroğlu *et al*., 2015). Researches pointed out that blind pursuit of high alfalfa yield would lead to the desiccation in the deep soil layer on the Loess Plateau, and thus decrease grassland productivity and also cause degradation (Li, 2001, 2002; Li & Shao, 2005; Wan *et al*., 2007). The main reasons are due to its high water consumption and low water efficiency, which would greatly affect the instability planting area and productivity in water-limited regions (Shan *et al*., 2000; Shan & Xu, 2009; Şakiroğlu *et al*., 2015). In the semiarid loess hilly-gully area, relatively low annual rainfall (300-600 mm) with highly variable distribution (70%-80% in July-September) greatly affects the growth and biomass production of alfalfa (Shan & Chen, 1993; Xu *et al*., 2006). In the past decades, lots of alfalfa cultivars were introduced and planted in the region for improving soil quality, controlling soil erosion, increasing land coverage and developing farmhouse livestock, but they yield poorly in agricultural systems such as short-term persistence and instability in biomass production (Li & Shao 2005; Shan & Xu, 2009). It is necessary to compare the eco-physiological and water use characteristics of different alfalfa cultivars and screen more drought-tolerant alfalfa cultivars. Thus, we conducted the experiment to evaluate field performance of six alfalfa accessions, of which two were naturalized alfalfa collected from Ningxia and Xinjiang Provinces, and four were introduced from America and Canada. Our objectives were to see their differences in photosynthetic characteristics during growing season and determine their water use efficiency. The present study will provide new insights into finding appropriate alfalfa cultivars for artificial alfalfa grassland construction on the semiarid Loess Plateau and also enrich our knowledge about their eco-adaptation.

Materials and Methods

Site description: The experiments were carried out at the research farm of Ansai Research Station of Chinese Academy of Science in Shaanxi Province (36°51'30"N, 109°19'23"E; 1068 m a.s.l.)from May to September in 2014. The experimental site is located in the semiarid region of northwestern China, where the loessial soil is characterized as silty loam. The annual mean precipitation is 510 mm and the frost-free period is 159 d. Moreover, the yearly mean temperature of this region is 8.8°C, the mean minimum and maximum temperature is −6.9°C in January and 22.6°C in July, respectively. The active accumulated temperature (≥10°C) is about 3,119°C per year.

Field experimental design: The experimental field was on a lowland field previously planted with apple trees (*Malus domestica*) from 1992 to 1997. The trees were felled in October 1997, then the field was utilized for growing smooth brome grass (*Bromus inermis*) during 2000 and 2008. In 2009, the field was used for planting alfalfa. The cultivars used included six cultivars, which were Polaris, Alfalfaqueen, Algonquin, Sanditi, Ningxia, and Xinjiang Daye. The germination rates of alfalfa seeds were more than 90% after 7 days cultivation at 25ºC through common tissue method.

The experimental plot size was 7 m × 4 m. All the plots were arranged in a randomized complete block design with three repeats for each cultivar. The seeds were sown by hand on 17 April, 2009 with the density of 15 kg ha^{-1}. Row spacing was 20 cm. Fertilizers K, P and Nwere applied prior to plowing at a rate of 45 kg N ha^{-1}, 45 kg P ha^{-1}, and 60 kg K ha^{-1}, respectively. Field management was carried out according to the measures used in farmland. And there was no irrigation and any other form of water supplement during the experiment.

Photosynthetic parameters measurement: For each measurement, two newly-expanded leaves from five plants in each plot were randomly selected to analyse the leaf net photosynthesis rate (P_N) and transpiration rate (E) through a portable photosynthesis system (CIRAS-2, PP Systems, USA) at ambient environment. Measurements were carried out from 8:00 h to 18:00 h with an interval of 2 h at three continuous sunny days. Environmental factors including air relative humidity (RH), photosynthetically active radiation (PAR) and air temperature (T_{air}) were surveyed at the same time. Leaf instantaneous water use efficiency (WUE) was calculated via dividing P_N by E (Fischer & Turner, 1978). No measurements were conducted in June due to wind and clouds.

Leaf water potential measurement: Leaf water potential (ψ_L) was analyzed using the pressure chamber (Model 1000, PMS, USA), and conducted during the same day as gas exchange measurement. Four measurements were made during the daytime: from 6:30 hto 18:30h at four hours intervals. The same sequence of marked individuals was followed, and each measurement was repeated three times.

Soil water content measurement: Soil water content (SWC, ω %) was surveyed at the center of two rowsaccording to the soil core sampler method (Ø4 cm cores) during the eco-physiological measurement in each month. Soil sample was dried at 105ºC for 24 h. The analysis of soil gravimetric water contents was utilized for the measurements of SWC which was calculated as follows:

$$\omega\,(\%) = \frac{(W_W - D_W)}{D_W} \times 100\% \qquad (1)$$

where *Ww* and *Dw* were the wet and dry weight mass of soil samples. SWC was analyzed down to 100 cm at 10 cm depth intervals.

Statistical analysis: The data were analyzed by standard one-way ANOVA using SPSS 17.0. The Paired-Samples T and LSD tests were used for comparison between months for each cultivars or between cultivars for each month (p=0.05).

Results

Monthly precipitation: According to the record, total precipitation of the growing season from April to October was 547.20 mm in 2014, which was higher compared with the long-term average (501.65 mm, 1951–2004). Almost 78.6% and 78.7% of the precipitation occurred in June to September in 2014 and 1951-2004, respectively. The heaviest precipitation was detected in September with 124.6 mm, while the lightest was detected in October with just 13.2 mm in 2014. The precipitation in April and September of 2014 was higher than the historical 50-year average, while the latter was higher in other growing months especially October (Fig. 1).

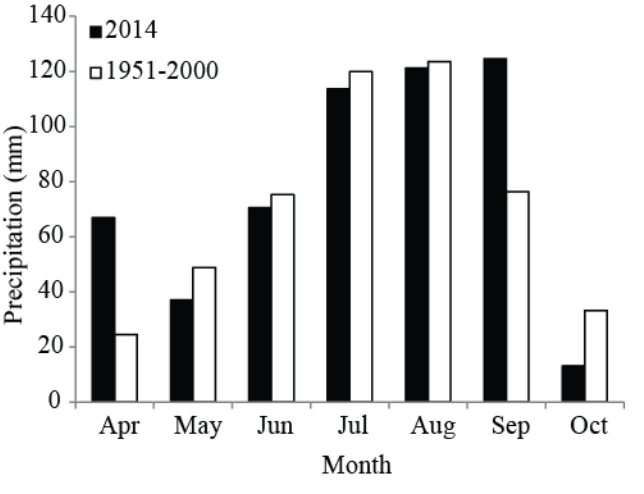

Fig. 1. Monthly precipitation during April and October in 2014 and 1951-2000 at the experimental site.

Environmental factors: The trend of diurnal changing in photosynthetically active radiation (PAR) exhibited a unimodal pattern in each month, with the highest values occurring between 12:00–14:00 h (Fig. 2). Air temperature (T_{air}) generally paralleled with PAR, increasing from a low value at 07:00 h to a maximum value at 16:00 h. The air relative humidity (RH) decreased gradually from the morning to the lowest at 15:00 h in May, July and August, while 18:00 h in September, and increased hereafter (Fig. 2). In a daily scale, both T_{air} and RH were higher in August than the other months. The morning T_{air} in May and September are lower than July and August.

Soil water content: The 0-100 cm average soil water content (SWC) in September was 13.88%, 15.28%, 14.81%, 16.35%, 14.77% and 15.92% for cvs. Polaris, Alfalfaqueen, Algonquin, Sanditi, Ningxia and Xinjiang Daye alfalfa, respectively (Fig. 3). The SWC in September was higher than those in May with increments of 40.63%, 40.31%, 47.22%, 101.11%, 55.80% and 57.31% for the six alfalfa cultivars, respectively. In May, SWC for cv. Ningxia was nearly the same in each layer along the 0-100 cm soil profile, while for the other five cultivars, it was slightly lower in the upper 0-40 cm than the left 60 cm depth. In

July, average SWC in the 0-100 cm layer was 7.53%, 8.94%, 8.19%, 8.12%, 7.00% and 9.25% for the six cultivars, respectively. The reduction was mainly due to the sharp decrease in the SWC at the 0-40 cm soil profile. In August, SWC in 0-100 cm for the six alfalfas were 10.64%, 11.24%, 11.47%, 12.28%, 12.06% and 15.58%, respectively. Soil water in the 0-70 cm layer was continuously recharged, especially for cv. Xinjiang Daye alfalfa which was increased in the whole profile. The mean SWC increased continuously in September and the values were 13.88%, 15.28%, 14.81%, 16.35%, 14.77% and 15.92% for cvs. Polaris, Alfalfaqueen, Algonquin, Sanditi, Ningxia and Xinjiang Daye, respectively. Generally, soil water distribution curves of cvs. Polaris and Algonquin were similar, whereas cv. Xinjiang Daye exhibited virtually different soil moisture distribution (Fig. 3).

Leaf water potential (ψ_L): All the six alfalfa cultivars showed similar daily variation patterns in ψ_L from May to September (Fig. 4). The ψ_L value for each cultivar reached the highest in the morning at 6:00 h, then decreased to the daily lowest at 14:00 h in each month, and then recovered at 18:00 h. In May, cv. Polaris had lower ψ_L at each hour and daily mean, and cv. Xinjiang Daye had relatively higher ψ_L values in the morning and afternoon at each hour. In other three months, there were no obvious differences in instantaneous ψ_L value among the six cultivars during the daytime. In May, cv. Xinjiang Daye showed the highest daily mean ψ_L values, while in the other three months, cv. Polaris had relatively lower daily mean ψ_L values (Tables 1-4). In each month, cv. Algonquin showed lower variations in ψ_L values difference at 18:00 h and 14:00 h, while cvs. Santati, Ningxia and Xinjiang Daye showed the same ψ_L values at 6:00 h in the morning.

Leaf photosynthesis: Diurnal courses of $P_N$for all six alfalfa cultivars presented a bimodal pattern in each month, except cv. Ningxia showed unimodal pattern in May and August (Fig. 5). For each cultivar, the highest daily mean P_N values were observed in May (11.8-21.9 mmol m^{-2} s^{-1}), followed by September, and the lowest values were observed in July and August without significant difference between (6.7-12.7 mmol m^{-2} s^{-1}) (p>0.05). There was no obvious consistence in the show time of daily maximum P_N value in the six alfalfas, and generally, the daily maximum P_N values appeared at 10:00 h or 12:00 h (Fig. 5). Cvs. Ningxia and Xinjiang Daye alfalfa had relatively lower daily mean P_N value among the six cultivars in each month.

The diurnal course of E experienced a bimodal pattern in May, July and August, except cv. Polaris in May and cv. Algonquin in August, which showed a unimodal pattern (Fig. 6). Except cv. Algonquin, the diurnal variations of E in all the other five cultivars displayed a unimodal pattern in September. Polaris had relatively lower daily mean E in May, July and September, and it was cv. Ningxia alfalfa in August. In May and July, cv. Alfalfaqueen showed higher daily mean E values, while in August and September Sanditi took the position.

In May, WUE for each alfalfa decreased gradually from the morning until afternoon, except cv.Polaris whose rose a little since 16:00 h (Fig. 7). In July, except Polaris, the daily change course of WUE for the other five cultivars presented a "L" pattern, and the inflection point was 14:00 h or 16:00 h. In August and September, The diurnal course of WUE of all six cultivars experienced a bimodal pattern, except in September cvs. Sanditi and Xinjiang Daye decreased gradually from 8:00 h as in May. In August, cv. Ningxia had significantly higher daily mean of WUE than the others (p<0.05). In July, cv. Polaris had significantly higher while Ningxia had significantly lower daily mean WUE (p<0.05). In May and September, cv. Polaris had significantly higher while cv. Xinjiang Daye had significantly lower daily mean WUE (p<0.05).

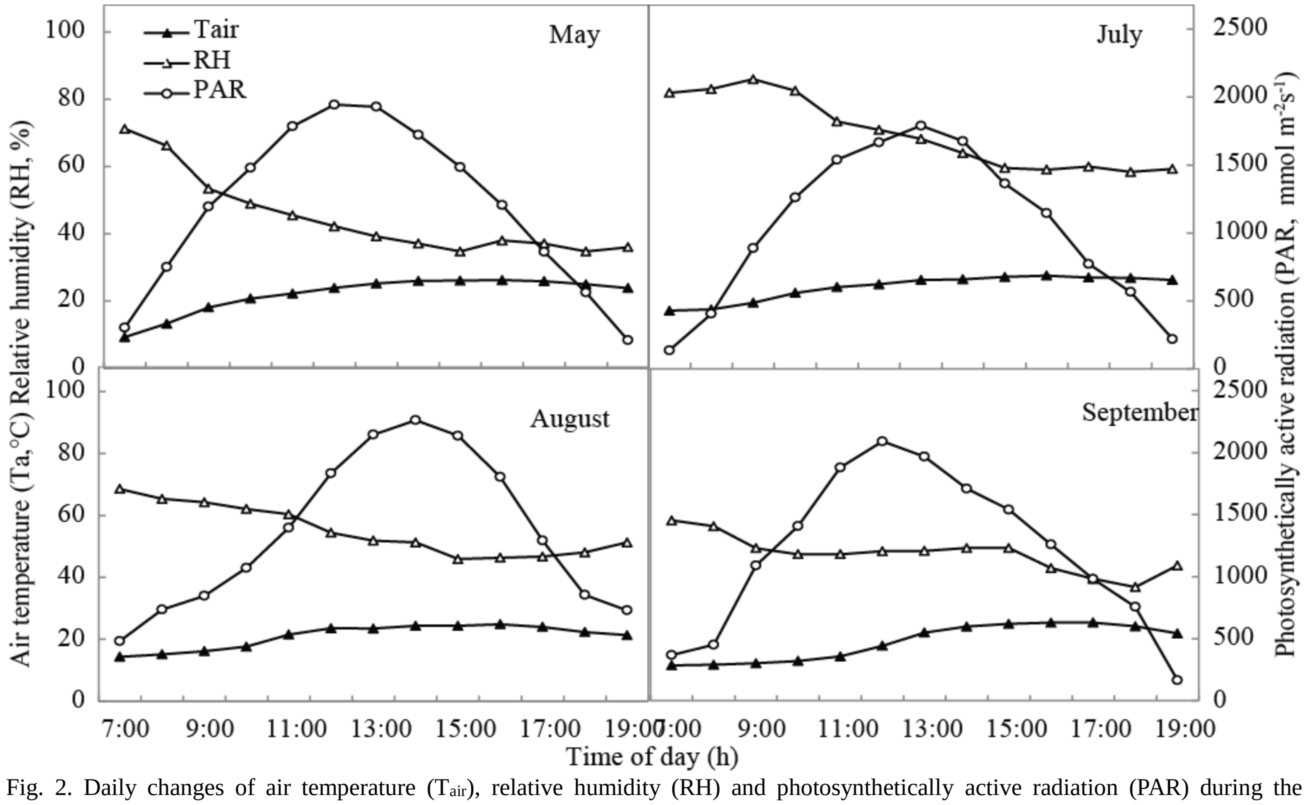

Fig. 2. Daily changes of air temperature (T_{air}), relative humidity (RH) and photosynthetically active radiation (PAR) during the experimental month in 2014.

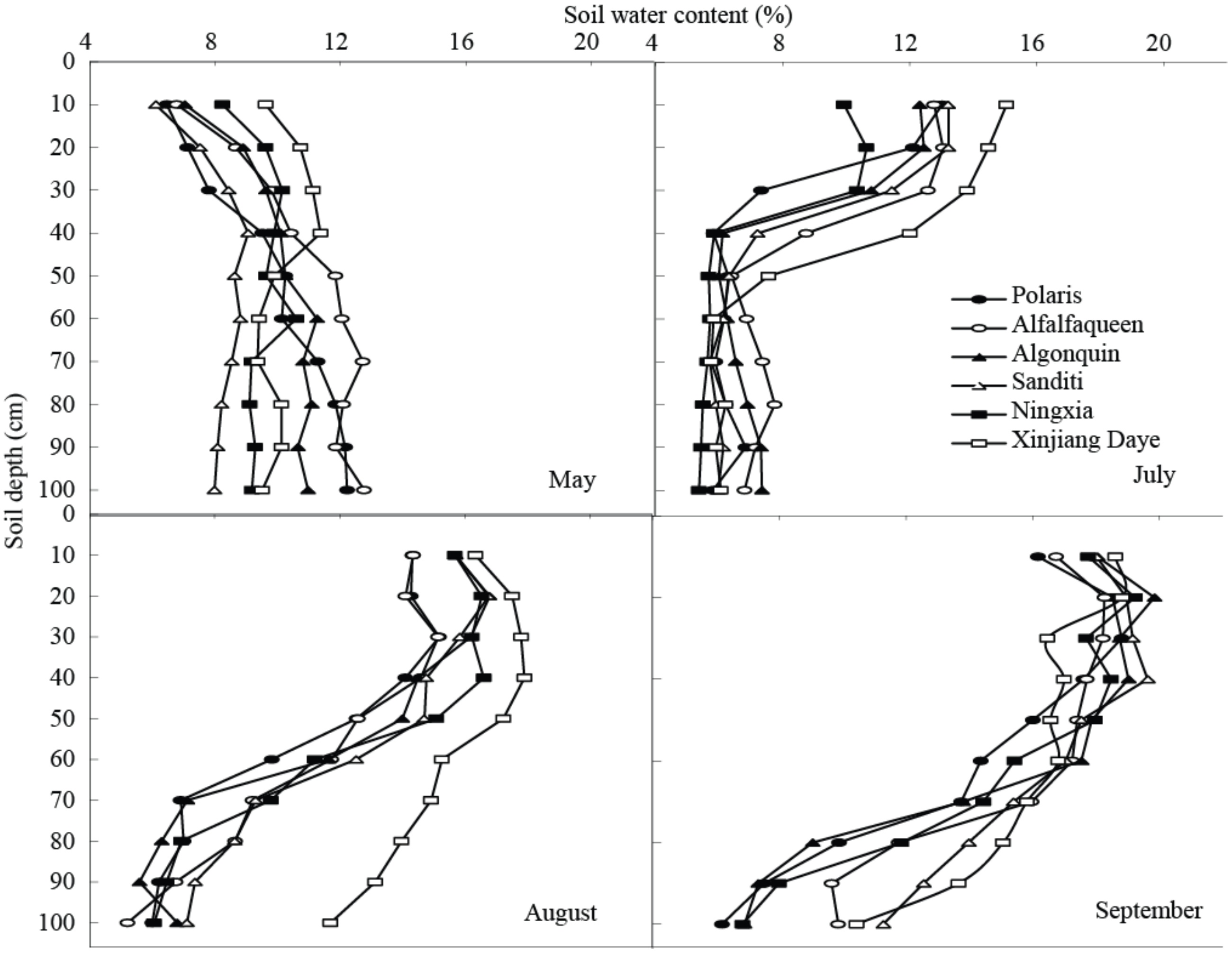

Fig. 3. Soil water content distribution at each growth month in 2014.

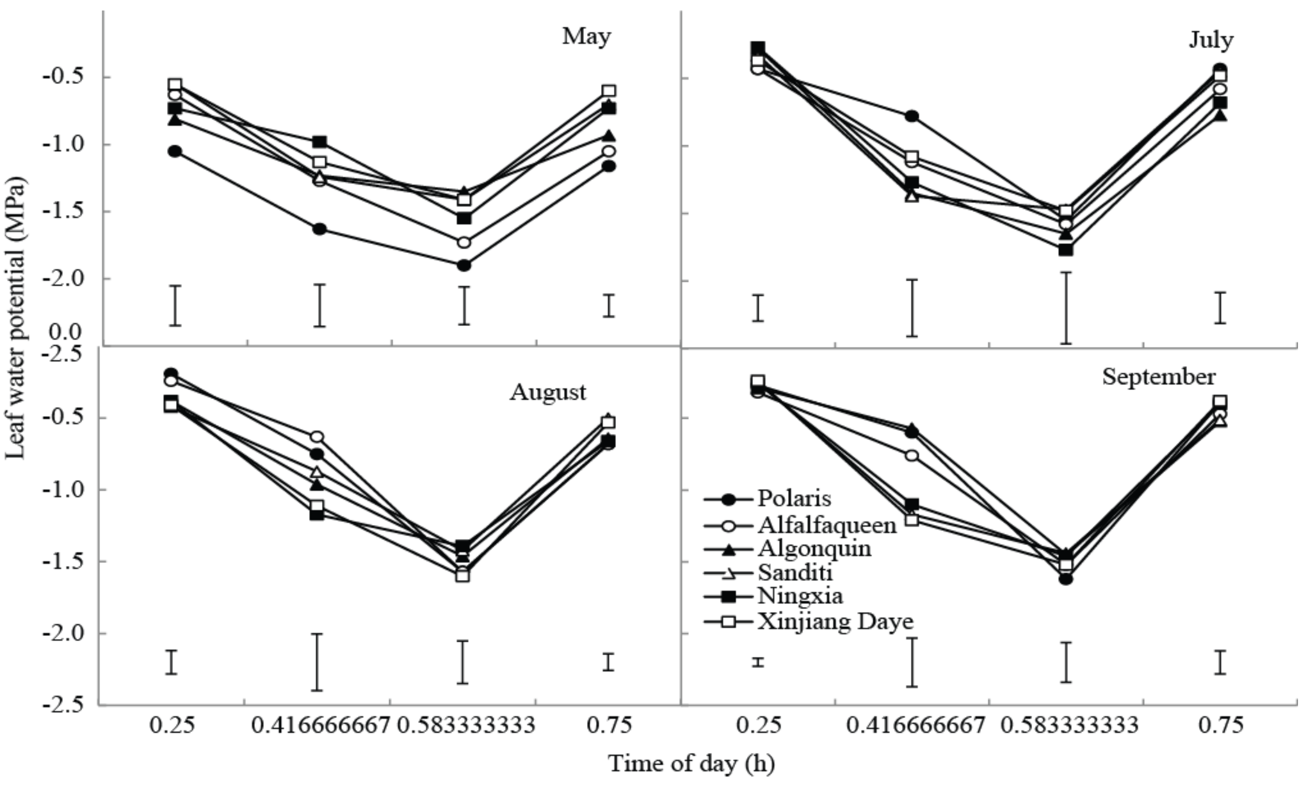

Fig. 4. Daily change of leaf water potential of the six alfalfa cultivars at each growth month in 2014. Vertical bars indicates the LSD value ($p \leq 0.05$) for differences between alfalfa cultivars at each hour.

Table 1. Daily changes of leaf water potential (Ψ_L, MPa) of six alfalfa cultivars in May, 2014.

Alfalfa	Time				Daily averaged	Difference of Ψ_L at 14:00 and 6:00	Difference of Ψ_L at 18:00 and 14:00
	6:00	10:00	14:00	18:00			
Polaris	-1.05 ± 0.07	-1.63 ± 0.06	-1.90 ± 0.08	-1.16 ± 0.07	-1.44 ± 0.40	0.85 ± 0.14	0.74 ± 0.09
Alfalfaqueen	-0.63 ± 0.06	-1.27 ± 0.06	-1.73 ± 0.05	-1.05 ± 0.04	-1.17 ± 0.46	1.10 ± 0.09	0.68 ± 0.02
Algonquin	-0.81 ± 0.18	-1.23 ± 0.10	-1.35 ± 0.09	-0.93 ± 0.05	-1.08 ± 0.25	0.54 ± 0.23	0.42 ± 0.13
Sanditi	-0.55 ± 0.07	-1.24 ± 0.14	-1.41 ± 0.09	-0.70 ± 0.08	-0.98 ± 0.41	0.86 ± 0.14	0.71 ± 0.03
Ningxia	-0.73 ± 0.08	-0.98 ± 0.13	-1.55 ± 0.13	-0.73 ± 0.02	-1.00 ± 0.39	0.82 ± 0.05	0.82 ± 0.11
Xinjiang Daye	-0.55 ± 0.08	-1.13 ± 0.10	-1.41 ± 0.10	-0.60 ± 0.04	-0.92 ± 0.42	0.86 ± 0.13	0.81 ± 0.06

Table 2. Daily changes of leaf water potential (Ψ_L, MPa) of six alfalfa cultivars in July, 2014.

Alfalfa	Time				Daily averaged	Difference of Ψ_L at 14:00 and 6:00	Difference of Ψ_L at 18:00 and 14:00
	6:00	10:00	14:00	18:00			
Polaris	-0.43 ± 0.08	-0.78 ± 0.08	-1.55 ± 0.13	-0.43 ± 0.03	-0.80 ± 0.53	1.12 ± 0.15	1.12 ± 0.16
Alfalfaqueen	-0.43 ± 0.10	-1.12 ± 0.03	-1.58 ± 0.18	-0.58 ± 0.08	-0.93 ± 0.53	1.15 ± 0.26	1.00 ± 0.13
Algonquin	-0.30 ± 0.03	-1.40 ± 0.20	-1.70 ± 0.22	-0.80 ± 0.06	-1.01 ± 0.61	1.40 ± 0.21	0.90 ± 0.20
Sanditi	-0.33 ± 0.03	-1.37 ± 0.14	-1.47 ± 0.15	-0.45 ± 0.09	-0.90 ± 0.60	1.13 ± 0.13	1.02 ± 0.08
Ningxia	-0.27 ± 0.03	-1.27 ± 0.12	-1.77 ± 0.06	-0.68 ± 0.08	-1.00 ± 0.66	1.50 ± 0.05	1.08 ± 0.03
Xinjiang Daye	-0.37 ± 0.03	-1.08 ± 0.03	-1.48 ± 0.10	-0.48 ± 0.03	-0.85 ± 0.52	1.12 ± 0.08	1.00 ± 0.10

Table 3. Daily changes of leaf water potential (Ψ_L, MPa) of six alfalfa cultivars in August, 2014.

Alfalfa	Time				Daily averaged	Difference of Ψ_L at 14:00 and 6:00	Difference of Ψ_L at 18:00 and 14:00
	6:00	10:00	14:00	18:00			
Polaris	-0.19 ± 0.05	-0.75 ± 0.08	-1.57 ± 0.04	-0.68 ± 0.05	-0.80 ± 0.57	1.38 ± 0.09	0.89 ± 0.07
Alfalfaqueen	-0.24 ± 0.11	-0.63 ± 0.11	-1.57 ± 0.12	-0.68 ± 0.02	-0.78 ± 0.56	1.33 ± 0.12	0.89 ± 0.11
Algonquin	-0.38 ± 0.05	-0.96 ± 0.21	-1.46 ± 0.15	-1.07 ± 0.14	-0.86 ± 0.46	1.07 ± 0.14	0.82 ± 0.15
Sanditi	-0.42 ± 0.04	-0.87 ± 0.18	-1.42 ± 0.10	-0.50 ± 0.01	-0.80 ± 0.46	1.01 ± 0.13	0.92 ± 0.10
Ningxia	-0.38 ± 0.03	-1.17 ± 0.17	-1.49 ± 0.15	-0.66 ± 0.09	-0.93 ± 0.46	1.11 ± 0.17	0.83 ± 0.21
Xinjiang Daye	-0.41 ± 0.06	-1.11 ± 0.11	-1.60 ± 0.08	-0.53 ± 0.05	-0.91 ± 0.55	1.19 ± 0.12	1.06 ± 0.09

Table 4. Daily changes of leaf water potential (Ψ_L, MPa) of six alfalfa cultivars in September, 2014.

Alfalfa	Time				Daily averaged	Difference of Ψ_L at 14:00 and 6:00	Difference of Ψ_L at 18:00 and 14:00
	6:00	10:00	14:00	18:00			
Polaris	-0.27 ± 0.02	-0.60 ± 0.09	-1.62 ± 0.03	-0.39 ± 0.02	-0.72 ± 0.61	1.35 ± 0.05	1.22 ± 0.05
Alfalfaqueen	-0.32 ± 0.02	-0.76 ± 0.04	-1.52 ± 0.03	-0.47 ± 0.07	-0.77 ± 0.53	1.19 ± 0.04	1.05 ± 0.10
Algonquin	-0.29 ± 0.01	-0.57 ± 0.11	-1.45 ± 0.09	-0.52 ± 0.06	-0.71 ± 0.51	1.16 ± 0.08	0.93 ± 0.08
Sanditi	-0.25 ± 0.01	-1.17 ± 0.18	-1.44 ± 0.08	-0.51 ± 0.03	-0.84 ± 0.55	1.19 ± 0.08	0.93 ± 0.11
Ningxia	-0.26 ± 0.02	-1.10 ± 0.05	-1.46 ± 0.05	-0.40 ± 0.05	-0.81 ± 0.57	1.20 ± 0.04	1.06 ± 0.04
Xinjiang Daye	-0.24 ± 0.02	-1.21 ± 0.03	-1.52 ± 0.13	-0.38 ± 0.03	-0.84 ± 0.62	1.28 ± 0.11	1.14 ± 0.15

Discussion

Although environmental factors play important impacts on plant eco-physiological appearances in the field, and here the six alfalfa cultivars were cultivated in the same place, their performance differences in leaf water relations and photosynthesis were mainly due to the inherent difference (Anower *et al*., 2015). All the six alfalfa cultivars exhibited diurnal fluctuations in ψ_L as evaporative requirements varies during the daytime (Figs. 4 and 6). For the water status of plants recovers in the night through root water absorption and reach the highest level before sunrise, theψ_{PL} value has been regarded as the indicator of plant level water status (Sato *et al*., 2006). Generally, the ψ_{PL} values for each alfalfa in May was lower than in the other three months, consisting with low SWC in the 0-100 cm profile (Fig. 3). Gradual changes of water potential determine the rate of sap flow within a plant and build an important link between the atmospheric demand and stomata(Agele *et al*., 2006). The water potential gradient *i.e*. ψ_L differences between 18:00 h and 14:00 h indicated the plant ability in recovering water status after intense vapour pressure released, and the values bigger, the stronger the plants in maintaining water balance (Sato *et al*., 2006). Results showed in May, the ψ_L value changes between 18:00 h and 14:00 h of cvs. Ningxia and Xinjiang Daye were significantly (p<0.05) compared with the other four cultivars, indicating that domestic cultivars were superior in adjusting water status than introduced cultivars in dry month (Table 1). The daily decline of ψ_L (predawn ψ_L to midday ψ_L) is related to the stomatal closure pattern and water storage in plant (Hinckley *et al*., 1983; Bargali & Tewari, 2004). In May, Algonquin alfalfa had significantly lower water potential gradient between predawn ψ_L to midday ψ_L, and also between 18:00 h and 14:00 h, respectively, indicating that it had stronger ability in maintain water status in dry month (Table 1) (Bargali & Tewari, 2004).

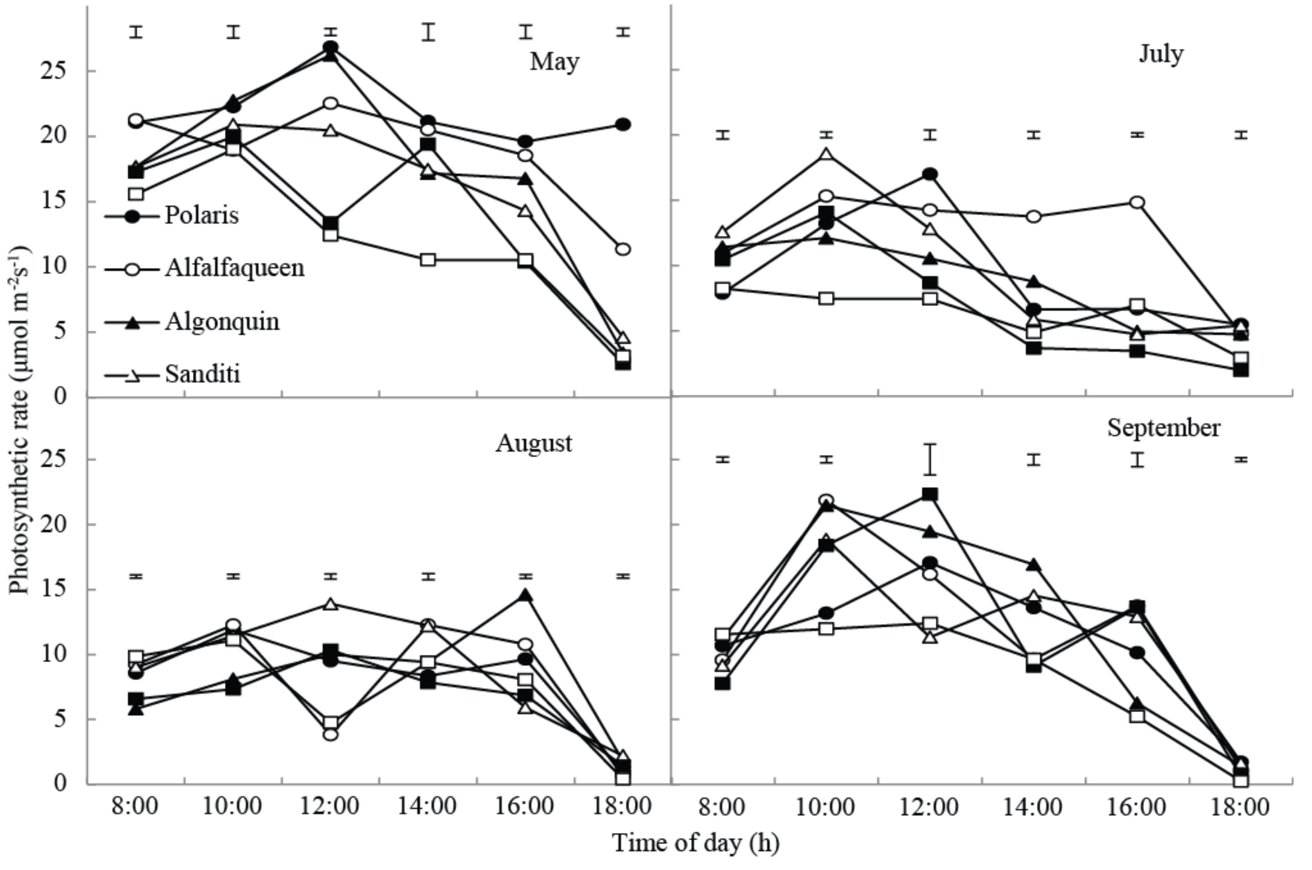

Fig. 5. Daily changes of leaf photosynthetic rate (P_N) of the six alfalfa cultivars at each month in 2014. Vertical bars indicates the LSD value ($p\leq0.05$) for differences between alfalfa cultivars at each hour.

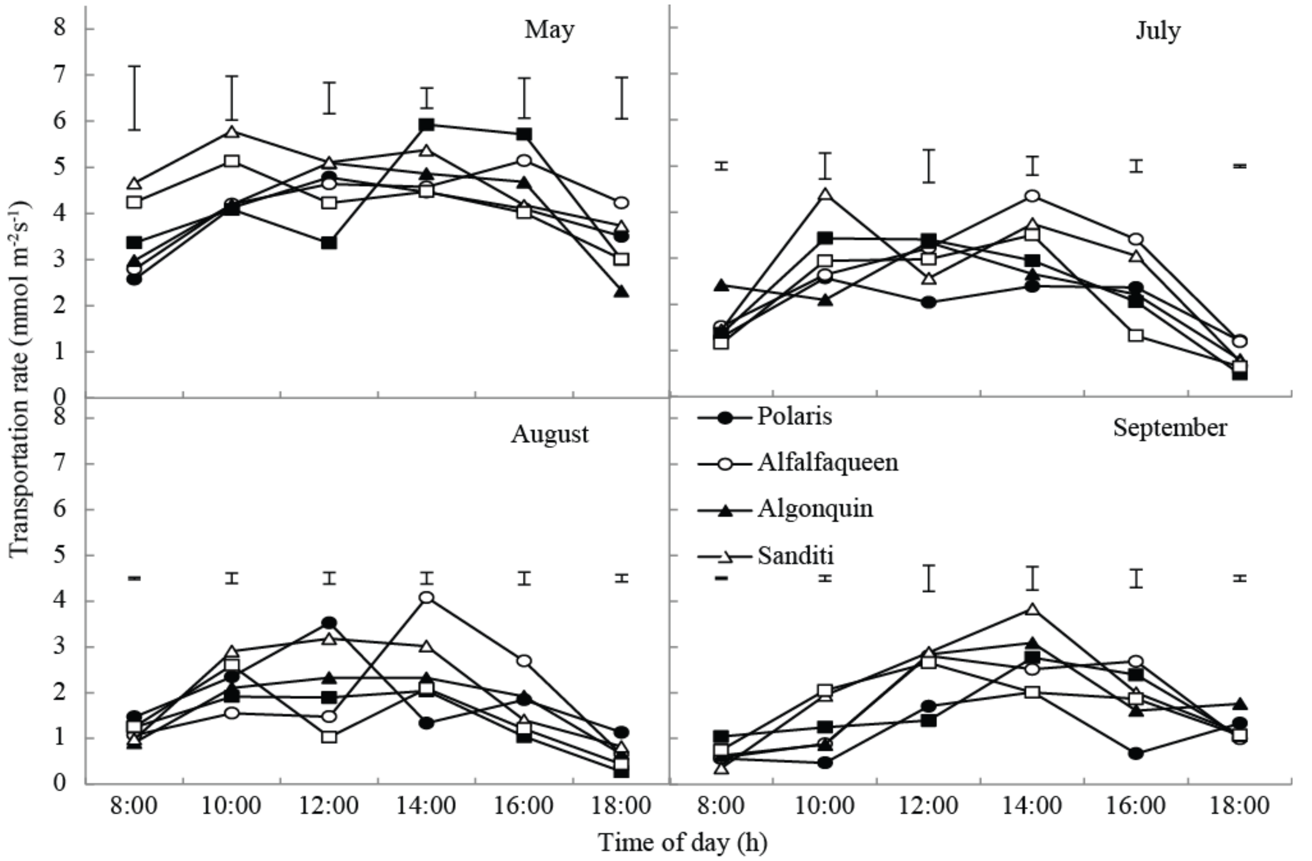

Fig. 6. Daily changes of leaf transportation rate (E) of the six alfalfa cultivars at each month in 2014. Vertical bars indicates the LSD value ($p\leq0.05$) for differences between alfalfa cultivars at each hour.

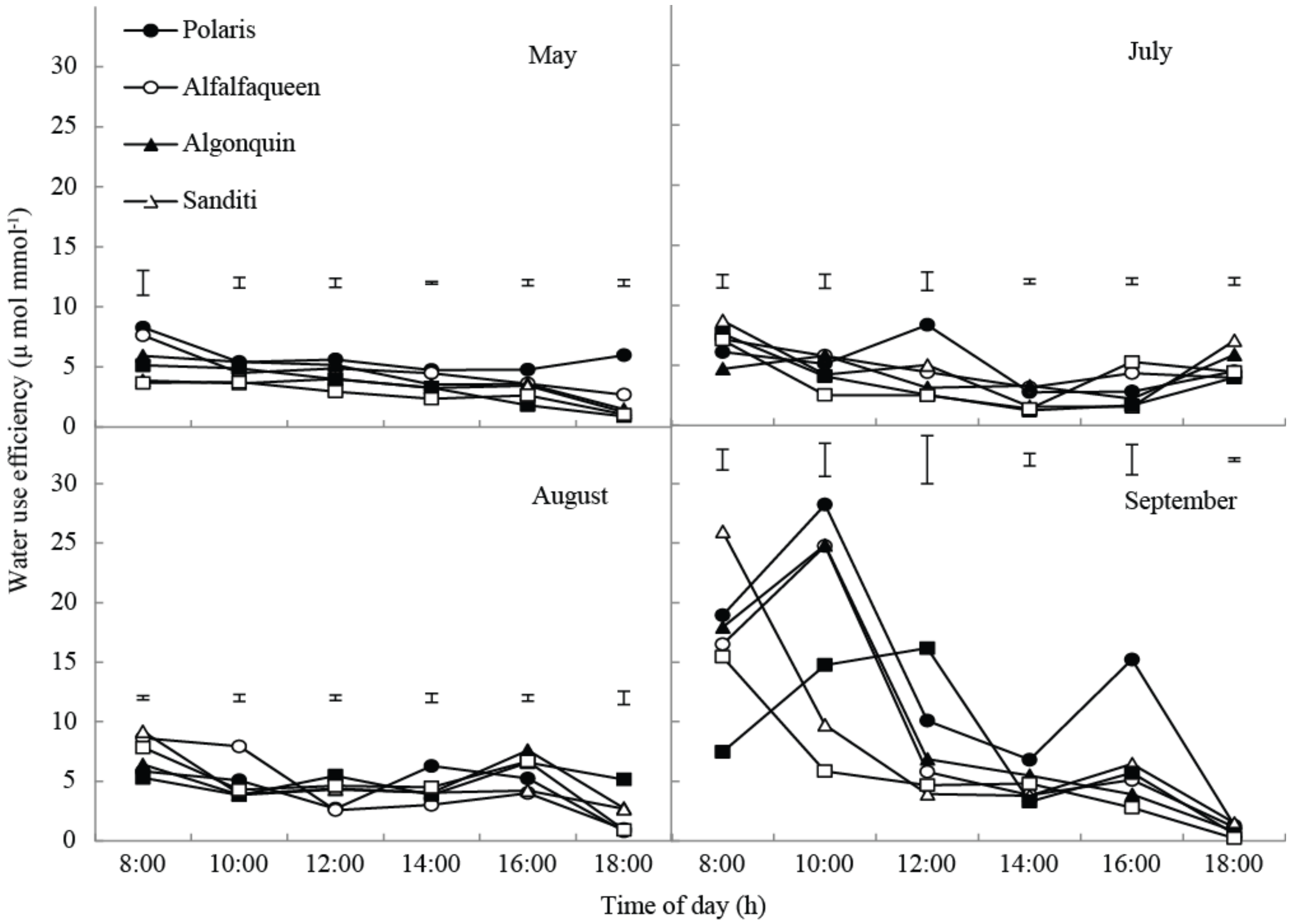

Fig. 7. Daily changes of water use efficiency (WUE) of the six alfalfa cultivars at each month in 2014. Vertical bars indicates the LSD value ($p \leq 0.05$) for differences between alfalfa cultivars at each hour.

Environmental stresses such as high irradiances, high vapour pressure deficits (VPD) and high air temperature, and physiological and biochemical limitations affect plant photosynthetic performance (Singaas *et al*., 2000; Zong & Shangguan, 2014; Ali *et al*., 2015). All of six alfalfa cultivars showed daily and seasonal variations in transpiration rate, photosynthetic rate, and leaf instantaneous water use efficiency (Figs. 5-7). In all the four months, cv. Polaris did not show obvious decline in photosynthesis during 12:00 h and 14:00 h in each month, suggesting that no midday depression was present during the measuring period (Hirasawa & Hsiao, 1999). Combined with the daily changes of ψ_L, it can be concluded that cv. Polaris had strong ability in maintaining photosynthesis under low leaf water potential status than the other five cultivars (Singaas *et al*., 2000).Midday depression in photosynthesis was observed in cv. Ningxia but transpiration rate did not decrease or dropped much less in each month, suggesting that P_N midday depression could be due to the reduced photosynthetic activity of mesophyll cells, rather than the stomata closure (Jifon & Syvertsen, 2003; Huang *et al*., 2006; Hu *et al.*, 2009).

Higher photosynthetic rate and WUE means plant use less water while produce more biomass (Erice *et al*., 2011). Higher WUE is an important part of plant eco-adaptation, and a key approach to improve plant performance under drought environment, especially for alfalfa, which is high-water consuming forage crop around the world (Shan & Xu, 2009; Anower *et al.*, 2015). Research showed that the four introduced alfalfa cultivars had higher WUE according to biomass production and soil water consumption (Wan *et al*., 2007). Cv. Xinjiang Daye had significantly lower daily mean P_N and leaf WUE in each month among the six alfalfa cultivars (Figs. 5 and 7). In this study, daily mean P_N and leaf WUE values of cvs. Ningxia were higher than Xinjiang Daye, while lower than the four introduced cultivars. Higher P_N and leaf WUE of the four introduced alfalfa cultivars implied that they were more efficient in using water and yield biomass than the other two domestic cultivars.

Conclusions

We have briefly reported the daily fluctuations and monthly variations in photosynthesis and leaf water potential of six alfalfa cultivars on the semiarid Loess Plateau at a normal rainfall year. Results showed that four introduced alfalfa cultivars had relatively higher photosynthetic rate and water use efficiency than the two domestic ones, indicating their adaptive ability to drought environments and their promising in cultivation. Weaker performance in leaf photosynthesis and water use efficiency of domestic cultivars in the regionlimit biomass production and their extension in growing areas in the semiarid regions on the Loess Plateau.

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