

RELATIONSHIP BETWEEN PHYSIOLOGICAL INDICATORS OF OAT AND METEOROLOGICAL FACTORS IN TIBET'S ALPINE PASTORAL AREAS

TANG, P. C.^{1,2,3} – XU, B.^{3*} – GAO, Z. Y.^{1,2} – LI, H. P.³ – XU, Y.⁴ – HE, M.⁴

¹State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin
No. 1 Fuxing Road, 100038 Beijing, PR China

²China Institute of Water Resources and Hydropower Research (IWHR)
No. 1 Fuxing Road, 100038 Beijing, PR China

³Institute of Water Resources for Pastoral Area of IWHR
No. 128 Daxue East Road, Saihan, 010020 Hohhot, PR China

⁴Hebei Institute of Water Resources
No. 310 Taihua Road, 050000 Shijiazhuang, PR China

*Corresponding author

e-mail: 543077207@qq.com; phone: +86-188-4717-1366

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Abstract. According to large daily temperature difference, strong solar radiation and significant change of air humidity in the alpine area of Tibet, a field experiment was conducted to analyze the oat's diurnal variation of the leaf water potential (ψ_L), transpiration rate (Tr) and net photosynthetic rate (Pn). Meanwhile, the relationship between oat's physiological indicators and typical meteorological factors (atmospheric temperature (T), solar radiation (R_s), relative air humidity (RH)) were investigated with regression models. Results showed that the oat's daily change curve of ψ_L showed 'V-type' in the seeding and heading stages and 'W-type' in the jointing and tillering stages. As shown in the results, oat's Pn presented a decreasing tendency in a day and the peak appearing between 9:00 and 10:00 at one day in each growing stage. The Tr presented double-peak curves and midday depression in the seeding and heading stages. The variation tendency about oat's Tr in the tillering stage and jointing stage was "Multi-peak" type without distinct midday depression and parabolic tendency. By multiple regression analysis between the data of oat's physiological indexes and comprehensive factors, the ψ_L , Tr and Pn of oat in alpine region can be predicted under condition of adequate water supply.

Keywords: oat, leaf water potential, transpiration rate, net photosynthetic rate, meteorological factor, high-altitude area

Introduction

In recent years, with the development of pasture land water conservancy, the study of artificial grass water requirement and irrigation program is a public concern. Then the moisture physiological characteristics of pasture are of special note. For example, Liu et al. (2009) studied the effect of soil water stress on osmoregulation substance content of oat leaf. However, the relationship between leaf water potential (ψ_L), transpiration rate (Tr), photosynthetic rate (Pn), which are the important parameters in the water cycle processes and meteorological factors are rarely investigated.

The leaf water potential is a basic indicator to reveal the status of crop water. The change of leaf water potential depends on many requirements of soil-plant-atmosphere continuum and complex interaction among the regions of plant. The daily variation rule of leaf water potential about winter wheat in the filling stage under the condition of

sprinkling irrigation and surface irrigation were investigated by Yao et al. (2009). It found that the leaf water potential of winter wheat irrigated by sprinkling irrigation was higher than that by surface irrigation. Due to the individual and environmental variations, the leaf water potential of different plants will be different. The value of leaf water potential is associated closely with its yield, which is also varied with environmental factors. Kang et al. (1994) found that the Ψ_L of winter wheat will decrease with crop growing. Fu et al (2012) showed that the soil moisture content and temperature were the main factors for the leaf water potential change of *Phragmites* in arid areas. However, the relationship between leaf water potential of oat and meteorological indexes is remains unclear.

Transpiration regulates the water balance in plants and is influenced indirectly by environmental factors through effects on stomatal opening (Tamang and Sadok, 2018). Liu et al. (2003) studied the transpiration diurnal characteristics of spring wheat and found that the solar radiation and temperature will affect transpiration obviously. Peng et al. (2005) considered that the reduction of soil water content would put off the diurnal maximum of transpiration of late rice. His study also showed that there were different effects degree of vapor pressure deficit and stomatal conductance on transpiration of late rice in the different growth stages. Evapotranspiration and stomatal conductance are known to decrease as leaves age increasing in many species (Sobrado et al., 1994). Meanwhile, stomatal conductance for transfer of water vapor from the interior of the leaf to the atmosphere is affected by irradiance, leaf age, temperature, leaf water status, and the difference in absolute humidity between ambient air and the interior of the leaf (Wardlaw et al., 1967; Johnson et al., 1983; Ku et al., 1977; Li and Zhou, 2004; Zhao et al., 2011). Some studies found that there was significantly correlational relationship between stomatal conductance and temperature, humidity and leaf water potential. At present, the model about relationship between stomatal conductance and environmental factors is composed of two classes. One is empirical model, such as Jarvis, Ball and so on (Ball et al., 1987; Jarvis et al., 1976; Leuning, 1995). Others are the optimization theory of stomatal regulation proposed by Cowan and Farquhar (1977) and optimization model of stomatal conductance established by Medlyn et al. (2011).

The diurnal variation of plant photosynthesis is not only the basic unit of material accumulation and physiological metabolism in the plant's production process but also an important method to analyze the impact of environment on plant growth and metabolism. Under normal circumstances, the daily change curve of plant photosynthesis is a bimodal type or unimodal type. Yu et al. (2015) reported that the diurnal variation of net photosynthesis of *maize* presenting the bimodal curve with apparent photosynthetic "noon break" phenomenon. The diurnal variation of plant photosynthesis is different from the separate plant species and the surrounding environment change (Farquhar and Sharkey, 1982). Many environmental factors will affect the plant photosynthesis, such as Photon flux density, temperature, relative humidity and so on. Under natural conditions, the influence of environmental factors on plant photosynthesis is the result of combination. However, there is hardly any research on the impact of meteorological indexes on oat photosynthesis is rarely.

The objectives of this research are:

- (1) To investigate the daily variation of oat's Ψ_L , P_n and Tr in different growth stages on the condition of full irrigation in plateau area.
- (2) To determine the relationships between oat's physiological indexes and meteorological factors in plateau area.

Materials and methods

Experimental site

Tibet, which is mainly located in Qinghai-Xizang Plateau, is in the average elevation of 4000 m. There are 820 million ha natural grasslands in the alpine area of Tibet and the meteorological characteristics are large daily temperature difference, strong solar radiation and significant change of air humidity in this area. The problems of uneven distribution of water-heat resource in space-time and soil depletion are severe in the northern of Tibet plateau region especially. The special physiographic factors and production custom make the grass irrigation technology lagged far behind.

Field experiments were conducted in the central Tibet with longitude 90°45'-91°31' and north latitude 29°31'-31°04' in the Damxung County in Lasa (Fig. 1). The region with an average altitude of 4200 m is plateau-continental climate and the rainy season and dry season are clear. The annual mean precipitation is 480 mm and the rain mainly fall between June and September. In the region, with multi-year average evaporation being 1966 mm, the frost-free period is only 60 days and percentage of sunshine is above 60% in a year. The study area has adequate solar resource but is lack of hot resource. Table 1 presents information on the physical properties of the soil in the field area. Surface soil above 40 cm mainly consists of loam, while the lower layer mainly consists of silver sand and rubble.

Table 1. Physical properties of the soil in the field area

Soil horizon (cm)	Field capacity (%)	Soil bulk density (g/cm ³)	Percent clay (%)	Percent loam (%)	Percent sand (%)	Soil texture
0-10	17.96	1.48	7.8	44.07	48.13	Loam
10-20	16.14	1.59	7.66	43.48	48.85	Loam
20-30	18.03	1.55	7.51	42.8	49.69	Loam
30-40	18.28	1.56	8.08	47.11	44.81	Loam

Note: Soil texture classification according to the quality standard of America

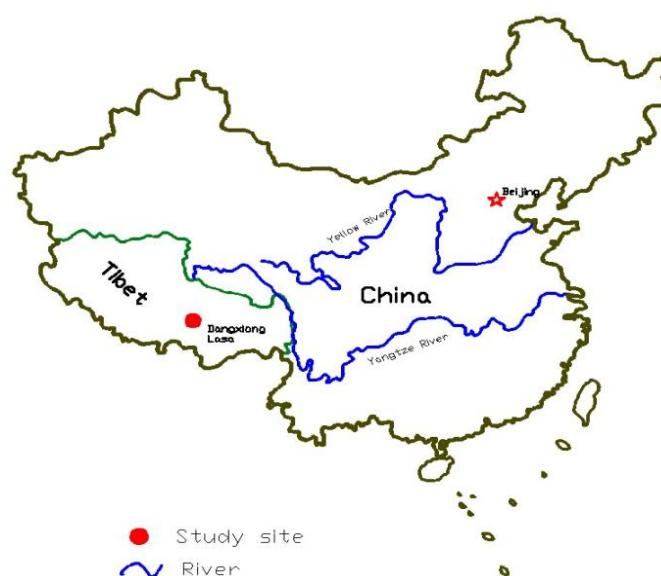


Figure 1. The location of study site

Agronomy

The experimental design was a randomized complete block with 3 replications. Each experimental plot was 12 m long by 5 m wide (60 m²) with 30 cm height ridge. A buffer zone spacing of 2.00 m was provided between the plots. The oat (Danmai 444) was used for the experiment and planted on June 15th in 2013. The sowing rate was 187.5 kg/ha and the planting method was strip seeding with line spacing of 25 cm. Before planting, 4.5 t/ha organic fertilizer and 224.9 kg/ha N (as ammonium nitrate) were fertilized. One and half months after planting, a further 74.96 kg/ha of N (as ammonium nitrate) was applied. Crops were manually harvested when ripe rate reached about 95% (early September). Soil moisture was measured once every 7 days using TDR and validated by soil samples using soil drilling. The experiment was carried out without water stress. When the soil moisture was lower than the lower irrigation limit (W_{cg}), the irrigation would be carried out with ground irrigation. The detailed growing period information of oat and lower irrigation limit are shown in *Table 2*.

Table 2. Growing period of oat and lower irrigation limit

Growth period	Seeding stage		Tillering stage	Jointing stage	Heading stage
	Pre-emergence	After emergence			
P_g	Early June-late June	Late June-early July	Early July-middle of July	Late July- middle of August	Late August-harvest
W_{cg}	70(%) FC	70(%) FC	70(%) FC	75(%) FC	70(%) FC

Notes: (a) Each stage water condition refers to the percentage of maximum field capacity (FC); W_{cg} : Lower irrigation limit in different growth period with full irrigation (b) P_g : The beginning and ending of growth period

Meteorological factors

Due to the large daily temperature difference, strong solar radiation and significant change of air humidity, in the research district, we selected the T , R_s and RH as the typical meteorological factors. The data of RH and T were measured by the meteorological station in farmland of Damxung and R_s was calculated from the *Equations 1* and *2* (Allen et al., 1998).

$$R_a = \frac{12 \times 60 \times G_{sc} \times dr [(\omega 2 - \omega 1) \sin(\Phi) \sin(\delta) + \cos(\Phi) \cos(\delta) \sin((\omega 2) - \sin(\omega 1))]}{\pi} \quad (\text{Eq.1})$$

$$R_s = \left(0.25 + 0.5 \times \frac{n}{N}\right) \times R_a \quad (\text{Eq.2})$$

where R_a is extraterrestrial radiation, MJm⁻² h⁻¹; R_s is solar radiation, MJm⁻² h⁻¹; G_{sc} is solar constant, 0.082; dr is the reciprocal of relative distance between the sun and earth; δ is the solar declination; Φ is the geographical latitude; $\omega 1(\omega 2)$ is the solar hour angle in the early (late) period and n/N is the relative sunshine duration.

Measurements

Oat blade with well growth, normal color and size (second leave from the top of plant in seedling stage and third leave from the top of plant in tillering stage, jointing

stage and heading stage) were selected to monitor the leaf water potential (ψ_L , MPa) with 3 plants replication using the water dew point meter (Psypro, Wescor Inc in USA) every one hour. Oat blades with well growth and normal color and size were selected to monitor the transpiration rate (Tr , millimol \cdot m $^{-2}$ s $^{-1}$) and net photosynthetic rate (Pn , μ mol \cdot m $^{-2}$ s $^{-1}$) using automatic portable photosynthesis system (LCPro-SD, ADC in British) every 1 h with 3 plants replication. The meteorological characteristics of measurement's days are better sunshine, gentle breeze and no rainfall. The ψ_L was measured for one day in seeding, tillering and heading stage, and measured for 6 days at jointing stage. The Tr and net Pn were measured for one day in seeding, tillering, jointing and heading stage, respectively.

Data analysis

The data were subjected to the analysis of regression for meteorological factors and crop physiological indexes using SPSS software. The significance of regression model was determined with an F test. The F-protected least significance difference (LSD) was calculated at the 0.05 and 0.01 probability level, respectively.

Results and discussion

Daily variation of oat's leaf water potential, net photosynthetic rate and transpiration rate at different growth stages

Daily variation of oat's leaf water potential in different growth stages

Under conditions of full irrigation, ample sunshine and suitable temperature, diurnal variation of ψ_L in different growth stages were selected to contrast (Fig. 2). According to the data, the diurnal ψ_L in growth periods ranged largely with maximum of 6 MPa under the special environment of high altitude, strong radiation and large diurnal temperature range in Tibet. However, the ψ_L of winter wheat's variation value was only 3 Mpa and the ψ_L of Mongolian blue-beard grew in the alpine region is only 1.24 Mpa (Han et al., 2008; Tong et al., 2005).

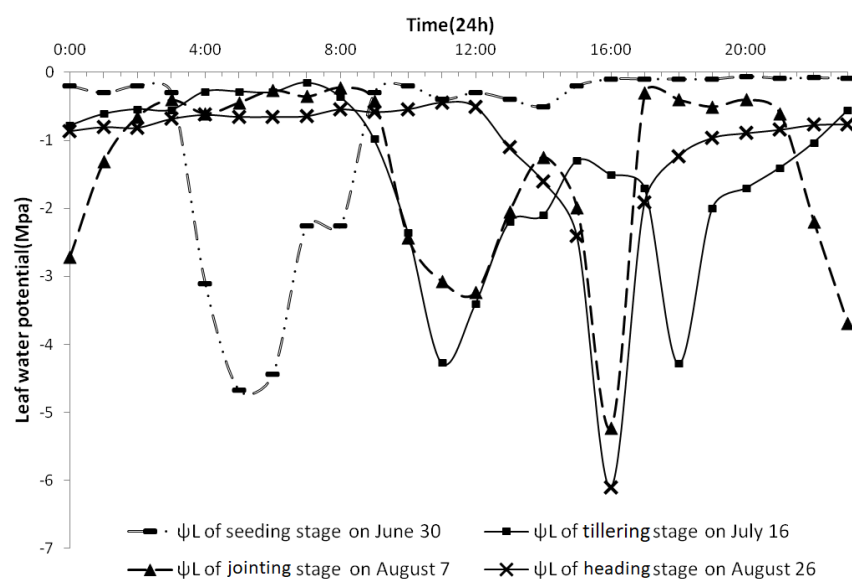


Figure 2. Daily variation of ψ_L under different growing periods

In the seedling stage, the ψ_L usually changed at night and the minimum of -4.67 MPa appeared at day break, and the change trend showed "V-type". The trough of ψ_L happened five hours before sunrise, when T and R_s were lower with the RH being larger. The ψ_L would reach the larger value in the day time. This is due to cells of seedling leaf avoiding to be damaged by radiation or avoiding the effect of water stress on crops by excessive transpiration. The frequent fluctuations of ψ_L at dawn reflected the frequent water exchange with external and stronger life activity in the seedling stage of oat. This indicates that the oat could adapt to the low temperature at night in the seedling stage. In contrast, high temperature and radiation will inhibit the growth of oat in the seedling stage, which is related to the undeveloped oat root and immature mechanism of stomata cell for opening and closing.

(2) In the tillering stage, the oat grew quickly and exchange moisture with external environment frequently. The ψ_L fluctuated significantly at daytime and the trend showed "W-type". The lowest trough of ψ_L appeared at the 10:00 to 11:00 with a minimum value of -4.27 MPa and 18:00 with a minimum value of -4.28 MPa (Fig. 1). With the rise of R_s and T , the oat reduced their own tissue water potential to absorb more moisture for the life activity. The ψ_L decreased after sunrise. The temperature reached the maximum at noon. Through regulating the stomata opening and closing, the oat reduced water loss. Then as the sun set, the T fell, ψ_L reduced again to absorb more moisture. The ψ_L returned to a higher value of -1.7 MPa at 21:00. The results support the conclusions of Guo, et al. (2006) and Tong et al. (2005) that the trend of ψ_L showed "W-type" on the condition of full-irrigation. The oat had already certain adaptability to the change on meteorological factors in the tillering stage. The life activity at daytime was going to be vigorous than it at night.

(3) The jointing stage is the critical period for the organic synthesis and accumulation of plant (Tian et al., 2012). The diurnal variation of ψ_L tended to be stable and the trends were similar to that in the tillering stage with two troughs. The time when the first trough appeared at 11:00 was consistent with the moment of tillering stage's first trough; however, the second trough was about two hours upfront than that in tillering stage with a minimum value of -5.22 Mpa. This phenomenon can be attributed to the special meteorological conditions. The general trend of ψ_L was higher in the morning and evening and the ψ_L was significantly reduced with great fluctuations. At 14:00, the ψ_L was at a high value of -1.24 MPa, when the oat's stomatal conductance decreased rapidly, guard cell shrinkage and partial stomata closure in response to intense light and drying air. Therefore through short "nap", the oat could adapt the change of weather factor and control water balance of the body (Kang et al., 1991).

(4) In heading stage, the reproductive growth replaced the vegetative growth gradually. The ψ_L maintaining a relatively high value tended to "V-model" with a minimum of -6.1 MPa at 16:00 (Fig. 1). The occurrence time of trough agree with the moment of the second trough appeared in tillering and jointing stages. The results are keeping with the conclusions of Guo et al. (2006) that the trend of ψ_L showed "V-type". This proved that water currently had strong driving force to promote water from soil to root at 16:00-18:00 under non-water stress condition. To some extent, it indicates that the heading stage is the critical period to translate the energy to organics and so the lack of water will affect the quality of artificial grassland. However, further study is needed to confirm why the ψ_L with a minimum of -6.1 Mpa at high altitudes lower than other areas obviously.

Daily variation of net photosynthetic rate of oat in different growth stages

In low elevation regions, previous studies suggested that the curves of diurnal variation on P_n of gramineous plants presented double-peak, and an obvious midday depression at 12:00 o'clock (Li et al., 2013; Liu et al., 2006). This study showed that P_n has its unique change rule at high altitudes. The daily variation patterns of P_n of oat are presented in *Figure 2*. As the trend lines implied in *Figure 3*, it presented a decreasing tendency in a day. The variation tendency of oat's P_n were basic consistent without fixed peaks and troughs model in different growth stages. The P_n on the morning was higher than that on the afternoon and the peak appeared between 9:00 and 10:00 at one day. After the peak value appeared, there would be a reduction and the downturn would last a long time in the tillering stage and heading stage. The maximum of P_n in the seeding stage, tillering stage, jointing stage and heading stage were $10.56 \mu\text{mol m}^{-2} \text{s}^{-1}$, $9.91 \mu\text{mol m}^{-2} \text{s}^{-1}$, $10.01 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $9.01 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively.

At 12:00 am and 4:00 pm, an obvious valley appeared in the seeding stage; likewise the valley appeared on the morning and afternoon in the jointing stage, while the minimum values of P_n were $5.1 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $5.4 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively. The P_n in tillering stage witnessed significant downturn at 12:00-14:00, which was similar to the P_n in heading stage at 11:00-14:00, troughs appeared with the minimum value of $5.2 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $4.4 \mu\text{mol m}^{-2} \text{s}^{-1}$, respectively.

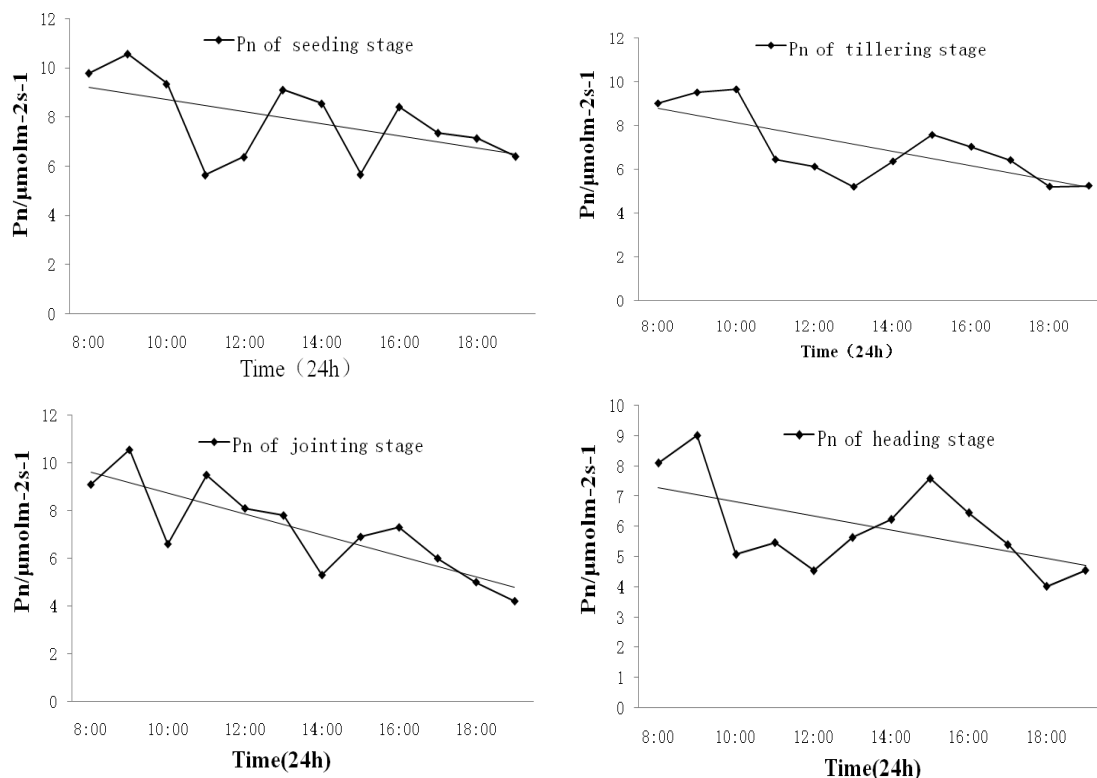


Figure 3. Daily variation of P_n under different growing periods

Daily variation of oat's transpiration rate at different growth stages

The Tr of oat in the seeding stage is obviously less than that in the tillering stage, jointing stage and heading stage (*Fig. 4*).

(1) The Tr presents double-peak curves and midday depression in the seeding and heading stage

The obvious tendency of bimodal patterns about Tr are appeared in the seeding stage and heading stage of oat. This changing trend is similar to the result reported by Luo et al. (2011), the curves of diurnal variation in Tr of *Medicago sativa* had two peaks and an obvious midday depression with or without water stress at lower altitude. At 12:00, the Tr in the seeding stage peaks at the maximum of $45.3 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$, while the midday depression appearing from 13:00 to 16:00. The Tr value is the minimum of one day with being $15.2 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$ at 8:00 in the morning. In heading stage, the maximum value ($64.5 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$) of Tr appeared at 11:00 and the minimum value ($13.7 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$) of Tr appeared at 20:00. The curves of diurnal variation in Tr had an obvious midday depression between 12:00 and 14:00.

(2) The Tr presents “Multi-peak” type in the tillering stage and jointing stage

Different from the current research about grass, the variation tendency on Tr of oat in the tillering stage and jointing stage was “Multi-peak” type without distinct midday depression and parabolic tendency. In tillering stage, the Tr would rise rapidly after sunrise and reach to the first summit ($66.1 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$) at 11:00, and there were more peak values which appeared at 14:00 and 17:00 respectively in one day. In jointing stage, the Tr reached to the first peak ($73.8 \text{ millimol}\cdot\text{m}^{-2} \text{ s}^{-1}$) at 11:00 similarly, and there were more peak values which appeared at 13:00, 15:00 and 17:00 respectively in one day. In this research, the variation tendency of in the tillering stage and jointing stage was different from most graminaceous plants with a single peak (Philip et al., 1966; Yuan et al., 2009).

This study investigated its emergence reason and regulation. On one hand, the result is due to the strong nutritional growth of oat in the tillering stage and jointing stage. There are frequent matter and energy exchange with the environment in these two phases. On the other hand, it is related to the specific weather conditions (such as amounts of moisture in atmosphere vary greatly as a direct result of stronger solar radiation and frequent rainfall in a day) in Tibet alpine pasture.

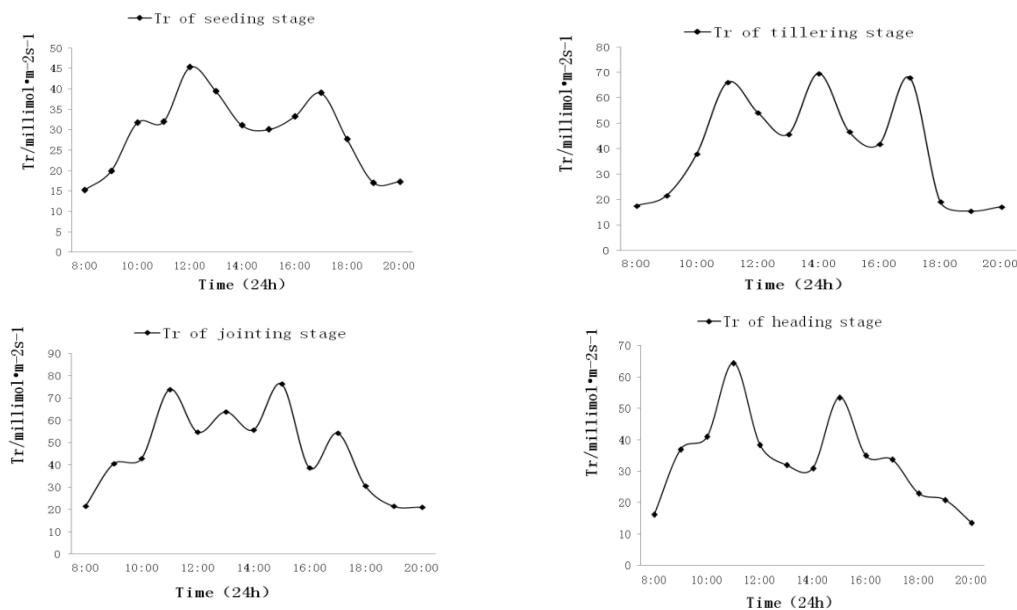


Figure 4. Daily variation of Tr under different growing periods

Relationships between physiological indexes of oat and single meteorological factor

The daily variation relationships between ψ_L , Tr , Pn and T , R_s , RH were analyzed with SPSS and presented in Table 3. Results showed that the change trend of ψ_L could be predicted simply by typical meteorological factors, as many studies reported that there were obvious relationships between the T , R_s , RH and ψ_L (Zhang et al., 2008). The correlation order of T , R_s , RH with ψ_L was: $T > RH > R_s$ with correlation coefficients of 0.728, 0.676 and 0.353, respectively. From the models, the ψ_L decreased by 1.96 Mpa with the temperature increasing by 10°C. Due to the R_s was always positive number, the relationship between ψ_L and R_s was inversely proportional quadratic parabola trend. Different from the other two meteorological factors, the logarithmic relationship appeared between ψ_L and RH .

Table 3. Regression model of single meteorological factors and crop physiological indexes

Crop physiology index	Meteorological factor	Regression model	Determinate coefficient R ²	F test value
ψ_L (Mpa)	RH	$\psi_L = -30.46 + 6.65 \cdot \ln(RH)$	0.676**	45.413
	R_s	$\psi_L = -2.066 - 0.647R_s - 0.077R_s^2$	0.353*	4.523
	T	$\psi_L = -0.101 - 0.196T$	0.728**	58.578
Tr (millimol·m ⁻² s ⁻¹)	RH	$Tr = -43.544 + 2.481RH - 0.021RH^2$	0.504*	5.584
	R_s	$Tr = 12.121 \cdot \exp(0.2880 \cdot R_s)$	0.360*	6.180
	T	$Tr = -19.369 + 13.897 \cdot \ln(T)$	0.328*	5.867
Pn (μmol·m ⁻² s ⁻¹)	RH	$Pn = -43.465 + 2.198 \cdot RH - 0.0002 \cdot RH^3$	0.529*	6.173
	R_s	$Pn = 28.165 + 8.008R_s$	0.354*	3.041
	T	$Pn = 12.947 \cdot T^{0.392}$	0.538*	8.166

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Number of samples for ψ_L was 216 (24 × 9 = 216), number of samples for Tr was 48 (12 × 4 = 48) and number of samples for Pn was 48 (12 × 4 = 48)

The R_s guarantees the energy for crop transpiration. The crop transpiration rate (Tr) increases with the increase in water potential gradient, caused by stronger R_s , higher temperature and reduced atmospheric water. The correlation order between Tr and T , R_s , RH was: $RH > R_s > T$ with correlation coefficient of 0.504, 0.36 and 0.328, respectively. The relationship trend between Tr and RH was the quadratic downward. The relationship between Tr and RH was different from ψ_L with the trend of inversely proportional quadratic parabola. The maximum Tr appeared when the RH equaled to 59.07% and the Tr would decrease with RH increasing when the RH was greater than 59.07%. Differently from others, the relationship trend between Tr and R_s was exponential. The minimum Tr was 12.121 millimol·m⁻² s⁻¹ while R_s was 0. Logarithmic relationship was shown between Tr and T and there was not transpiration when the temperature was less than 4.03 °C. Then the transpiration rate will increase with the increase in temperature.

The impact factors on Pn of oat are not only the temperature but also the crop stomatal opening, transpiration changes and intercellular carbon dioxide concentration.

Nevertheless, the P_n will affect the crop development. The correlation order between P_n and T , R_s , RH was: $T > RH > R_s$ with correlation coefficient of 0.538, 0.529 and 0.354, respectively. Different from the Tr , the relationship trend between P_n and RH was the cubic polynomial. The linear relationship was presented between P_n and R_s . An $80.08 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ P_n increment appeared when the R_s increased by $10 \text{ MJ m}^{-2}\text{h}^{-1}$. The relationship trend between P_n and T was different from others. Power function was showed between P_n and temperature with the power exponent of 0.392.

Then the relationship between ψ_L and physical signs will be introduced in great detail. If irrigation is sufficient, the change trend of ψ_L is affected not only the different growth stages but also the meteorological factors. The change of ψ_L can reflect the crop ability adapting to the environment.

With the uncertain meteorological condition, the data of ψ_L and meteorological factors collected from August 7th to August 12th when the weather conditions and humidity were suitable for analysis, in order to eliminate the particular of observation data as much as possible in one day. The metrological and ψ_L data observed over six days were averaged, which is an effective measure to reduce the error caused by the particular data.

(1) The diurnal variation relationship between ψ_L and R_s

From the change curve (Fig. 5), the change trend about the ψ_L and R_s are negative correlation ($R^2 = 0.353$). The R_s started to change from negative value to positive value at 5:00. It reached maximum ($3.45 \text{ MJ m}^{-2}\text{h}^{-1}$) at 12:00. However, the ψ_L decreased rapidly from -0.32 MPa at 7:00, reached the first minimum at 13:00 and started to increase after two slight rebounds between 13:00-15:00. The fluctuation of ψ_L may be impacted by other meteorological factors (Yang et al., 2012). From the above analysis, the changes of ψ_L lagged behind the changes of R_s .

(2) The diurnal variation relationship between ψ_L and RH

The change trend of ψ_L and RH are a positive correlation ($R^2 = 0.676$; Fig. 5). After the sunrise, RH tended to drop off over time with the maximum 87% at 8:00. The minimum appeared at 18:00 with 42.67%. Both ψ_L and RH started to rise after the sunset and the ψ_L reached to -1.8 MPa in the end.

(3) The diurnal variation relationship between ψ_L and T

The change trend of ψ_L and T are a negative correlation obviously ($R^2 = 0.728$) (Fig. 5). At daylight, the ψ_L decreased while T was rising, and T reached to minimum of $3.15 \text{ }^\circ\text{C}$ at 7:00, however ψ_L was at a higher value with -0.32 MPa . T tended to drop off after it reached the maximum value of $27.5 \text{ }^\circ\text{C}$ at 15:00. In addition, the continuous high temperature would lead to ψ_L picks up again with “nap”.

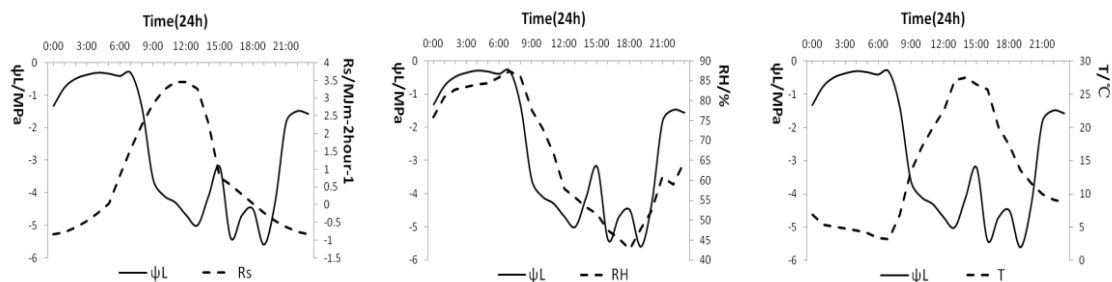


Figure 5. The relationship between daily variation of leaf water potential and meteorological factors

Relationships between physiological indexes of oat and comprehensive factors

The crop physiological indicators are usually influenced by multiple meteorological factors comprehensively, such as temperature, humidity and so on. For example, the daily variation of ψ_L is little on cloudy days with large humidity and wind speed, while the daily variation of ψ_L is larger on sunny day with small wind speed and moderate humidity. By multiple regression analysis between the data of oat's physiological indexes and comprehensive factors, the ψ_L , Tr and P_n of oat in alpine region can be predicted under condition of adequate water supply. The regression models between ψ_L , Tr , P_n and meteorological factors are presented in Table 4. The correlation coefficients are 0.86, 0.78 and 0.66, respectively.

Table 4. Regression model of multi-meteorological factors and crop physiological indexes

Crop physiology index	Regression model	Determinate coefficient R^2	F test value
ψ_L (Mpa)	$\psi_L = -11.271 - 0.882R_s + 0.076T + 0.123RH$	0.86**	40.95
Tr (millimol·m ⁻² ·s ⁻¹)	$Tr = -39.375 + 1.606T + 0.453RH + 0.056R_s$	0.78*	11.90
P_n (μmol m ⁻² s ⁻¹)	$P_n = -7.603 + 0.919T + 0.319RH + 5.848R_s$	0.66*	10.40

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

Number of samples for ψ_L was 216 ($24 \times 9 = 216$), number of samples for Tr was 48 ($12 \times 4 = 48$) and number of samples for P_n was 48 ($12 \times 4 = 48$)

Conclusions

With the water resources becoming scarcer, the water-saving agriculture in Tibet plateau has drawn much attention. At the same time, the oat physiological indexes research is indispensable for water-saving agriculture. The results show that the daily oat's ψ_L changed obviously during the different growth stages. The daily change curve of oat's ψ_L showed 'V-type' in the seeding and heading stages, and the lowest value appeared at 5:00 and 16:00 respectively. However, oat's ψ_L showed 'W-type' in the jointing and tillering stages in which the lowest value both appeared in the morning and afternoon. The maximum change range of ψ_L can reach to 6 MPa in a day.

The variation tendency of oat's P_n was basically consistent without fixed peaks and troughs model in different growth stages. As the facts mentioned above, P_n presented a decreasing tendency in a day. The P_n on the morning was higher than that on the afternoon and the peak appeared between 9:00 and 10:00 at one day. The maximum of P_n in the seeding stage, tillering stage, jointing stage and heading stage were 10.56, 9.91, 10.01 and 9.01 μmol m⁻² s⁻¹, respectively.

The Tr of oat at the seeding stage was obviously less than that in the tillering stage, jointing stage and heading stage. The Tr presented double-peak curves and midday depression in the seeding and heading stage. Different from the current research about grass, the variation tendency about Tr of oat in the tillering stage and jointing stage was "Multi-peak" type without distinct midday depression and parabolic tendency.

Based on the regression analysis, the correlation coefficients between meteorological factors and oat's four physiological indicators were: $T > RH > R_s$; $RH > R_s > T$; $T > RH > R_s$, respectively for ψ_L , Tr and P_n . By multiple regression analysis between the data of oat's physiological indexes and comprehensive factors, the ψ_L , Tr and P_n of

oat in alpine region can be predicted under condition of adequate water supply. These results are useful to understand the hydrologic cycle of the irrigated grass and determine the scientific irrigation schedule to improve water use efficiency of grass in the alpine area.

The studies about ψ_L , Tr and P_n in this paper are under the condition of full irrigation. Therefore, in order to determine the scientific irrigation schedule, the influence of water stress on ψ_L , Tr and P_n will be the focus of the further study.

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