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EVAPORATIVE CHARACTERISTICS OF WINTER WHEAT IN THE GUANZHONG LOESS PLATEAU REGION OF SHAANXI, CHINA

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Abstract

This study is the evaporative characteristics of winter wheat in the Guanzhong Loess Plateau region of Shaanxi through stem flow meters and weighing lysimeters. It examines the diurnal variations in evapotranspiration rates, leaf area index, and soil moisture's impact on winter wheat evaporation. Additionally, it explores the ratio of transpiration to evaporation and compares the evaporation measured by the water balance method with that of the lysimeters. The findings reveal distinct diurnal variations in transpiration rates under different weather conditions, with sunny days exhibiting an unimodal curve while cloudy and rainy days showcase irregular multi-peaked curves. The evaporation curve generally follows an unimodal pattern, with both leaf area index and soil moisture significantly influencing the evaporation process. From heading to early grain filling, the ratio of transpiration to evaporation ranges from 80.3% to 83.4%. Evaporation obtained through the water balance method (0-220 cm) is 6% less than that measured by the lysimeters.

Introduction

Transpiration, stands as a pivotal constituent of the terrestrial water cycle, embodying a significant and intricate physical process within the soil-plant-atmosphere continuum (Hasan *et al.* 2023). Across agricultural systems, a substantial portion of water is consumed through transpiration. Research endeavours encompassing irrigation management, crop yield estimation, soil moisture dynamics forecasting, and water resource assessment, alongside prudent exploitation, all necessitate relevant transpiration data (María and Bailey 2024). Hence, fortifying the investigation into field crop transpiration plays a vital role in agricultural hydraulic application and water resource management, bearing immense significance in agricultural production.

Currently, there exist various methods for quantifying plant transpiration, each with its inherent limitations (Wu and Wang 2021). The stem flow meter offers a simple and effective means for such determination. A plethora of research has been conducted by scholars worldwide on field transpiration, encompassing methodologies such as water balance, energy balance, plant physiological measurements, micrometeorological techniques, infrared remote sensing, and the utilization of Penman's formula to calculate crop transpiration (Cai *et al.* 2020). Among these, the utilization of the evaporimeter to measure plant transpiration has garnered widespread scholarly attention (Knauer *et al.* 2020). Through comparative analyses of various measurement methods, Vargas *et al.* (2020) posit the evaporimeter as the most representative approach for measuring transpiration, offering significant reference value for calibrating eddy covariance, Bowen ratio, energy balance, and water balance methods. Sharma (Sharma and Kathleen 2020) utilized a weighing evaporimeter to investigate the relationship between maize transpiration, yield, and water use efficiency. Guiguitant *et al.* (2020) measured the transpiration of rice and sunflowers using the evaporimeter. Bouranis (2016) studied the transpiration patterns of winter wheat fields in

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the Nanjing region using a large-scale weighing evaporimeter. Timo *et al.* (2017) combined a large-scale evaporimeter with small-scale inter-row evaporators, measured the transpiration of winter wheat fields in the foothills of the Taihang Mountains, investigated the daily transpiration process during the winter wheat growth period. Research on field transpiration in the Loess Plateau region remains relatively scarce. Angadi *et al.* (2019) utilized a large-scale weighing evaporimeter to study the transpiration characteristics of winter wheat in the Loess Plateau region, noting variations in transpiration levels across different years, thus necessitating further investigation into transpiration levels in the area between 2003 and 2004. In arid and semi-arid regions, understanding crop transpiration characteristics holds paramount significance for reducing water consumption during the crop growing season, enhancing plant water use efficiency, and fostering the development of water-saving eco-agriculture. This study employed stem flow meters and large-scale weighing evaporimeters to measure the transpiration of winter wheat in the Guanzhong Loess Plateau region, exploring the dynamics of transpiration-to-evapotranspiration ratios, aiming to provide a theoretical foundation for enhancing water use efficiency in field crops in the region.

Materials and Methods

The experiment was conducted within the ecological experimental station on the Loess Plateau during 2011-2012. This region is characterized by a temperate continental monsoon climate, with an average annual temperature of 9.1°C and an average annual precipitation of 584 mm. The soil in this area is Chernozem. The tested winter wheat variety was Long drought 58, sown on September 25, 2011, and harvested on June 30, 2012.

A large-scale weighing lysimeter was erected in the field to measure the evapotranspiration of agricultural land. The lysimeter has a surface area of 3 m^2 and a depth of 3 m, with an intact soil column extending to a depth of 2.6 m. Its measurement precision was 0.05 mm, with data automatically collected 1 hour (Hasanuzzaman *et al.* 2017). Meteorological data such as sunlight, atmospheric temperature, ground temperature, relative humidity, solar radiation, wind speed and direction, and precipitation were obtained from an automatic meteorological station situated on the west side of the lysimeter, with data collected every hour and stored automatically (Slominski *et al.* 2018). The stem flow of winter wheat was measured using a wrapped stem flow gauge, with data recorded by a CR200 data logger (Song *et al.* 2016). The lysimeter was equipped with a neutron tube for measuring soil moisture every 5 days using a neutron probe. Water surface evaporation was measured using an E601 evaporimeter installed in the meteorological field. The leaf area index of winter wheat was determined using a LAI2000 canopy analyzer (Kühnhammer *et al.* 2019).

The weighing lysimeter was employed to measure the evapotranspiration of agricultural land. The water balance equation can be found in Eq. (1).

$$\Delta W = P + I + G - R - D - ET \tag{1}$$

ΔW represents the variation in soil moisture content (mm), P stands for precipitation (mm), I denotes irrigation volume (mm), G signifies groundwater recharge (mm), R indicates runoff (mm), D represents drainage (mm), and ET represents evapotranspiration in agricultural fields (mm).

Results and Discussion

During the winter wheat growth period, the diurnal variation of winter wheat transpiration rates varies under different weather conditions. As depicted in Fig. 1, the transpiration rate exhibits an unimodal curve. At 8, the transpiration rate rapidly increases from 11 to 14, it remains relatively stable, reaching its peak around 14 at 2.2 g/h. During 17:00 the transpiration rate decreases rapidly, reaching approximately 0.7 g/h around 19:00 with transpiration tending towards zero at night. On overcast (May 24 and rainy days (May 23), the diurnal variation of transpiration rates followed an irregular multimodal curve. During overcast conditions, the transpiration rate decreases around 14 reaching its daily maximum (1.5 g/h) at 15:00 and decreases to 0.3 g/h by 19:00. Transpiration onset was delayed on rainy days compared to sunny and overcast days, with minimal variation. The maximum value (0.5 g/h) was reached at 13:00, and transpiration ceases earlier in the day, dropping to 0.1 g/h around 18:00. Multiple data analyses during the observation period indicate that transpiration rates were significantly lower on cloudy and rainy days than on sunny days, with the lowest rates observed on rainy days, highlighting the significant influence of different weather conditions on transpiration rates.

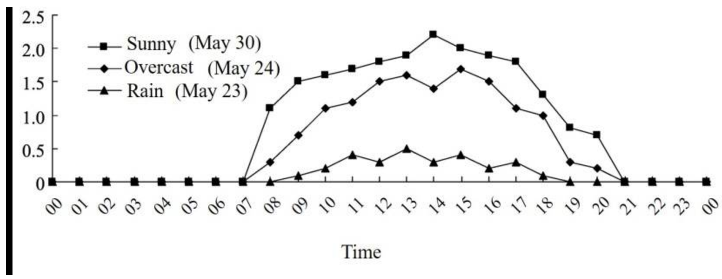

Fig. 1. Variation of transpiration rate of winter wheat.

During winter wheat's reproductive heading stage, a representative selection of three different weather conditions i.e., overcast , partly cloudy and clear was chosen to analyze the diurnal variation of evapotranspiration. As depicted in Fig. 2, the diurnal variation of evapotranspiration exhibits an overall unimodal curve. The abundant solar radiation on sunny days, compared to cloudy or overcast days, exerts a significant influence on evapotranspiration dynamics. From the diurnal variation of evapotranspiration in winter wheat fields, it was evident that evapotranspiration begins to increase around 07:00, with the peak occurring around 15:00 on sunny days, reaching 1.27 mm. On overcast and cloudy days, the peaks are reached around 12-13, with values of 0.25 mm and 1.02 mm, respectively, starting earlier than on sunny days. Subsequently, evapotranspiration decreases, fluctuating around zero around 20 with minimal nocturnal variations. The daily average evapotranspiration was 0.37 mm on sunny days, 0.26 mm on cloudy days, and a minimal 0.05 mm on overcast days, with a relatively gradual diurnal variation in evapotranspiration on overcast days. Negative nocturnal evapotranspiration values were observed due to lower temperatures and higher humidity, leading to condensation on the leaf and soil surfaces of winter wheat.

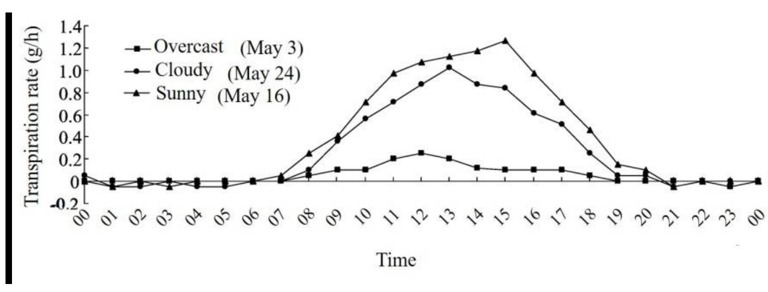

Fig. 2. Daily variation of evapotranspiration in winter wheat fields under different weather conditions.

In the circumstances of ample external moisture supply, the transpiration of winter wheat was significantly influenced by the leaf area index and soil moisture conditions. The variation in soil moisture content in deeper layers was minimal. Hence the analysis was conducted using the volumetric soil moisture content within the range of 0 to 40 cm. From the heading to the maturity stage, the daily transpiration of winter wheat fields in relation to the leaf area index and soil moisture content is depicted in Fig. 3. As the crop progresses, the leaf area index of winter wheat increased from 3.83 on May 13 to 4.91 on May 23, subsequently showing a declining trend after entering the grain-filling stage, decreasing to 3.01 on June 22. Following flowering on May 18, the soil moisture content begins to decrease from 12.9 to 10.31%; during the grain-filling period from May 23 to June 17, the variation was minimal due to three instances of precipitation replenishing the soil moisture. Subsequently, the soil moisture content gradually decreases. After the heading stage of winter wheat, the leaf area index continues to increase. With adequate soil moisture supply, the crop's transpiration intensifies, leading to a corresponding increase in winter wheat transpiration. Prior to the grain-filling stage, the daily transpiration showed an increasing trend, reaching 9.18 mm/day on June 2 and peaking at 9.32 mm/day on June 12 during the early grain-filling period, followed by a continuous decline to 3.62 mm/day on June 22; on May 23, influenced by rainfall, the daily transpiration was only 3.06 mm/day.

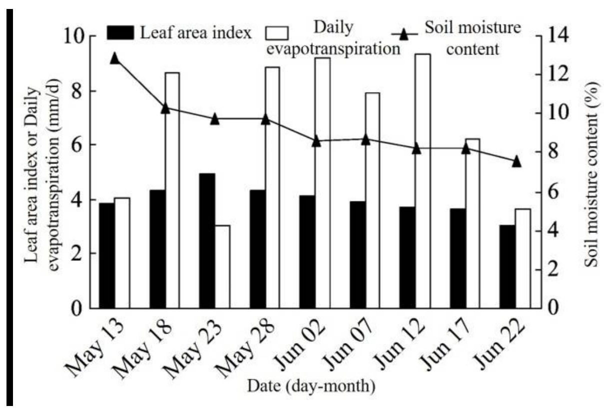

Fig. 3. Relationship between daily evapotranspiration from booting to maturity of winter wheat and leaf area index and soil moisture content.

The variations in transpiration and evaporation of winter wheat at different stages are depicted in Table 1. Evaporation peaked on May 29 (9.36 mm/day), and in mid-June, due to rainfall replenishing moisture, evaporation increased, reaching 9.32 mm/day on June 12. From heading to the early grain-filling stage, the ratio of transpiration to evaporation of winter wheat ranged between 80.32 and 83.41%.

In this experiment, soil moisture content was measured by a neutron probe in the lysimeter, and the evaporation amount was calculated according to the general water balance method for a certain soil volume. The results obtained by the lysimeter method itself are also based on the principle of the soil water balance method, directly obtaining the evaporation amount by calculating the weight difference of the soil-crop system at two time points. During the period from May 12 to June 25, 2012, the rainfall was 57.8 mm. The cumulative evaporation amounts obtained by the general water balance method and the lysimeter method were 282.6 mm and 301.1 mm, respectively, with the former being 6% less than the measurement of the lysimeter. The difference in the depth of the soil body measured was one of the reasons why the water balance method yields a smaller evaporation amount. The depth of the lysimeter was 260 cm, while the depth calculated by the water balance method was 220 cm.

Table 1. Comparison of transpiration and evapotranspiration of winter wheat at different weather conditions.

Date (month-day)	Weather condition	Transpiration (mm/d)	Evapotranspiration (mm/d)	Transpiration/ Evapotranspiration (%)
05-14	Sunny	6.92	8.45	81.88
05-17	Sunny to cloudy	7.47	9.10	82.13
05-20	Overcast	4.81	5.92	81.25
05-25	Cloudy	5.66	6.84	82.76
05-29	Sunny	7.81	9.36	83.41
05-31	Overcast	3.70	4.51	82.04
06-03	Sunny to cloudy	6.98	8.69	80.32
06-08	Cloudy	4.88	5.96	81.95
06-12	Sunny	7.77	9.32	83.37
06-16	Sunny	5.74	7.06	81.23

Through the analysis of evaporation from winter wheat fields under different weather conditions, the daily variation curve of evaporation, showing a unimodal pattern, was clarified. This finding is consistent with the research results of Wang *et al.* (2011) and others who used a large-scale weighing lysimeter to study the law of evaporation from winter wheat fields. Evaporation begins to increase around 07:00, reaching its peak around 13:00 or 15:00, with peaks appearing earlier on overcast days than on sunny days, followed by a gradual decrease in evaporation values, fluctuating near zero during the night, with negative values occasionally observed.

The daily variation in transpiration rate of winter wheat under different weather conditions exhibits distinct characteristics. On sunny days, the daily variation in transpiration rate follows a unimodal curve, gradually increasing with rising temperatures, reaching its peak around 13:00 to 14:00, and approaching zero during the night. The transpiration rate on cloudy and rainy days was more complex due to the influence of external environmental conditions, exhibiting an unstable daily variation and presenting an irregular multi-peak curve. A comparative analysis of transpiration and evaporation of winter wheat indicates that from heading to pre-filling stage, both transpiration and evaporation of winter wheat showed a decreasing trend overall, with the ratio of transpiration to evaporation ranging from 80.32 to 83.41%, similar to the ratio observed in the study by Liu *et al.* (1998) using a large-scale weighing lysimeter to investigate the ratio of transpiration to evaporation in winter wheat.

The evapotranspiration of winter wheat was influenced by both the leaf area index and soil moisture content. Following the heading stage of winter wheat, the leaf area index continues to increase, accompanied by sufficient soil moisture supply, leading to a continuous increase in evapotranspiration. During the early grain filling stage, rainfall ensures adequate soil moisture supply, resulting in increased evapotranspiration of winter wheat, followed by a gradual decrease in daily evapotranspiration, reaching its lowest point at the maturity stage. Field evapotranspiration was also influenced by meteorological factors such as solar radiation, temperature, and wind speed.

The evapotranspiration of winter wheat fields was influenced by crop factors and various external conditions. Due to factors such as the depth of the measured soil body, the evapotranspiration obtained using the general water balance method (0-220 cm) was 6% lower than that measured by the lysimeter. The lysimeter is a more accurate method commonly used for calibrating other measurement methods and theoretical models. Utilizing a large-scale weighing lysimeter to measure the evapotranspiration of winter wheat fields provides the basis for understanding the water demand characteristics of winter wheat, thereby facilitating rational irrigation practices and improving water use efficiency in winter wheat fields. Due to the high sensitivity of the weighing lysimeter, it was susceptible to both human and natural disturbances so efforts should be made to minimize interference, conduct regular data checks, and ensure the normal operation of the instrument.

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