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Article

Water Consumption of Seven Forage Cultivars under Different Climatic Conditions in the North China Plain

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Abstract: The objectives of this study were to determine the characteristics of water consumption of seven forage cultivars, ryegrass (*Secale cereale* L.), triticale (×*Triticosecale Wittmack*), sorghum hybrid sudangrass (*Sorghum biolor*× *Sorghum Sudanense* c.v.), ensilage corn (*Zea mays* L.), prince's feather (*Amaranthus paniculatus* L.), alfalfa (*Medicago sativa* L.), and cup plant (*Silphium perfoliatum* L.), in response to climate variability (especially precipitation). Field experiments were conducted at Yucheng Integrated Experiment Station from 2005 to 2009. Fifteen irrigated lysimeters were used to measure evapotranspiration (ET) and crop coefficient (K_c) of these seven forage varieties under ample water supply. The mean Kc for alfalfa is 1.08, and the mean Kc for other forage varieties ranges from 0.79 to 0.94. Kc for hibernating forage is higher in wet years than that in dry years, followed by normal years, while for annual forage, Kc is higher in dry years than in normal years, and is the lowest in wet years. For perennial varieties the order is normal years, dry years, and wet years. Among the annual varieties, ensilage corn is the first choice due to its highest average forage N yield and water use efficiency (WUE). Sorghum hybrid sudangrass is another forage cultivar that grows well under all climatic conditions. It can achieve 1.08–2.31 t ha^{-1} y^{-1} N yield under all circumstances. Prince's feather is sensitive to climate change and its N yield dropped below half even when ample water was applied in dry and normal years. Ryegrass and triticale have the advantage of growing in the fallow phase after cotton is harvested in the North China Plain (NCP) and the latter performed better. For perennial varieties, alfalfa performed better than cup plant in dry years. With ample irrigation, alfalfa can achieve higher biomass and WUE under arid climate condition, but excessive rain caused reduction in production.

Key words: forage cultivars; evapotranspiration; crop coefficient; water use efficiency; climatic patterns

1 Introduction

The North China Plain (NCP) is the most important grain production area as well as a major area for animal husbandry in China. It produces 20.2% grain, 37.0% meat, 49.1% beef, 41.3% mutton, 43.7% poultry, 31.1% milk, and 58.6% eggs for the nation respectively, while its arable land covers only 13.8% of the national total. Water shortage is the primary limiting factor for crop production and the long-term agricultural sustainability of the area.

The continuous wheat-maize double cropping system dominates in this area. Annual evapotranspiration (ET) of this continual cropping system may go up to 800–900 mm (Liu *et al*. 2002), which is higher than the annual precipitation (580.6 mm) in the region. Irrigation is required and the water is diverted from the Yellow River or as groundwater to maintain this intensive cropping system. There is a great challenge to the agricultural and environmental sustainability with the drying up of rivers and declining of groundwater levels (Fang *et al*. 2010; Hu *et al*. 2005). Water management at farm-level includes the determination of water use and schedule of irrigation, which are key measures to solve water shortage problem in this region (Wang *et al*. 2001; Zhang *et al*. 2005; Fang

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et al. 2007, 2010). Substantial experimental and modelling studies have addressed this issue (Zhang *et al*. 2004; Zhang *et al*. 2005; Yu *et al*. 2006; Sun *et al*. 2006; Li *et al*. 2007).

In the past decade, there was an increasing demand for forage cultivation due to changes in dietary structure and the development of animal husbandry in the NCP, particularly in the Shandong Province (Hong 2000; Lu *et al*. 2002; Lin 2004; Liu *et al*. 2004). However, compared to research on crop water consumption, research in determining water use of forage cultivars is lacking (Pan *et al*. 2007). This may have impeded farm-level decision making of forage planting. We need to determine water usage during the growing period for each forage cultivar in order to provide policy makers with the necessary information for choosing suitable forage cultivars and for optimizing irrigation management in the NCP. The method to measure forage water consumption is based on soil water balance equation which is similar to field crop water requirement determination. Soil water content was measured usually using a neutron moisture meter (Latta *et al*. 2001, 2002). Lysimeters applications are also common for it can directly measure evapotranspiration for crops and forage. For example, Mueller *et al*. (2005) used groundwater lysimeter to measure water use of different crops and the result showed that the highest WUE occurred with the highest crop biomass. Wei *et al*. (2005) summarized some experimental and modelling research of forage water use patterns in China. Xiong *et al*. (2003) determined that alfalfa consumed 4.15 mm d^{-1} of water by the pot experiment. Wan *et al*. (2004) compared WUE of twelve alfalfa cultivars in Shaanxi Province. These studies provided r use.

However, all the conclusions were drawn from one or two years of experiments.

In recent years climate change and global warming research are the hot topics, and researchers around the world have paid great attention to these issues. Global warming may have notable influence on the hydrological cycle and some parts of the world may see significant reductions in precipitation or major alterations in the timing of wet and dry seasons (IPCC 1996; Arnell 1999; Xia *et al*. 2010). We should employ different water use strategy in the future in order to deal with stresses on water resources from climate change. Analysis of forty years' (from 1961 to 2000) climate data showed that precipitation had the greatest variability in the NCP (Chen *et al*. 2010). Thus it is necessary to measure the water consumption of forage varieties under different climate conditions (especially precipitation) and develop reasonable water use strategies in the NCP.

The objectives of this study were to quantify the evapotranspiration, crop coefficient and water use efficiency of seven forage varieties under three climate conditions.

2 Methods and materials

2.1 Experimental site

From 2005 to 2009, experiments of five-year duration were conducted at the Yucheng Integrated Experimental Station of the Chinese Ecological Research Network (CERN),

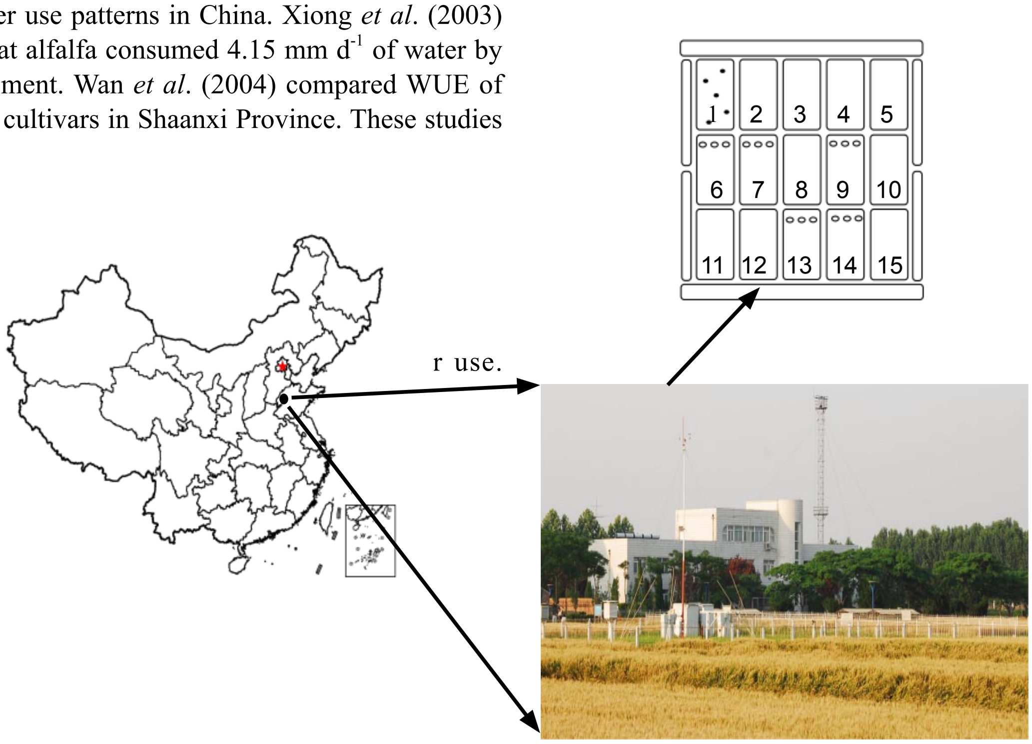

Fig. 1 Location of the Yucheng Integrated Experimental Station in the North China Plain and schematic diagram of experimental plots. The numbers represent the experimental plot number, the dots represent the five soil sampling sites (the five samples are mixed into one), and the circles represent irrigated lysimeters.

located in Yucheng, a county seat in Shandong Province (36°49′52″N, 116° 34′19″E, and 23 m a.s.l.) (Fig.1). It is located in an alluvial plain of the Yellow River with a temperate monsoon climate. The mean annual precipitation at this station over the past 58 years was 580.6 mm (1951–2008), with a minimum of 279.4 mm (2002) and a maximum of 1027.7 mm (1964). Nearly 75% of the rain falls within the period of June to September. The mean annual air temperature is 13.1 °C, with a minimum and maximum temperature of -22.0 and 47.7 °C. The soil was formed from the sediments deposited over time by the Yellow River and is calcareous and rich in P and K. The main soil type is silty loam with an average bulk density of 1.43 g cm^{-3}.

2.2 Design of water budget system

2.2.1 Description of Lysimeters

Fifteen irrigated lysimeters were designed to measure evapotranspiration of seven forage varieties with three replications for each during April 2005 to September 2009. Each lysimeter (Fig.2) is 0.3 m^2 in surface area (0.618 m in diameter) and 0.8 m in depth, with a mesh of cone-shaped cylinder at the bottom (Cheng *et al*. 1994, 2002). There is a catheter at the bottom in order to keep the drainage flow from the lysimeter. Each upper layer of the cone is a filtration layer. It contained, from the base upwards, gauze shops, 5 cm of gravel and 5 cm of sand, then 60 cm (20–80 cm from the surface) backfilled soil, 20 cm (0–20 cm from the surface) soil, which were repacked to obtain bulk densities similar to that of the surrounding field. The seepage water from the lysimeter flowed through the catheter then got collected in the kegs with a petiole inside the leaking barrel. Leaking barrels were added barrelhead in order to prevent the entry of rain and evaporation of collected seepage water.

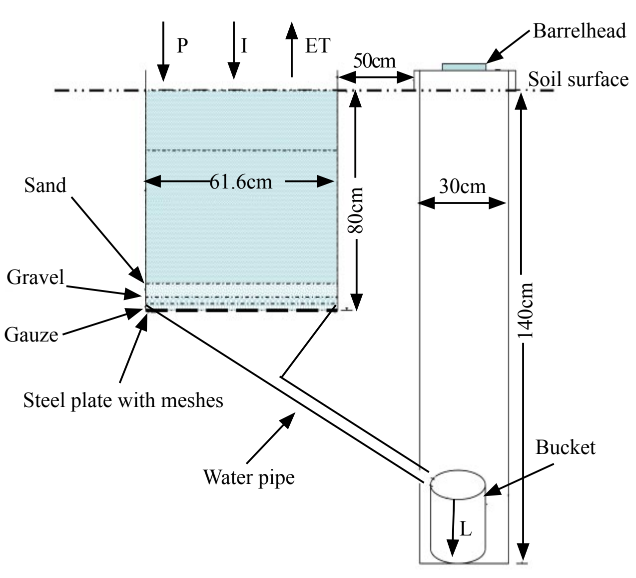

Fig.2 Schematic diagram and water balancing of irrigated lysimeter. Soil was re-filled at the depth of 20–80 and 0–20cm from the bottom to the top.

2.2.2 Evapotranspiration calculation

The evapotranspiration was calculated based on the field scale soil water balance equation (Eq.1):

$$P + I - ET_C - F - (L - C) + \Delta W - \eta = 0 \qquad (1)$$

where P is precipitation (mm), I is irrigation (mm), ET_C is evapotranspiration, F is surface runoff (mm), L is drainage (mm), C is upward capillary water and ΔW is soil water content variables (mm). η is error, including other factors not taken into account in the equation (Lin 1997; Lin *et al*. 2000).

Irrigation management in the lysimeter aimed to maintain the soil moisture at around 70% of the field capacity (FC) to avoid water stress in the forage growing period. In the evenings, all lysimeters were irrigated till the soil inside it became saturated and there was extra water out. When the gravitational water was completely excluded till next morning, the soil water content became close to the FC. We irrigated the lysimeter till the soil saturated when soil water content dropped to70% of the FC. Soil water content was monitored by the evaporation of 20 m^2 evaporation pond in the station. Thus soil water content at the beginning and end of the observation is at the FC. As a result,

$$\Delta W = 0 \qquad (2)$$

There was no surface runoff and upward capillary water occurred in the lysimeters. Therefore, F and C were treated as zero in this study. η is less than 10% in the regional soil water balance model (Lin 1997), for a lysimeter it can be ignored as there is no assumption that errors exit and η can be reduced by duplication. So Eq.1 can be simplified into to Eq.3:

$$ET_C = P + I - L \qquad (3)$$

where ET_C is the forage evapotranspiration, P is the precipitation during the observation period, measured by rain gauges in the meteorological station (about 2 m from the experiment site), I is the irrigation water, added manually by certain volume of containers, the amount was recorded when irrigation happened, L is drainage, measured with graduated cylinder. All terms in Eq.3 are expressed in mm.

2.2.3 Crop Coefficient

Crop Coefficient, Kc, was calculated by the following equation:

$$Kc = {ET_c}/{ET_0} \qquad (4)$$

ET_C is crop evapotranspiration measured by Eq. (3) and ET_0 is reference evapotranspiration calculated by 24-h time steps, from meteorological data by using Penman-Monteith equation (Allen *et al*. 1998):

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{T+273} u_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)}$$

where ET_0 is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s-e_a is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}), γ is psychrometric constant (kPa °C^{-1}). (5)

All meteorological data, such as temperature, humidity, radiation, hours of sunshine, and wind speed were observed from the meteorological station.

2.2.4 Water use efficiency

In this study, *WUE* is defined as follows:

$$WUE = Y / EY_c \quad (6)$$

where *WUE* (kg ha^{-1} mm^{-1}) is water use efficiency, ET_C is evapotranspiration (mm) and Y is crop yield (t ha^{-1} y^{-1}). For forages, Y is the N yield (crude protein yield).

2.3 Materials and management

Winter wheat-summer maize rotation was the previous cropping system and corn stubble remained in the field before the study was conducted. A system of water budget and forage production for seven varieties of forage (annual ryegrass, triticale, sorghum hybrid sudangrass, ensilage corn, and prince's feather for annual varieties; and alfalfa and cup plant for perennial varieties, Table 1) was designed under ample water supply. Two cropping systems were established: (i) two continuous perennial grass (alfalfa and cup plant) system and (ii) annual grass rotation system. Forage water use (lysimeter irrigation and drainage) and production (biomass and leaf area index [LAI]) were measured every 5–10 days.

The system includes 15 plots (5 m × 10 m, 5 m east-west, 10 m north-south), in a randomized design with three replicates for each cultivar. Lysimeters were installed in five plots, three in one plot, for replication. Groundwater was extracted for irrigating the experimental plots. Initial

Table 1 Information on the forage varieties and management of the experiments.

Forage	Variety	Seeding Date	Mowing Stage	Stubble Height
Alfalfa	WL323HQ	2005-04-27	Early flowering (10% bloom)	4–5 cm
Cup plant	Common species	2005-04-27	50–70 cm height	5–10 cm
Sorghum hybrid sudangrass	Runbao	2005-04-27	140 cm in height	5 cm
	Runbao	2006-06-03		
	Chaoji-2	2007-05-18		
	Chaoji-2	2008-05-20		
	Chaoji-2	2009-05-24		
Prince's feather	Common species	2005-04-27	60–80 cm in height	20–30 cm
	Common species	2006-06-03		
	Common species	2007-05-18		
	Common species	2008-05-20		
	Common species	2009-05-24		
Ensilage corn	Xinqing-1	2005-04-27	Dough stage	0 cm
	Keduo-4	2006-06-03		
	Keduo-4	2007-05-18		
	Sibao-1	2008-05-20		
	Sibao-1	2009-05-24		
Ryegrass	Wintergrazer-70	2005-10-18	Jointing	5 cm
	Wintergrazer-70	2006-09-14		
	Wintergrazer-70	2007-10-17		
	Wintergrazer-70	2008-10-11		
	Wintergrazer-70	2009-09-23		
Triticale	Triticale -830	2005-10-18	Jointing	5
	Triticale -830	2006-09-14		
	Triticale -830	2007-10-17		
	Triticale -830	2008-10-11		
	Triticale -830	2009-09-23		

Table 2 Initial soil physicochemical properties (Sampling on 2005-05-18).

Soil depth (cm)	Organic matter (%)	Total nitrogen (%)	Total phosphorus (%)	Total potassium (%)	Conductivity (ms/cm)	Salinity (%)	pH
0–20	1.32± 0.14	0.08± 0.01	0.19± 0.03	2.35± 0.12	0.36± 0.04	0.11± 0.01	8.52± 0.07
20–40	0.87± 0.20	0.05± 0.01	0.15± 0.02	2.36± 0.06	0.22± 0.03	0.07± 0.01	8.77±0.04

Note: Total phosphorus stands for P_2O_5, total potassium stands for K_2O, n=15.

soil physicochemical properties were determined at the beginning of the experiment (Table 2). Before planting, the plots were fertilized with 180.8 kg P_2O_5 ha^{-1}, 66 kg K ha^{-1}, and 92.4 kg N ha^{-1}. The plots were irrigated using groundwater drawn from the well by the experiment field. The amount of fertilizers applied was decided by the average level of application by local farmers. Weeds were removed manually, whereas pesticides and herbicides were not applied in the study fields. Cultivation and fertilization of lysimeters were the same as the surrounding plots.

2.4 Observations and measurements

2.4.1 Crops (biomass, LAI, and phenology)

Aboveground biomass and green leaf area index (LAI) were determined by hand-cutting 30 cm in length of single row for annual ryegrass and triticale and 3 stalks for others in each plot every 5–10 days. Plant samples were detached into several parts, i.e. stems, green leaves, withered leaves, and spikes. The dry weight of each part was measured after drying in a controllable oven (firstly deactivated enzymes at 105°C for 1.5 hours, then at 75°C for until dried, i.e., reached a constant weight. It took 8 h for ryegrass and triticale and 48 h or longer for other varieties). LAI (for green leaves) was measured using the LI-3000C Portable Area Meter in combination with the LI-3050C Transparent Belt Conveyer Accessory. 1 m × 3 rows of plants were chosen for average plant height determination (20 readings were recorded), consistent with the sampling frequency of biomass.

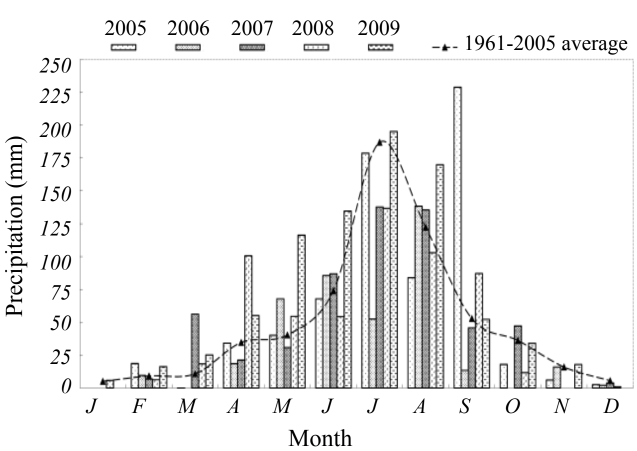

Fig. 3 Monthly precipitation of the experimental years (2005–2009) and long-term average over 1961–2005 at Yucheng Station. Missing column denote zero rainfall.

Forage yield was obtained by manually harvesting 2m × 3 rows of plants that was randomly selected in the plot at suitable mowing stages (Table 1). Forage yield was determined by oven-dry weight of samples. Dried forage material (stems, leaves, and spikes) was digested in concentrated H_2SO_4 and $KClO_4$ and analysed for total N content using Kjeldahl method (GB7173-87). Forage phenology was observed every 5 days.

2.4.2 Soil water (method and instruments)

Soil water content of the plots was measured every 7–10days (10 days for winter season and 7 days for other seasons) from an aluminium access tube in each plot by using a moisture meter (CNC503DR, Beijing Nuclear Security and Nuclear Instrument Co., Ltd.) The measurement of the five plots with lysimeters was from the depth of 20 to 140 cm with 20 cm measurement intervals, while for others it was from 20 to 100 cm in depth with 20cm intervals.

Weather data are from the Bureau of Meteorology of Yucheng County. There was a large inter-annual variability of monthly rainfall across experimental years (Fig.3). However, the inter-annual variability of monthly temperature was small for the period of 1961 to 2005 (Fig.4). Accordingly, we categorized climate patterns for the experiment years based on the characteristics of inter-annual precipitation.

3 Results

3.1 Evapotranspiration (ET_c) for seven forage cultivars under different climatic conditions

Water demand of forage plants is closely linked to climate through precipitation and atmospheric evaporation demand. Average annual precipitation at the experiment area from 1951 to 2005 was 580.4 mm. Taking 580.4mm as a standard, climate in these forty-five years were divided into three patterns (dry, wet, and normal), so is the five-study years (Table 3a). Climate in ryegrass growing periods (from October of the previous year to April) were also divided into three patterns (Table 3b). The same method was used for classifying ensilage corn growing seasons (Table 3c).

The average ET for all experimental years and ET under the three types of climatic conditions are showed in Fig 5. Perennial varieties consumed 500–850 mm y^{-1} of water, while annual varieties consumed 300–410 mm y^{-1}.

Table 3a Classification of long-term (1951–2005) annual precipitation.

Climate patterns	Annual precipitation	Definition
Wet year	≥ 696.5 mm	Greater than or equal to 120% of the average
Normal year	<696.5 mm, >464.4 mm	Between 120% and 80% of the average
Dry year	≤464.4mm	Less than or equal to 80% of the average

Note: Annual precipitation (mm): 2005, 678.4; 2006, 403.6; 2007, 571.7; 2008, 579.1; and 2009, 816.4.

Table 3b Ryegrass and triticale growing season (from October in the previous year to April) climate patterns.

Type of the year	Precipitation	Definition
Wet year	≥ 133.8 mm	Greater than or equal to 125% of the average
Normal year	< 133.8 mm, >80.3 mm	Between 125% and 75% of the average
Dry year	≤ 80.3 mm	Less than or equal to 75% of the average

Note: Precipitation (mm): 2005–2006, 54.4; 2006–2007, 102.3; 2007–2008, 182.0; and 2008–2009, 109.1.

Table 3c Ensilage corn growing season (May to September) climate patterns.

Type of the year	Precipitation	Definition
Wet year	≥ 592.9 mm	Greater than or equal to 125% of the average
Normal year	<592.9 mm, >355.7 mm	Between 125% and 75% of the average
Dry year	≤355.7 mm	Less than or equal to 75% of the average

Note: Precipitation (mm): 2005, 599.3; 2006, 357.5; 2007, 436.5; 2008, 435.4; and 2009, 668.2.

ET of each forage cultivar varied under different climatic conditions, with the lowest ET in wet years, except ryegrass, triticale and sorghum hybrid sudangrass. The results also show that annual varieties matured in various numbers of days after planting under different conditions. Ryegrass and triticale matured 13–19 days earlier in normal years than in the other years. The maturing date of sorghum hybrid sudangrass and ensilage corn was advanced 3–13 days. For prince's feather it was advanced 29–59 days. This indicated that prince's feather is most sensitive to soil water variation.

3.2 Crop Coefficient (K_c) under different climatic conditions

Kc is an effective tool for estimating ET and to provide farm managers knowledge on improving water use efficiency. The mean K_c for alfalfa is the highest, slightly greater than 1. The result indicates that ET of alfalfa is higher than ET_0 over the same period. The mean Kc value

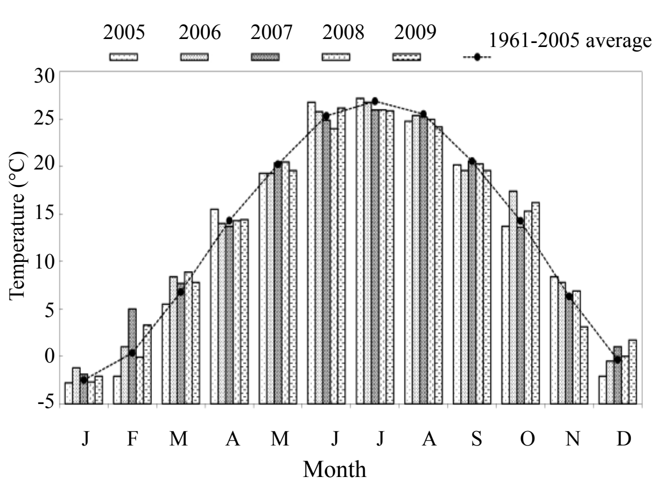

Fig. 4 Monthly temperature of the experimental years (2005–2009) and long-term average over 1961–2005 at Yucheng Station.

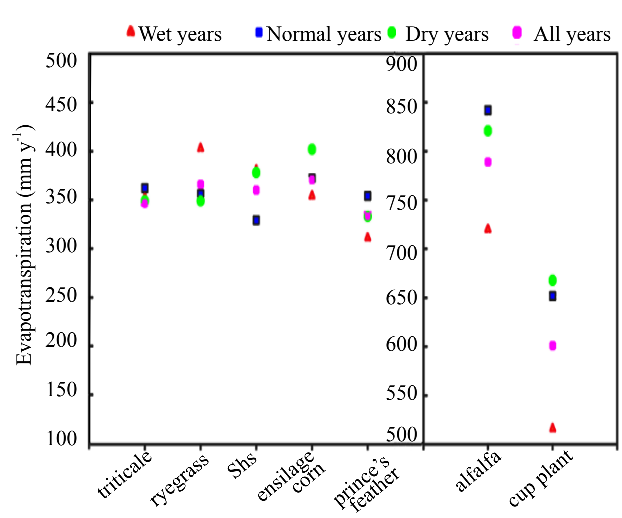

Fig. 5 Evapotranspiration for seven forage cultivars under different climatic conditions. Shs represents sorghum hybrid sudangrass.

for prince's feather is the lowest, while for other annual forage plants it is from 0.82 to 0.94. Crop coefficient reflects the characteristics of plants and the effects of soil evaporation. The results show that Kc values are related to each forage variety's growing season and different climatic conditions (Fig. 6). Kc for hibernating forage ryegrass and triticale in wet years is higher than that in dry years, followed by normal years, while K_c for annual forage sorghum hybrid sudangrass, prince's feather, and ensilage corn is higher in dry years than in normal years, and is lowest in wet years. For perennial varieties alfalfa and cup plant, the order is normal years, dry years, and wet years.

Kc for forage cultivars under different climatic conditions is useful for estimating water consumption and providing a basis for determining irrigation time and amount. Estimation of ET_c by FAO 56 Kc ET_0 method is feasible in most places, since weather data collection can be done conveniently and inexpensively by the electronic weather station (Allen *et al*. 1998; Allen 2000). It can provide decision makers information of the appropriate selection of forage variety and the acreage of planting for a particular region.

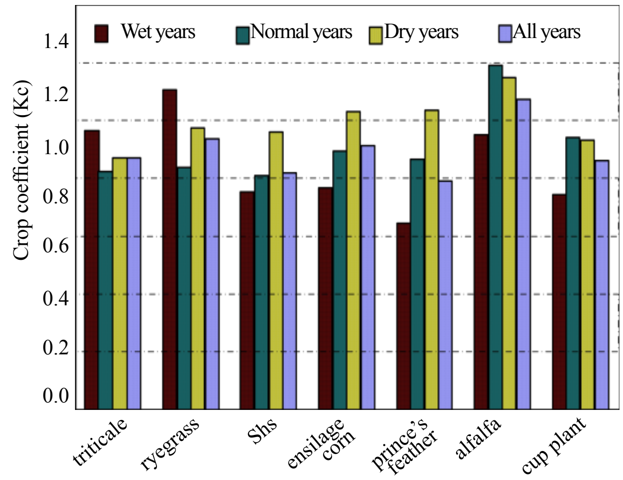

Fig. 6 Crop coefficient for the seven forage cultivars under different climatic conditions. Shs represents sorghum hybrid sudangrass.

3.3 Water use efficiency under different climatic conditions

The pattern of water use efficiency for each forage variety under different climatic conditions is consistent with the N yield (Tables 4 and 5). WUE for ryegrass and triticale is higher in dry years than in normal years, and is lowest in wet years. WUE for sorghum hybrid sudangrass and prince's feather is higher in wet years than in normal years, followed by dry years, and for alfalfa, WUE is higher in dry years than under other conditions. Ensilage corn has the highest WUE (16.99 kg ha^{-1} mm^{-1}) in normal years compared with other forage varieties. This may be related to the highest N yield (Table 5). Ensilage corn has

Table 4 Water use efficiency under different climatic conditions (kg ha^{-1} mm^{-1}).

Forage	Wet years	Normal years	Dry years	All years
Triticale	3.99	5.29	10.58	6.62
Ryegrass	4.06	4.96	8.09	5.7
Prince's feather	6.12	2.66	2.31	3.69
Sorghum hybrid sudangrass	6.04	3.27	3.24	4.18
Ensilage corn	7.45	16.99	7.19	10.54
Cup plant	12.13	3.45	5.3	6.96
Alfalfa	3.4	2.12	6.6	4.04

Note: Water use efficiency based on N yield (crude protein yield).

Table 5 Nitrogen (Crude protein) yield for each climatic condition (t ha^{-1} y^{-1}).

Forage	Wet years	Normal years	Dry years	All years
Triticale	1.41	1.92	3.69	2.34
Ryegrass	1.64	1.77	2.82	2.08
Prince's feather	1.91	0.94	0.77	1.21
Sorghum hybrid sudangrass	2.31	1.08	1.22	1.54
Ensilage corn	2.65	6.32	2.89	3.95
Cup plant	6.27	2.25	3.54	4.02
Alfalfa	2.45	1.78	5.41	3.22

the highest average WUE over the five experiment years, followed by cup plant and triticale, while alfalfa and prince's feather have the lowest WUE. WUE for the other four cultivars ranges from 3.69–6.96 kg ha^{-1} mm^{-1}.

4 Discussion and conclusion

This study determined the characteristics of water consumption of the seven forage cultivars under three climatic conditions in the NCP on the basis of continuous five-year experimental research. This study found that water demand and crop coefficient data of the forage cultivars under different climatic conditions are important for improving water use efficiency in a region with limited water resources.

For annual varieties, ensilage corn is the first choice of forage cultivar due to its highest average N yield and WUE. Mueller *et al*. (2005) drew a similar conclusion from the research conducted in the vicinity of Berlin, Germany. Sorghum hybrid sudangrass is another forage cultivar grew well under all these climatic conditions. It can achieve 1.08–2.31 t ha^{-1} y^{-1} N yield under all circumstances. Prince's feather is sensitive to climate change. Under dry and normal conditions the N yield would drop below half even when enough irrigation water was applied.

Based on our measurement, ryegrass and triticale need 170–281mm of irrigation water, while winter wheat needs 154.8–318.2 mm of irrigation water according to the 30 tons weighing lysimeter determination in the station (Yang *et al*. 2000). So incorporating ryegrass and triticale into the cropping system in the NCP is feasible if sound water resource management options are put in place. Furthermore, ryegrass and triticale have the advantage of growing in the fallow phase after cotton is harvested in the NCP. Cotton is the third primary crop in the NCP. Cotton cultivation area is about 1.9–3.6 × 10^6 ha in the period of 1998 - 2008 in this region, which accounts for 3.8%–7.0% of the sowing acreage and covers 51.2%–63.1% of the national total cotton cultivation area (National Bureau of Statistics of China). The growing season of cotton starts in late October and ends in late April the following year. There is a roughly five to six months' fallow period in between the growing seasons in cotton producing areas, which provides opportunities for the growth of ryegrass and triticale. This not only can greatly improve the utilization of resources of the fallow fields, but also can alleviate the shortage of green feed in winter and early spring in the region. Of these two cultivars, triticale performed better because of its higher N yield and WUE. For perennial varieties, alfalfa performed better than cup plant in dry years, and worse under other conditions. Alfalfa consumed 721 mm of water under wet conditions, which is close to the finding of Wan *et al*. (2004). Wan *et al*. measured water use efficiency of alfalfa in Baoji City, Shaanxi Province, in 2002. Their results showed that alfalfa consumed 666.6 mm of water and its WUE reached 21.52 kg ha^{-1} mm^{-1} under 632.5 mm rainfall, non-irrigated condition. Our experiments indicate that alfalfa can achieve two to three times of N yield and WUE under arid climate conditions compared with that of normal and wet years.

Results from this study will be very useful for developing adaptation strategies in the face of climate change in the region. And the K_c values of different forage varieties under various climatic conditions need to be estimated in order to provide more solid knowledge for making management decisions.

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华北平原7种人工牧草不同气候条件下的耗水规律

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摘要：本文主要目的是研究华北平原不同气候条件下7种人工牧草的耗水规律。试验于2005–2009年在中国科学院禹城综合试验站进行，牧草品种有一年生牧草黑麦(*Secale cereale* L.)、小黑麦(× *Triticosecale Wittmack*)、高丹草(*Sorghum biolor* × *Sorghum Sudanense* c.v.)、青饲玉米(*Zea mays* L.)和籽粒苋(*Amaranthus paniculatus* L.)，多年生牧草苜蓿(*Medicago sativa* L.) 和串叶松香草(*Silphium perfoliatum* L.)。结果显示，苜蓿的Kc值为1.08，其他牧草在0.79–0.94。不同气候条件下的Kc值大小规律为，越年生牧草：湿润>干旱>平常；一年生牧草：干旱>平常>湿润；多年生牧草：平常>干旱>湿润。本文建议青饲玉米和高丹草为夏季播牧草的优选牧草，籽粒苋对气候变化最敏感，干旱和平常季节会减产一半以上。黑麦和小黑麦蒸是冬闲田种植的优选牧草，小黑麦因为耗水量较小，优于黑麦。苜蓿在干旱季节的表现优于串叶松香草，但当降雨达592.9mm以上反而会引起减产。该研究的结果能为牧草在华北平原的种植布局提供科学依据。

关键词：牧草品种；蒸散量；作物系数；水分利用效率；气候模式