Dynamic Simulation and Definition of Crop Coefficient for Typical Steppe in Inner Mongolia, China

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Introduction

There are few reference values for crop coefficients for natural grassland in FAO Irrigation and Drainage papers. The aim of this paper was to define crop coefficients under different water conditions for typical steppe vegeation in Inner Mongolia, based on actual observation data and statistical analysis, so as to accurately calculate the water demand and actual evapotranspiration of plant community in Inner Mongolia.

Methods

Data were collected from field experiments at Xilinhaote, Inner Mongolia in 2008, and meteorological data and soil water content data in the past 26 years were obtained from four stations. Using statistical analyses, the crop coefficients of typical steppe were calculated according to water balance equations, and the variations of crop coefficients in various growing periods and in different stations were analyzed. A correlation equation of standard crop coefficient with days after return of the green period of grass and accumulated temperature (≥ 0°C) were established. By analyzing relationships between humidity index, LAI, plant cover and crop coefficient, a climatic correction method for the standard crop coefficients and a correction method of crop coefficients under water stress were established.

Experimental pastures

The experiment was sited at four Xilinhaote national climatic observation stations in the *Stipa krylovii* steppe. Three water treatment plots were set in the enclosed and grazing pasture in 2008, which relative water content of 0.5 meter deep soil layers were above 70%, 50%-70% and 40%-50%. The height of dominant herbages, vegetation coverage, the aboveground biomass, leaf area index and soil moisture content were surveyed every ten-day in the growing season.

Data collection

The soil moisture content, vegetation coverage and biomass data and so on, which were collected from regular observation data of the four meteorological stations (Table 1).

Calculations

The calculation formula of crop coefficient (Kc):

$$Kc = ET_a / ET_o$$

where: ET_o was calculated by the Penman-Montieth formula recommend by FAO. The survey data of soil moisture content, precipitation and irrigation amount under the adequate water condition were used to calculate Et_a by the moisture-balancing formula as follows:

$$ET_a = (P + I - Q - \Delta W) / \Delta t$$

Estimated Evapotranspiration data

The experiment used auto-weighing lysimeters (4.0 m^2 surface area, 2.6 m deep, 0.1 mm test accuracy, 0.01mm sensitivity) to assess the estimated evapotranspiration that was collected day-to-day from 1999 during the growing season. The evapotranspiration surface refers to the grassland natural vegetation.

Humidity index (Iw)

$Iw = R/ET_o$, where R refers to the precipitation (mm) and ET_o refers to the crop evapotranspiration (mm).

Table 1. Geographical coordinates, main characteristics of climate and soil of four meteorological stations.

Stations	Longitude (E)	Latitude (N)	Altitude (m)	Annual precipitation (mm)	$Iw_{4\text{-}9}$	Annual mean air temperature (ºC)	Changing ratio of annual precipitation (%)	$W_{0\text{-}50}$ (mm)	$\gamma_{0\text{-}50}$ (g/m^3)
Xilinhaote	116°38'	43°57'	989.5	286.6	0.28	2.6	24.6	84.9	1.41
Xianghuang Banner	113°50'	42°14'	1 322.1	269.9	0.27	3.5	17.4	85.4	1.49
Chayouhou Banner	113°11'	41°27'	1 423.5	335.2	0.37	3.8	18.9	145.4	1.14
Ewenke Banner	119°45'	49°09'	620.8	345.6	0.44	–1.5	16.1	84.4	1.43

$Iw_{4\text{-}9}$, wetness index in growing season (April to Sept.); $W_{0\text{-}50}$, available field capacity of soil layer (0–50 cm); $\gamma_{0\text{-}50}$, average weight per volume of soil layer (0–50 cm).

Table 2. Dynamic simulating equations of Kc_s, *LAI* and coverage of typical steppe in Inner Mongolia under appropriate conditions of water.

	Simulation equations	R^2	F	Fitting ratio（%）
Standard crop coefficients	$Kc_s = -5.21\times10^{-0.7}D^3 + 0.000258D^2 - 0.0338D + 1.4712$	0.922 5	43.6^{**}	86.8
	$Kc_s = -1.6\times10^{-10}Tj^3 + 6.33\times10^{-07}Tj^2 - 0.000346Tj + 0.4666$	0.904 2	34.6^{**}	91.4
LAI	$LAI_D = -5.45\times10^{-10}Tj^3 + 2.45\times10^{-0.6}Tj^2 - 0.0018Tj + 0.5141$	0.982 5	153.5^{**}	81.5
Coverage of vegetation	$GD_D = -1.9\times10^{-5}Tj^2 + 0.09Tj -25$	0.932 2	171.9^{**}	78.1

D: days of year, 100 d < *D* < 290 d; *Tj*: accumulated temperature (> 0°C), 50°C < *Tj* < 300 0 °C ; LAI_D: expected value of *LAI* under appropriate water condition; GD_D: expected value of coverage degree under appropriate water condition; **, *P*<0.01.

Important findings

Under the experimental water conditions, trinomial equations were effectively fitted for the standard crop coefficient, based on the number of reviving days and accumulated temperature above 0°C of typical steppe throughout the whole growing season, and the correlation coefficient is greater than 0.9 (Table 2).

Local suitable crop coefficient ($Kc_{Local} = Kc_s \times Kc_I$) could be gotten after the climate modifications of formula as follows: $Kc_I = Iw^{0.4}$ (*Iw* refers to the humidity index of high flow year, n = 28, R^2 = 0.735, p < 0.001)

The correlation of crop coefficient, leaf-area-index, and relative coverage of vegetation could be effectively fitted by the exponential regression.

$$K_{cl} = 0.18 \times e^{1.7\times\frac{LAI}{LAI_D}}$$

(N=19, R^2=0.5943, fitting ratio, 83.6%)

$$K_{cg} = 0.16 \times e^{1.8\times\frac{GD}{GD_D}}$$

(N=71, R^2=0.6651fitting ratio, 77.7%)

Kc_l is the correction crop coefficient which depended on LAI, Kc_g is the crop coefficient which depended on *GD*, LAI_D and *GD* could be calculated through the formulas in Table 2, LAI is the actually measured leaf-area-index, and GD is the actually measured coverage of vegetation. Therefore, the crop coefficient of grassland community in each set of conditions can be expressed as follows, $Kc_x = Kc_s \times Kc_I \times Kc_l\ (Kc_g)$.

The average value of the standard crop coefficient of typical steppe for the whole growing season was 0.60, and the maximum value was 1.02. Typical values of crop coefficients in different growing stages were 0.40 for initial stage, 0.93 for medium stage and 0.80 for later stage; and threshold values of three growing stages were 0.35-0.45 for initial stage, 1.00-0.85 for medium stage and 0.9-0.7 for later stage, respectively.

Compared with measured data from lysimeters, the simulated values of ten days' evapotranspiration indicated an average relative error of 20-24% for whole growing season, and less than 10% for the active growing stage. The crop coefficients for typical steppe defined here had good adaptability in Inner Mongolia.