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Research Article

Water Requirement of Naked Oats under Subsurface Drip Irrigation in the North Foot of Yinshan Mountain Based on Single Crop Coefficient Approach

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In order to accurately and rapidly calculate the water requirement of naked oats under drip irrigation in the north foot of Yinshan Mountain, the study adopted the K_c and calculation method for potential evapotranspiration recommended in document FAO56 and applied SCCA to calculate the water requirement of crops based on the deficient irrigation experiments. The results indicated that the water requirements of naked oats without drought influence was 383.8 mm, and the maximum daily average water requirement intensity was heading flowering, which was the critical period of crop water requirement, and the mean value of ET_0 in the whole growth period was 3.89 mm/d. After correction, K_C of naked oats in the initial growth stage, crop development growth stage, mid-season growth stage, and late season growth stage was 0.34, 0.94, 1.05, and 0.36. The average K_C of naked oats in the whole growth stage was 0.71. SCCA does not consider the influence of wetting depth in the initial growth period of crops and the correction of local irrigation in the mid-season and late season stage of crops. Therefore, when the irrigation quota of naked oats is 315 mm, the crop water requirement calculated by SCCA is 363.84 mm, which is about 10% different from the measured value. The results show that SCCA can be used to calculate the water requirement of naked oats under drip irrigation at the northern foot of Yinshan Mountain in Inner Mongolia, and the calculation error is within the allowable range. However, it is also necessary to consider the influence of different irrigation forms and plant height of crops on calculation value.

1. Introduction

The calculation methods for crop water requirements generally consist of two categories, including the water requirement of crop growth period measured with water balance method, and actual crop water requirement calculated through the calculation of the water requirement of reference crop. Among them, FAO56 recommended crop coefficient approach has a relatively wide application for the water requirements of crop in current agricultural production activities [1]. The critical process for the application of SCCA recommended by FAO56 in the calculation of the crop water requirement is to calculate out the water requirement ET_0 of reference crop and K_C. K_C reflects the specific value between the crop water requirement Et_c in one certain growth stage and the potential evapotranspiration ET_0 of the reference crop, which is the comprehensive demonstration of the biological characteristics, status of soil, water and fertility, crop type, output, field management level, and other factors of the crop itself toward the crop water requirement. It is an important parameter for the differences between the water requirements of different crops and the water requirement of the reference crop. On account of different growth and development characteristics, crops in different varieties have quite different characteristics in water requirements in different growth stages [2–8].

The document of FAO56 provides recommended values for K_C of different crops in different growth periods. Considering that the values of K_c in FAO56 are given on the basis of certain climate and plant forms, it is necessary to verify and modify the values according to the actual application environment (variety, climate, water, and fertility conditions) [9–13]. Zhang et al. conducted irrigation experiments for silage corn and alfalfa in Uxin Banner and adopted the measured day-by-day Eta and PM formula of FAO56 to get the day-by-day ET_0 for analysis; K_C of alfalfa on Maowusu sandy land in the growth stage has been calculated [14]. Wang and Xie applied CERES-Wheat model to simulate and calculate out the K_C of north winter wheat in Fufeng County and Chencang District inn Baoji at the initial growing stage, wintering stage, growth peak stage, and final growth stage and compared them with the recommended K_C in FAO56 in terms of relevance and deviation [15]. Wang et al. applied leaf area index LAI and meteorological factors to simulate the crop coefficient and evapotranspiration of corn in the whole growth period. Based on the day-by-day meteorological data of Hebei in nearly 60 years from 1955 to 2014 and the Hebei Soil Data in the China Soil Database, Cao, Li and Zhu adopted SCCA recommended in FAQ to modify the value of K_C, got the spatial and temporal distribution law for the modification of K_C of main crops in the central south region of Hebei, and discussed the main meteorological factors associated with the changes in K_C [16, 17]. Wang et al. perform observation and experiment studies for crop coefficient and laws of rice in Yunnan. The result showed that the spatial differences of K_C did not have any obvious laws [18]. The value in areas with humid and semi-humid climate was relatively high, and the value in areas with wet cool climate was relatively low. Although K_C demonstrated the decline trend along with the ascending of the altitude, the correlation between them was relatively low. Li applied ET_0 and Eta to calculate out K_C on meadow and sand dune and constructed K_C inversion model from multiple vegetation indexes with concurrent consideration of leaf area index and soil moisture content [19]. Zhang et al. applied UAV remote sensing platform with multispectral sensor to implement synchronous observation for crop coefficients of corn in various growth stages under different moisture contents in Dalad Banner and modified the K_C recommended in FAO with dual-crop coefficient approach based on the meteorological data, soil quality, and other external conditions [20]. Based on the recommended method of FAO, Liu made selection for the ET_0 calculation method in Altay Prefecture of Xinjiang and applied actually measured water requirement to modify the K_C value recommended in FAO56 [21]. Ikram elaborated on the global importance of oats and production improvement, showing that oat is a crop that requires a lot of water to increase production, and in order to reduce the water requirement, a new concept is needed to improve productivity [22]. Ejaz indicated that groundwater resources in Pakistan are depleting and conducted groundwater simulations of different interventions in irrigation and planting practices. The results showed that it is suitable to plant wheat and oats in early spring and cotton in the rainy season; it could maximize the conservation of groundwater resources [23]. Schoot estimated the current and possible future irrigation water consumption of four important irrigated crops in the Rhine River Basin, sugar beet, potato, maize, and oat, and suggested to expand a dynamic crop plan extension model to accurately estimate the water requirement of each subbasin [24]. Djaman selected 28 oat genotypes suitable for planting in the western United States and conducted a four-year yield evaluation under sprinkler irrigation at the Agricultural Science Center, and the results showed that the oat crop water use efficiency (CWUE) varied by genotype and year [25].

At present, a large number of studies have used SCCA recommended in FAO56 to calculate the water demand of naked oats, alfalfa, cotton, and other crops, but most of the results do not consider the impact of irrigation forms on crop water requirement. Naked oats are one of the main nutritious grains in the alpine regions of northern China. In recent years, due to the increasing shortage of water resources in Northwest China, subsurface drip irrigation and underground drip irrigation are widely used in the naked oats planting area at the northern foot of Yinshan Mountain. Because the underground drip irrigation is located below the ground surface, it directly irrigates the roots of naked oats, reducing the evaporation of water on the soil surface, which is quite different from the traditional cultivation of naked oats. At the same time, FAO56 was published in 1998. Compared with now, there have been obvious changes in crop varieties, especially in plant height. How to quickly and accurately calculate the crop water demand of naked oats in the northern foot of Yinshan Mountain under the condition of carrying out field experiments as little as possible has become one of the important issues of water and soil resources management in the irrigation area.

This paper applied SCCA recommended in FAO to investigate the water requirement of naked oats in the north foot of Yinshan Mountain and verified with the measured value at the fields to study the practical application of SCCA in the calculation of crop water requirements of naked oats under drip irrigation in the north foot of Yinshan Mountain in the actual production and life. The research achievements provide basis for the accurate calculation of the crop water requirements of naked oats under drip irrigation in the north foot of Yinshan Mountain, as well as the formulation of scientific and reasonable irrigation system.

2. Materials and Methods

2.1. Regional Overview. The research area is located at Yinshanbeilu Grassland Eco-Hydrology National Observation and Research Station in Xilamuren Town, Damaoqi, Baotou, Inner Mongolia. With a distance of 80 km from Hohhot City, the research station situates on Wulanchabu grassland at the central position of Inner Mongolia and north foot of Yinshan. The place belongs to continental monsoon climate in warm temperate zone. The climate has the characteristics of droughty and windy springs and autumns, hot and short summers, and dry and cold winters. The annual mean precipitation is 284 mm, and the annual mean evaporation is 2305.0 mm. The precipitation is mainly concentrated in July and August. The annual mean temperature is 2.5°C, and the frost-free period is 83 days. The predominant wind is westerly wind and northwesterly wind, and the annual mean wind speed is 4.5 m/s. The mountainous area of Yinshan where the research station is located belongs to the transition belt of Inner Mongolian Plateau, which has the average altitude of 1600 m. The area has denudation landforms, as well as alluvial and constructional landforms.

The soil belongs to young soil developed based on base rocks, and the soil on high positions contains limited amount of soil humus. The soil texture is coarse and the distribution area is relatively small. Low places are generally distributed with relatively large area of chestnut soil, with the texture of light loam or sandy loam. With relatively abundant moisture and nutrients, the soil has certain production potential. The thickness of the surface soil layer is only 10 to 15 cm or thinner, and the thickness in low places could reach from 30 to 50 cm. However, the salt content is relatively high.

2.2. Experiment Materials. The varieties of naked oats applied in the experiment are Bayou No. 1 and Yajin No. 7. The initial division of the growth period is shown in Figure 1. The soil for test in the experiment pit is selected from the soil in the research station. The soil is back filled according to the actual volume-weight. The physical and chemical properties of the soil are shown in Table 1.

2.3. Experiment Design. The irrigation form is shallow drip irrigation. The experiment applied deficit irrigation approach, and set four treatment levels, including Without Drought (the moisture content of soil wetting layer is 90% of the field moisture capacity), Slight Drought (the moisture content of soil wetting layer is 80% of the field moisture capacity), Medium Drought (the moisture content of soil wetting layer is 70% of the field moisture capacity), and Severe Drought (the moisture content of soil wetting layer is 60% of the field moisture capacity). Each treatment level repeated for three times, reaching a total of 12 small areas. The experiment for two crops totally had 24 small areas, as shown in Table 2. The irrigation times of various treatments were 10 times, and the irrigation times are May 20, June 1, June 13, June 28, July 10, July 20, August 1, August 13, August 25, and September 5.

From May 5 to 6, the land was ploughed 25 cm deep and then leveled (15 000 kg rotten organic fertilizer was applied per ha as base fertilizer). Before sowing, seeds were mixed with 40% seed dressing double wettable powder according to 0.2% of seed weight to prevent smut. Sowing began on May 14. The seed fertilizer is 175 kg diamine per ha (nitrogen content 18%, phosphorus content 48%). After sowing, the soil must be covered in time to suppress and preserve moisture. The additional fertilizer shall commence from emergence and end in the heading stage. One additional fertilizer shall be arranged, and 60 kg carbamide is applied for each ha of the land.

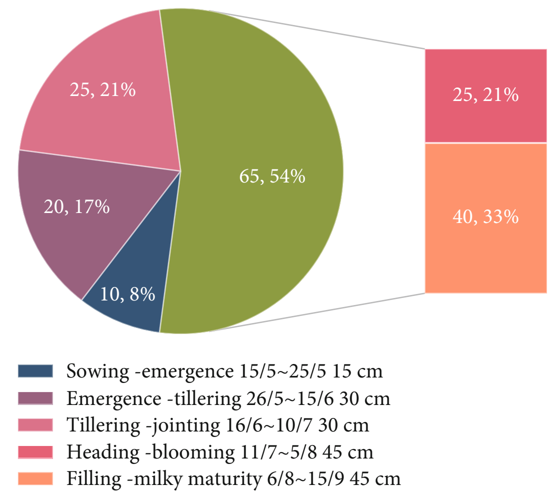

Figure 1: Division of the growth stages and soil wetting layer thickness.

Table 1: Basic physical and chemical properties of experiment soil.

Experiment pit	Naked oats
Bulk density (g/cm^3)	1.44
Saturated water content (%)	23.7
Field	
Water-holding capacity (%)	19.8
Total nitrogen (%)	0.017
Available nitrogen (mg/kg)	35
Rapid available phosphorus (mg/kg)	9.5
Rapidly available potassium (mg/kg)	195
Organic matter (%)	1.21
Soil texture	Loamy sand
Saltness (%)	0.62
pH value	7.8

2.4. Test Indicator and Method. The observation contents mainly include meteorological data, soil data, and physiological data of crops.

Meteorological data: apply the data from Hobo Meteorological Stations in the site.

Physical indicators of soil: moisture content, saltness, temperature, and soil water potential. The current soil sensor (EM50, Origin, USA) is used to measure the moisture content, saltness, and temperature of the soil. The reading intervals of the sensor may be one reading per hour. Use a laptop to regularly collect the water, salt, and temperature data stored in the sensor. The soil water characteristic curve (SWCC) of the soil samples in the test area was measured by a pressure plate extractor (1500F2, Soil Moisture Equipment Corp., Santa Barbara, CA, USA), and then the van Genuchten (VG) model was constructed by the SWCC. The measured soil moisture data is used to calculate the soil water potential through VG model.

Table 2: Experiment design for naked oats.

Treatment	No.	Irrigating water quota (mm)	Times	Irrigation quota (mm)
Severe drought	HM1	15	10	150
Medium drought	HM2	18	10	180
Slight drought	HM3	21	10	210
Without drought (CK)	HM4	24	10	240

Chemical indicators of the soil: organic matter, content of nitrogen, phosphorus, and potassium in soil, pH value, etc. Organic matter content was determined by low-temperature external thermal potassium dichromate oxidation colorimetry. The total nitrogen content was determined by alkaline hydrolysis distillation method. The total phosphorus and total potassium contents were determined by sodium hydroxide melting method.

Crop growing status: growth progress, main development indicators, output, etc. Growth progress: commence the daily measurement work from the seeding and record the seeding time, emergence time, emergence rate, entry time of various growth stages, and the final harvest time. Main development indicators: crop height, stem diameter, leaf area indicator; measure once in each ten days. Measure at least 10 plants in each small area, and sample in the shape of plum blossom; arrange at least 3 sampling points in each small area for the leaf area. Output: after the maturity of the naked oats, randomly select typical sampling points in the land plot to measure the output. The area of each sampling point is $1m^2$.

2.5. Data Analysis Method. The crop water requirement of naked oats in the irrigation test is calculated according to the water balance principle, as shown in Formula (1). According to Formula (1), the crop water requirement in the experiment can be calculated through the indicators such as naked oats irrigation amount, irrigation times, rainfall supply amount, and soil moisture.

$$ET_c = P_0 + K + M + W_t + \Delta W, \quad (1)$$

where ET_c is crop water requirement (mm); P_0 is the effective rainfall during the growth period (mm); K is groundwater recharge (mm); M is irrigation water volume during growth period (mm); W_t is the change of soil water content caused by the increase or decrease of the soil wetting layer thickness at the beginning and end of each growth period, and the increase or decrease of soil water storage caused by the increase or decrease of soil wetting layer thickness. Since there is no increase or decrease of the soil wetting layer thickness, this item can be ignored; ΔW is the increase or decrease of soil available water supply caused by the change of soil water content at the beginning and end of each growth period, which is ignored in this study.

The study compared the measured value in experiments with the data calculated out with SCCA and then used SCCA to calculate out the water requirement (Formula (2)) [1].

$$ET_c = ET_0 \cdot K_c, \quad (2)$$

where K_c is the crop coefficient in the whole growth period or in different growth stages of the crop; ET_c is the actual water requirement of the crop in the whole growth period or in different growth stages (the unit is mm); ET_0 is the potential evapotranspiration of the reference crop in the whole growth period or in different growth stages (the unit is mm).

Apply Penman-Monteith formula (Formula (3)) recommended in FAO56 to calculate the potential evapotranspiration ET_0 of the reference crop. Potential evapotranspiration ET_0 of the reference crop (1990): it is the evapotranspiration rate of the reference crop assuming that the crop height is 0.12 m, the fixed surface resistance y =70 s/m, and the reflection rate is a =0.23. Penman-Monteith formula has relatively thorough theoretical basis and high calculation precision. It takes energy balance and water vapor diffusion theories as the basis and considers the aerodynamic parameters and physiological feature of crops.

$$ET_0 = \frac{0.408(R_n - G) + \gamma(900/(T + 273))u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}, \quad (3)$$

where ET_0 is the evapotranspiration of the reference crop (mm/d); R_n represents the net radiation on canopy surface [MJ/(m^2•d)]; G is the soil heat flux [MJ/(m^2•d)]; T represents average temperature (°C); Δ represents the slope of the vapor pressure-temperature curve for saturated water (k Pa/°C); u_2 is the wind speed at the height of 2.0 m (m/s); e_s is the vapor pressure of saturated water (k Pa); e_a is the vapor pressure of the actual water (k Pa): γ is the constant of the hygrometer (k Pa/°C).

SCCA incorporates the influences of crop evapotranspiration and evaporation of soil into the K_C. To coordinate various characteristics of crops and average influence of soil evaporation, SCCA divides the growth period of crop into four growth stage and uses these four growth stages to describe the crop development process and biological and climate characteristics. These four stages are initial growing stage, wintering stage, growth peak stage, and final growth stage. The whole growth period just needs three K_c values (K_{cini}, K_{cmid}, and K_{cend}) to describe and draw the K_c curve.

3. Results and Analysis

3.1. Measured Water Requirements of Naked Oats. Water requirement characteristics of naked oats were expressed by modulus coefficient and water requirement intensity. The modulus coefficient represents the proportion of water requirement in a certain growth stage to the whole growth stage, and the water requirement intensity represents the average daily water requirement in the growth stage. It could be seen from Table 3 that the water requirements, modulus coefficient, and water requirement intensity of naked oats had the trend from low to high and then from high to low. The plants were relatively small in the seedling stage, and the land coverage was relatively low. Therefore, the surface evaporation took a vital portion in the water consumption. In addition to relatively low temperature and weak illumination, the water requirement model number and intensity in this stage were relatively low. The modulus coefficient is around 20%, and the water requirement intensity was from 2.56 to 3.91 mm/d. After the stage of Tillering-Jointing, the nutrient growing and evapotranspiration accelerated, leading to rapid expansion of the water requirement intensity. Therefore, the stage modulus coefficient was relatively high, which was around 28%. In the stage of Heading-Blooming, the plant height and leaf area of naked oats reached the highest value. In addition, the stage is just the season with the highest temperature in a year; the water requirement intensity reaches the highest level, which is between 3.08 and 4.70 mm/d. The water requirement modulus reaches the highest value of about 31%. This stage is critical for the growth of naked oats. As the gradual descending of the temperature in the stage of Filling-Milky Maturity, the leaves gradually become yellow, the evapotranspiration keeps decreasing, and the water requirement intensity comes across gradual decrease day after day.

3.2. Potential Evapotranspiration of Reference Crop. It could be seen from Figure 2 that the mean value of the potential evapotranspiration ET_0 in the whole growth period was 3.89 mm/d, which demonstrated the trend of high in the middle and low in the both ends. Due to the decrease in temperature at the stage of emergence, the value of ET_0 was relatively low, and the mean value was only 3.22 mm/d. As the gradual ascending in the temperature and increase in the solar radiation capacity, ET_0 maintained the gradual increase trend after reaching the stage of bud bearing and blossoming. ET_0 reached the highest value of 6.86 mm/d on July 20, and saw the lowest value of 1.82 mm/d on September 23.

3.3. Initial Selection of K_c under SCCA. In the whole growth period, K_c will change along with changes in the growth and development, ground coverage degree, crop height, and leaf area. According to FAO56 and actual growth performance of crops (Table 4), the growth and development period of the crop could be re-classified into the following stages according to the demands of SCCA.

The initial growth period is determined when about 10% of the soil surface is covered by green.

Crop development growth stage shall refer to the period when the surface coverage reaches about 10%, to the time when the surface is completely covered by green. On account of some physiological features of close crops like naked oats, it is very difficult to determine the effective time of complete shading in a visualized manner. Therefore, for the convenience of observation, the experiment takes the time when the average height of crops reaches about 0.5 meters as the effective time of complete shading.

The mid-season growth stage commences from the time of effective and full shading and ends on the maturity of the crops. The mid-season growth period under the experiment commenced from the time of effective and full shading to the time before harvest.

As annual crops used for grains and oil-bearing materials, naked oats enter into the late season growth stage after filling and would be harvested after become yellow and matured.

In accordance with data provided in No. 24 Document of FAO Irrigation and Drainage, under the conditions of the average sunshine and minimum relatively humidity ($RH_{\min}$) of about 45%, the average wind speed of 2 m/s, the absence of water stress and relatively high management level, the recommended values of naked oats under the three growth stages are K_{cini} =0.3, $K_{c\text{mid}}$ =1.15, and $K_{c\text{end}}$ =0.25.

3.4. Modification for K_c under SCCA

3.4.1. Calculation and Modification of K_{cini}. Only one drip irrigation is arranged on May 20 in the initial growth stage of the crops, and the irrigation amount of naked oats is 27 mm. According to the recommended calculation method of FAO, K_{cini} could be estimated and calculated with formula if the average infiltration depth is between 10 mm and 40 mm (Formula (4)).

$$K_{\text{cini}} = K_{\text{cini}-b} + \frac{(\mathrm{I}-10)}{(40-10)}\left[K_{\text{cini}-b} - K_{\text{cini}-a}\right], \tag{4}$$

where $K_{\text{cini}-a}$ represents average K_{cini} as related to the level of ET_0 and the interval between irrigations and/or significant rain during the initial growth stage for all soil types when wetting events are light to medium (3-10 mm per event), and $K_{\text{cini}-b}$ represents average K_{cini} as related to the level of ET_0 and the interval between irrigations greater than or equal to 40 mm per wetting event, during the initial growth stage for coarse-textured soils and medium and fine-textured soils [1], and I is the average infiltration depth (mm). According to the relevant data and materials in the figures and table, the value of K_{cini} under drip irrigation condition ascertained from the table is 0.3.

In FAO56, the calculation of K_{cini} still needs the modification for the energy restriction stage and soil moisture restriction stage in the surface evaporation process of the soil. According to the field moisture capacity and moisture rate on wilting point of the soil and the sand content Sa and clay content in the soil in the evaporation layer, K_{cini} for naked oats under drip irrigation is 0.34 when the irrigation quota is 270 mm.

Table 3: Water requirement and water requirement modulus coefficient of naked oats in various growth stages.

Growth stage	Emergence-Tillering			Tillering-Jointing			Heading-Blooming			Filling-Milky maturity		
Indicator	Water requirement	Modulus coefficient	Water requirement intensity	Water requirement	Modulus coefficient	Water requirement intensity	Water requirement	Modulus coefficient	Water requirement intensity	Water requirement	Modulus coefficient	Water requirement intensity
	mm	%	mm/d	mm	%	mm/d	mm	%	mm/d	mm	%	mm/d
YM1	51.18	20.56	2.56	69.17	27.79	2.77	76.97	30.92	3.08	51.58	20.72	1.29
YM2	60.18	20.48	3.01	82.67	28.13	3.31	90.47	30.78	3.62	60.58	20.61	1.51
YM3	69.18	20.41	3.46	96.17	28.38	3.85	103.97	30.68	4.16	69.58	20.53	1.74
YM4	78.16	20.36	3.91	109.64	28.57	4.39	117.44	30.6	4.7	78.56	20.47	1.96

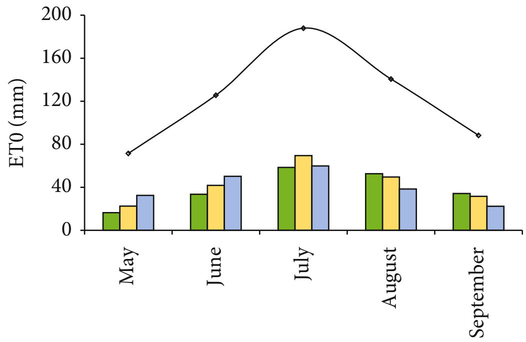

Figure 2: Evapotranspiration in growth period.

Table 4: Division of the actual growth stages of naked oats.

Growth stage	Date
Initial growth stage	May 5-June 15
Crop development growth stage	June 16-July 10
Mid-season growth stage	July 11-August 5
Late season growth stage	August 6-September 15

3.4.2. Calculation and Modification of K_{cmid}. With dry climate and windy and dusty weather, the north foot of Yinshan Mountain inn Inner Mongolia does not belong to the situations recommended in FAO-56. As for crop coefficient under non-standard situations, FAQ-56 provides the formula of modified K_{cmid} (Formula (5)):

$$K_{\text{cend}} = K_{\text{cend(Table)}} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45]\left(\frac{h}{3}\right)^{0.3}, \tag{5}$$

where $K_{\text{cmid}(T)}$ represents the recommended value of FAO; u_2 represents the average daily wind speed at the positions above 2 m in the growth stage; $RH_{\min}$ represents the mean value of the minimum daily relative humidity in the growth stage; h represents the mean height of the crop in the stage. Meteorological data were shown in Table 5. The value of K_{cmid} of naked oats is 1.05.

3.4.3. Calculation and Modification of K_{cend}. Values of K_{cend} of crops recommended in FAO-56 are typical expected values of mean K_{cend} under the standard climate conditions. The value of K_{cend} under drought and strong wind conditions would be higher, while the value of K_{cend} in wet places with relatively low wind speed would be lower. Under the climate conditions that $RH_{\min}$ is not equal with 45% or u_2 is higher or lower than 2.0 m/s, it is necessary to make specific calibration for K_{cend}. Formula (6) could be used for

Table 5: Days and meteorological factors of naked oats at different growth stages.

	Days/d	u_2/m·s^{-1}	$RH_{\min}$/%	h/m
Initial growth stage	20	3.42	38.95	0.32
Crop development growth stage	25	2.98	31.26	1.17
Mid-season growth stage	25	2.96	35.78	1.42
Late season growth stage	40	3.04	39.22	1.29

the calculation.

$$K_{\text{cend}} = K_{\text{cend(Table)}} + [0.04(u_2 - 2) - 0.004(RH_{\min} - 45]\left(\frac{h}{3}\right)^{0.3}, \tag{6}$$

where $K_{\text{cend (table)}}$ is the recommended value of 1.15 for K_{cend} in FAO; u_2 is the daily average wind speed (m/s) at the position with the height of 2 m, $1 \le u_2 \le 6$ m/s; $RH_{\min}$ is the mean value (%) for the minimum daily relative humidity, $20\% \le RH_{\min} \le 80\%$; h is the mean value of the crop height in the late season growth stage (m), $0.1 \le h \le 10$ m. The value of K_{cend} of naked oats is 0.34.

3.5. Crop Water Requirement Calculated with SCCA. In Formula (3), ET_0 and K_c after the modification were used to get the crop water requirements of naked oats in different growth stages, as shown in Figure 3. ET_0 of naked oats at the north foot of Yinshan Mountain in their full growth period in 2021 was 516.01 mm, the water requirements of naked oats under drip irrigation was 363.84 mm, and average K_c in the growth period was 0.71.

4. Discussion

The trend for the water consumption intensity of naked oats was from low to high and to low. The main water consumption of the soil in the seedling stage is mainly from soil evaporation between plants. Therefore, the water requirement is relatively low. Along with the accelerated growth speed and high temperature, the nutrient and reproduction of crops maintain simultaneous growth in the stage of Tillering-Jointing (Tillering-Squaring), and the crops growth rapidly in root, stem, and leaves, leading to strong photosynthesis. Together with high temperature and long sunshine duration, the water consumption comes across accelerated increase. The water requirement intensity of naked oats reached the peak at the Heading-Blooming stage. As the growth speed slows down, the water requirement amount and intensity experience certain decrease.

The water requirements of naked oats in various growth stages calculated out with SCCA were commonly lower than the actual crop water requirements measured at the field, especially that in the initial growth stage, which had certain relationship with the irrigation method of subsurface drip irrigation. In calculating the K_{cini}, the crop coefficient mainly depends on the wetting frequency of the surface soil due to

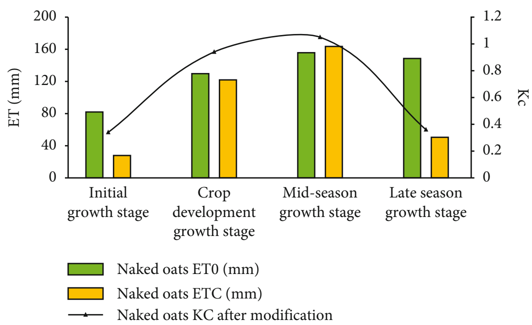

Figure 3: Calculation of crop water requirement under SCCA.

the low height and low shading coverage of plants. Under drip irrigation without any film protection, the crops would come across the influence from the supply of underground water due to excessive evaporation amount and relative high level of the underground water. The application of SCCA does not consider the influence of the wetting depth. As a result, the crop water requirement calculated for the initial growth stage of the crop is lower than the actual water requirement measured at the field.

K_c refers to the ratio of crop evapotranspiration and reference evapotranspiration under the standard conditions that crops without pests and diseases, soil fertility, and soil moisture status were good, and the potential maximum production could be obtained with certain climatic conditions. However, the difference in soil fertility, water stress, and management level will affect the value of K_c. Drip irrigation delivers water directly to the roots, reducing the surface water evaporation, but moistening the soil partially, which is quite different from the traditional irrigation form. In initial growth stage of crop, soil surface water evaporates quickly, but the evaporation of soil surface water slows down in the mid-season and late season growth stages. When applying SCCA to calculate K_C, the influence of soil moisture degree on K_C is considered, which plays a positive role in improving the accuracy of K_C calculation. However, because the influence of local irrigation on K_C is ignored, the deviation in the calculation of K_C value in the middle and later period appears.

5. Conclusions

The water requirement of naked oats without drought influence was 383.8 mm, and the respective peaks of the daily water requirement intensity appeared in the stage of Heading-Blooming, with the specific value of 4.70 mm/d. As a critical stage for water requirements of the crops, the water requirements in this stage took 30.60% of the total water requirements in the whole growth period.

The mean value of the potential evapotranspiration ET_0 in the whole growth period of naked oats was 3.89 mm/d; the value reached the peak of 6.86 mm/d in the last third of July and the bottom value of 1.82 mm/d in the last third of September.

After the modification, K_c of naked oats in the initial growth stage, crop development growth stage, mid-season growth stage, and late season growth stage was 0.34, 0.94, 1.05, and 0.36, respectively, and the mean value of K_c in the whole growth period was 0.71;

Combined with meteorological data, the SCCA can be used to accurately calculate the crop water demand of naked oats under drip irrigation in the northern foot of Yinshan Mountain in Inner Mongolia (the deviation is different under different experimental treatments, generally about 10%). When the irrigation quota of naked oats was 315 mm, the actual crop water requirement of naked oats was 383.8 mm, and the crop water demand calculated by SCCA was 363.84 mm.

Data Availability

After the paper is accepted, the experimental data of this paper will be uploaded to Baidu cloud for other researchers to download and use.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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