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Water Consumption Characteristics of Sugarcane in Dry-Hot Region under Climate Change

Xiaogang Liu*[a], Zhihui Han[a], Kun Hao[a], Xinle Wang[b], Qiliang Yang[a]

[a] Faculty of Modern Agricultural Engineering, Kunming University of Science and Technology, Kunming, China,
[b] Faculty of Foreign Language and Culture, Kunming University of Science and Technology, Kunming, China.
liuxiaogangjy@126.com

The analysis of the sugarcane water requirement regulation at different temporal scale can provide a basis for optimal water management. Based on the daily meteorological observation data in Yuanmou dry-hot region during 1956-2010, sugarcane water requirement and crop water surplus deficit index were estimated, and the variation characteristics were analyzed at different temporal scale. The impact of several meteorological factors on water requirement was studied by the partial correlation analysis method. The variation pattern was conducted on the data of the annual water requirement and crop water surplus deficit index by using the Mann-Kendall test. The result showed that sugarcane water requirement in dry-hot region was significantly higher than other months from June to October and less in April, May, November and December. The moisture profit and loss was comparatively large from June to December and sugarcane depended much on irrigation, but it was less in April and May and sugarcane depended less on irrigation. Sugarcane water requirement fluctuated decreasing trend in recent 55 years. Since the 1980s, water requirement and water deficit began to decrease significantly. The changes of sugarcane water requirement were primarily attributed to wind speed and sunshine hours in dry-hot region.

1. Introduction

The annual average surface temperature was significantly increased in recent 100 years, and increasing extent of temperature was slightly higher than the global average of the same period with global warming (Qin, 2007). The change trend of precipitation was not obvious, but since 1956 there had been a slight increase in the trend (Ding, 2006). Dry-hot region has characteristics of dry and hot climate, rich resources of light and heat, less rainfall and maldistribution in space and time, and outstanding seasonal drought, which all limited the high quality of sugarcane production. Determining the variation characteristics of sugarcane water requirement at different stages of growth under climate change can provide scientific reference basis for irrigation schemes.

The change of meteorological factors can significantly change the crop water consumption and water requirement. Many scholars have carried out a series of exploration on crop water requirement under the climate change. Nkomozepi and Chung (2012) reported water requirement and net irrigation water requirement of spring maize in natural agricultural ecological region with GCM and CROPWAT model. Reference crop evapotranspiration in Iran semi-arid plateau environment was analyzed based on limited weather data by using support vector machine, neural network and regression analysis (Tabari, 2012). Wang (2013) simulated the response of rice water requirement to climate change by rice model ORYZA2000 according to meteorological data and the statistical simulation results of HadCM3 atmospheric general circulation model A_2 and B_2. Yin (2010) studied the cause the variation trend of reference crop evapotranspiration and obtained the contribution rate of meteorological factors to the variation trend. Sugarcane is the main economic crop in China, but there has less study on water consumption under climate changes.

This paper analyzed the variation pattern about the sugarcane water requirement and crop water surplus deficit index at different temporal scale and discussed the influence of the meteorological factors on the water requirement of sugarcane in dry-hot region based on the daily meteorological data from 1956 to 2010.

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2. Data source and research method

Dry-hot region had annual rainfall of 600-800 mm and 90% rainfall was concentrated from June to October. The annual average temperature of dry-hot region was above 20℃ and effective accumulated temperature was above 7000-8000℃ which caused the annual evaporation was 6 times of annual precipitation. As a typical representative of the dry hot region, Yuanmou is located in Longchuan River downstream valley basin area, the northern plateau of the central Yunnan Province, China, there serious contradictory of water and heat.

Daily meteorological observation data of Yuanmou (101°52′E, 25°44′N) in dry-hot region during 1956-2010 provided by China Meteorological Science Data Sharing Service Network. Reference crop evapotranspiration is calculated by the latest revision Penman-Monteith formula that recommended by the FAO-56. Sugarcane growth period is divided into four stages according to growth characteristics, e.g. seedling stage (from April 10th to May 23rd), tillering stage (from May 24th to June 25th), elongating stage (from June 26th to October 8th) and maturity (from October 9th to December 30th). Crop coefficients are Kc_{ini}=0.40, Kc_{mid}=1.25 and Kc_{end}=0.75 (Allen, 1998).

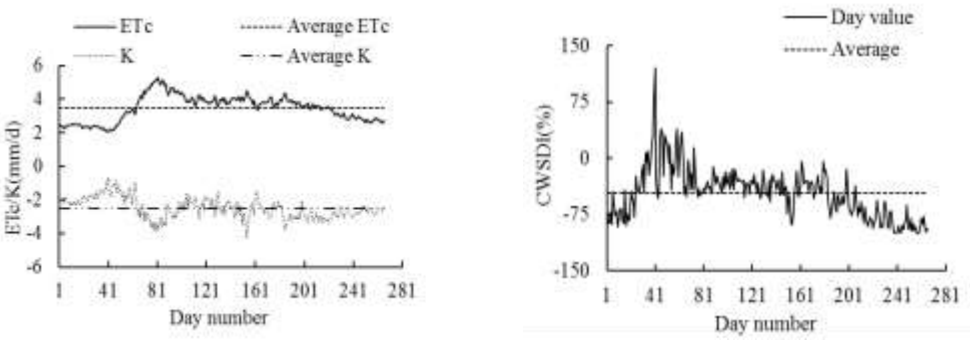
CWSDI (Water Surplus Deficit Index Crop) is composed of crop water requirement and available water supply, which indicates the degree of crop water budget (Wang, 2013). Reference crop daily evaporation and sugarcane water requirement were calculated and water surplus deficit index were obtained based on the daily meteorological data of Yuanmou dry-hot region according to Penman-Monteith formula and crop coefficient of FAO-56. SPSS software was used to analyze the partial correlation coefficient between the water sugarcane requirement and the meteorological factors, and the most significant meteorological factors were obtained. The Mann-Kendall trend test was carried out on the annual variation of sugarcane water requirement and some meteorological factors with Matlab7.0 software, and the variation trend and mutation of the water requirement and meteorological factors were analyzed.

3. Results and analysis

3.1 Daily variation

The change curves of sugarcane daily water requirement (ET_c), the profit and loss of moisture and the crop water surplus deficit index (CWSDI) in dry-hot region were shown in figure 1. The average daily water requirement was 3.5 mm/d during one year. The water requirement was stable from 1st to 51st day and increased day by day from 52nd day. Water requirement was higher than average from 65th day and reached a peak of 5.3 mm/d until 82nd day, and then, water requirement was gradually reduced and trended to average. The water requirement started lower than the average from 214th days, so it was clear that from 65th to 214th days was the peak of the water requirement of sugarcane. The daily profit loss of moisture of the sugarcane was negative and indicated that the annual water was deficient, and the average of was -2.5 mm/d. The daily profit loss of moisture was lower than the average from 66th to 104th days and from 169th to 266th days, and water deficit was obvious. The water deficit was smaller from 1st to 65th and 104th to 168th and the degree of dependence on irrigation of sugarcane in this stage was relatively low. The average of sugarcane crop water surplus deficit index (CWSDI) was -46.7%. CWSDI was significantly higher than the average from 26th to 127th and water deficit was relatively small.

The method of partial correlation coefficient can eliminate mutual influence between the elements according to the partial correlation coefficient between daily water requirement of sugarcane and meteorological factors in dry-hot region, the degree of correlation from high to low is: sunshine hours (0.473), wind speed (0.436), vapor pressure (0.398), pressure (0.208), relative humidity (-0.208), temperature (-0.115), precipitation (-0.087), daily maximum temperature(-0.05), daily minimum temperature(0.03). The water requirement was positively correlated with sunshine hours, wind speed, vapor pressure, pressure and daily minimum temperature, but negatively correlated with relative humidity, temperature, precipitation and daily maximum temperature.

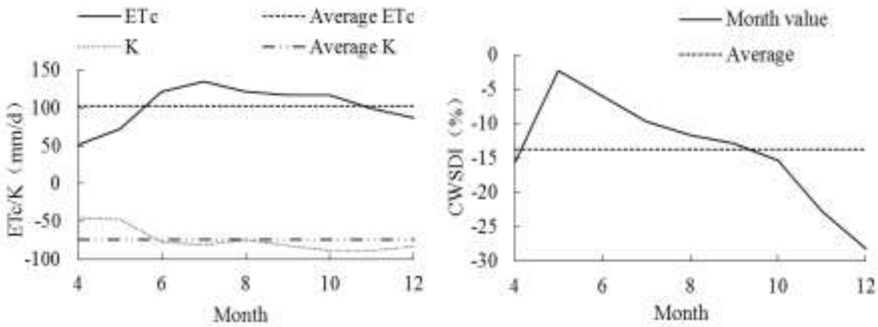


(a) (b)

Figure 1: Change curves of daily average water requirement, moisture profit and loss (K) and CWSDI

3.2 Monthly variation

Sugarcane monthly water requirement, moisture profit and loss (K) and the change of crop water surplus deficit index CWSDI curve were shown in figure 2. Monthly water requirement was increasing from April, reached the maximum of 134.7 mm in July, then decreased progressively, and it fell to the minimum of 86.5 mm in December. The average of sugarcane water requirement from June to October was significantly higher than 102.5 mm, and it was the peak of sugarcane water requirement. Sugarcane monthly moisture profit and loss were negative and monthly average deficit was 74.1 mm. The moisture profit and loss increased significantly since May and reached a maximum of 89.0 mm in October, and then decreased. Crop water surplus deficit index (CWSDI) reached to a peak of -2.3% in May, and from April to September CWSDI was significantly higher than the monthly CWSDI average of -13.8%. Thus, sugarcane water requirement in dry-hot region was significantly higher than other months from June to October and less in April, May, November and December. The moisture profit and loss was comparatively large from June to December and sugarcane depended much on irrigation, but it was less in April and May and sugarcane depended less on irrigation.



(a) (b)

Figure 2: Change curves of monthly average water requirement, moisture profit and loss (K) and CWSDI

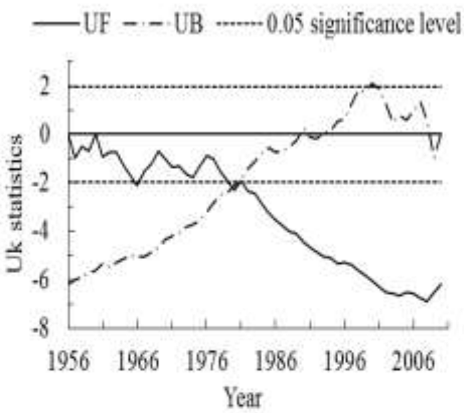
Making partial correlation analysis of monthly water requirement and meteorological factors to further explore the influence of meteorological factors on sugarcane water requirement, and the results were shown in Table 1. Wind speed and sunshine hours were the important factors that affected sugarcane water requirement. The partial correlation coefficient of wind speed and sunshine hours passed the test of the reliability of α=0.001, and two factors was significantly positive correlation with monthly water requirement. Sunshine hours was the most significant meteorological factors affecting the water requirement of sugarcane in May, June, July, August and September, and wind speed was the most significant meteorological factors in April, October, November and December. Therefore, wind speed and sunshine hours were the most significant impact on dry-hot sugarcane water requirement, which was consistent with the results of the daily water requirement and the partial correlation coefficient of the meteorological factors.

Table 1: Monthly water requirement and the partial correlation coefficient of the meteorological factors

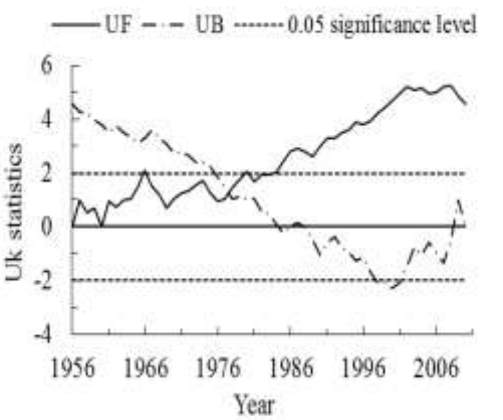
Month	Precipitation	Pressure	Wind speed	Temperature	Vapor pressure	Relative humidity	Sunshine hour	Daily minimum temperature	Daily maximum temperature
4	-0.187	0.070	0.726***	0.083	-0.195	0.084	0.487***	0.039	0.157
5	-0.252	0.055	0.616***	0.238	-0.567***	0.416**	0.750***	0.301*	0.023
6	-0.141	-0.029	0.326*	0.182	-0.238	0.050	0.771***	0.086	-0.058
7	-0.151	0.071	0.613***	0.640***	-0.613***	0.482***	0.959***	0.163	-0.324
8	0.482***	0.072	0.901***	0.474***	-0.465***	0.246	0.985***	0.114	0.090
9	0.065	-0.009	0.707***	0.128	-0.076	-0.062	0.887***	-0.031	-0.080
10	0.069	0.083	0.664***	0.331*	-0.267	0.178	0.618***	-0.097	-0.204
11	-0.193	0.093	0.540***	0.171	-0.101	0.026	0.324*	0.003	-0.107
12	0.001	0.068	0.656***	0.001	-0.381**	-0.007	0.531***	0.258	0.022

3.3 Annual variation

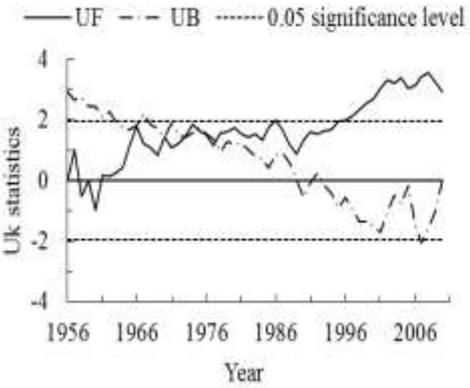
Trend analysis on sugarcane water requirement, moisture profit and loss (K) and CWSDI in dry-hot region and the change curve were showed in figure 3. Since 1960, sugarcane water requirement began a downward trend in dry-hot region and felled below the threshold until 1980 (Fig 3a). Then this decline was more than significant level of 0.05 critical line, and even over 0.001 significance level ($u_{0.001}$=2.56). Therefore, the downward trend of the sugarcane water requirement in nearly 20 years was extremely significant. Annual average of moisture profit and loss was negative (Fig 3b). Sugarcane profit and loss of moisture was large than 0 since 1956 and water deficit decreased gradually. The water profit and loss of moisture exceeded the critical line in 1984 and the water deficit reduced significantly after 1980s. The curves of UF and UB appeared intersection in1978 and the intersection was in the critical line. Thus water deficit was less after 1980s and it appeared mutation phenomenon in 1978. The crop water surplus deficit index (CWSDI) was all negative nearly 55 years. The UF statistic was larger than 0 since 1961 and CWSDI showed a trend of increase. The water surplus deficit index surpassed critical value until 1997 and presented a significant decrease trend (Fig 3c).



(a) Water requirement



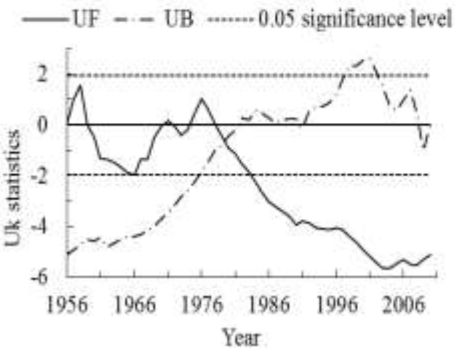
(b) Profit loss of moisture



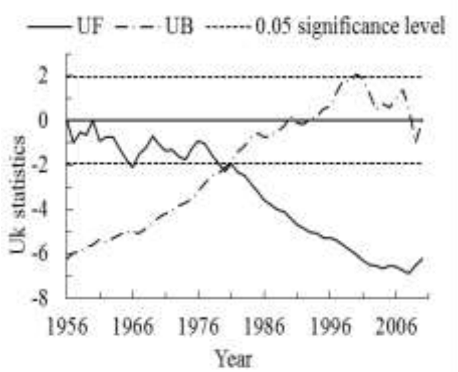
(c) CWSDI

Figure 3: Mann-Kendall test curves of water requirement, moisture profit and loss and CWSDI

Wind speed and sunshine hours were the most significant meteorological factors affecting water requirement according to the correlation between the meteorological factors and the water requirement of sugarcane. The average trend of wind speed and sunshine hours in dry-hot region was analyzed by Mann-Kendall test (Fig. 4). The wind speed appeared a growth trend in dry-hot region (Fig. 4a). The curves UF and UB appeared intersection between critical lines and mutation phenomenon. Then wind speed began to show a decreasing trend and fell below the critical value until 1984. UF statistics were beyond the 0.001 significant level ($U_{0.001}$=2.56) and wind speed decreased significantly since 1980s. The results of Mann-Kendall test of sunshine hour showed in Fig. 4b, and UF statistics was less than 0 since 1956. Thus, sunshine hours showed a downward trend and it was beyond the level of significant levels of 0.05 until 1982, which indicated that sunshine hours showed a significant downward trend in dry-hot region from late of 1980s.



(a) Wind speed



(b) Sunshine hours

Figure 4: Mann-Kendall test curves of wind speed and sunshine hours

4. Discussion

In recent years, the temperature in southwest China was a significant upward trend, but sugarcane water requirement was a significant downward trend in dry-hot region for the last 55 years, which indicated that the temperature change was not effect of changes in crop water requirement dominant factor and agreed with previous result which was confirmed (Gu, 2008). Crop water requirement is mainly affected by radiation variables and aerodynamic variables (McVicar, 2007). In this study the most significant meteorological factor affecting sugarcane water requirement were wind speed and sunshine hours, which was confirmed (Zhang, 2010; Roderick, 2007 and Liang, 2010).

There was a close relationship between sugarcane water requirement in dry-hot region and the local climate change. At the same time, the complex terrain of dry-hot region also affected sugarcane water requirement, but the paper only studied the change characteristic of sugarcane water requirement and water surplus deficit index from the perspective of climate change. The factors of topography, soil conditions and irrigation conditions and other factors that impact on crop water requirement should be considered in future.

5. Conclusions

1) Sugarcane water requirement in dry-hot region was significantly higher than other months from June to October and less in April, May, November and December. The moisture profit and loss was comparatively large from June to December and sugarcane depended much on irrigation, but it was less in April and May and sugarcane depended less on irrigation.
2) The correlation degree from high to low according to partial correlation coefficient of meteorological factors and sugarcane daily water requirement was wind speed, sunshine hours, vapor pressure, pressure, relative humidity, temperature, precipitation, daily maximum temperature and daily minimum temperature. Wind speed and sunshine hours were the most significant impact on the sugarcane water requirement.
3) Sugarcane water requirement fluctuated decline trend in dry-hot region, and the gross water surplus deficit was negative in near 55 years. Sugarcane water requirement was significantly decreased trend since 1981, which was consistent with the variability of wind speed and sunshine hours.

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