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Response of yield and water use efficiency to different irrigation levels at different growth stages of Kenaf and crop water production function

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ABSTRACT

To provide a rational irrigation management for high yield cultivation of Kenaf, the effects of three irrigation levels at the three growth stages on raw fiber yield, shoot dry mass and water use efficiency of two Kenaf varieties were investigated, and crop water production function was simulated by the Jensen's model. Two Kenaf varieties (V) included hybrid variety (Hongyou 2, V_1) and conventional variety (Fuhong 992, V_2). Three irrigation levels at different growth stages included (1) high water level (A_1), middle water level (A_2) and low water level (A_3) at the seedling stage, (2) high water level (B_1), middle water level (B_2) and low water level (B_3) at the vigorous growth stage, and (3) high water level (C_1), middle water level (C_2) and low water level (C_3) at the flowering and fruiting stage. Orthogonal test with replicates, unequal level and the existence of interaction was designed. Orthogonal test indicates that significant effects of variety and irrigation level at the vigorous growth and flowering and fruiting stages on raw fiber yield were found, and the raw fiber yield of Hongyou 2 was significantly higher than that of Fuhong 992. The best combination of two varieties and three irrigation levels at the three growth stages was $V_1A_2B_1C_1$ for raw fiber yield and shoot dry mass and $V_1A_3B_1C_3$ for water use efficiency on the basis of dry raw fiber yield (WUE_{rf}). Simulation results of the Jensen's model show that the sensitivity coefficient (λ_2) was the highest at the vigorous growth stage, and significantly higher than those of other growth stages, showing that Kenaf was the most sensitive to water deficit at the vigorous growth stage, and the vigorous growth stage was the critical stage of water requirement for Kenaf. For Hongyou 2 and Fuhong 992, raw fiber yield was improved with the increase of irrigation amount at the vigorous growth stage and flowering and fruiting stage, and the simulation of the Jensen's model also proved that Kenaf was very sensitive to water deficit at the vigorous growth stage, so Kenaf should be supplied by adequate irrigation at the vigorous growth stage. The raw fiber yield of two varieties had the highest at $A_2B_1C_1$, but Honyou 2 had more raw fiber yield. As the response of Fuhong 992 to irrigation level at different growth stages was not more significant than that of Hongyou 2, Hongyou 2 should be planted under better water and fertilizer condition.

1. Introduction

Kenaf (*Hibiscus cannabinus* L.) is a short-day phloem fiber crop, which belongs to *Hibiscus* of *Malvaceae*. Kenaf grows faster, needs more water and has better fiber quality (Tahery, 2011; Bahtoee et al., 2012). Kenaf is widely used in boutique high-end textile, papermaking, oil and feed etc. In recent years, Kenaf is served as new biomass energy plant (Alexopoulou et al., 2000; Song and Wang, 2014).

At present there are some studies on the effect of water deficit on growth and yield of Kenaf. Jie and Wang (2000) indicated that water stress reduces the growth rate and plant leaf area, inhibits dry mass accumulation and increases root/shoot ratio of Kenaf, and the response of Kenaf to water stress is more sensitive at later vigorous growth stage than at the early growth stage. Reduced irrigation amount significantly decreases raw fiber yield and shoot dry mass of Kenaf under adequate fertilizer condition (Danalatosa and Archontoulis, 2000; Moreno et al., 2004). At the same time, irrigation method and amount also affect the growth and yield of Kenaf.

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Drip irrigation can significantly improve raw fiber yield and shoot dry mass of Kenaf hybrid variety (Hongyou 2) (Wang et al., 2015). Nkaa and Ogbonnaya (2007); Quaranta et al. (2000) showed that with the increase of irrigation amount, the stem dry mass increases but the water use efficiency decreases. However, the stem diameter and other growth parameters had no significant difference. With the increase of irrigation amount, total dry mass of Kenaf increases, and the maximum value obtained at 125% ET_c (reference crop evapotranspiration) (Bañuelos et al., 2002).

Crop water production function represents the relationship between crop yield and water consumption, including dynamic yield model and final yield model. Jensen (1968) proposed a model that can describe the relationship between final crop yield and water consumption. Previous studies have indicated that the Jensen's model is a relatively good water production function. Chai et al. (2014) indicated that the Jensen's model is suitable for water production function of both early rice and late rice. Gao (2014) determined the relationship between yield and water consumption of winter wheat using the Jensen's model, and concluded that the heading, filling and jointing stages are the critical stage of water requirement, and water stress at the re-greening and maturing stages has no significant effect on the yield. In fiber crops, Xiao et al. (2010) established the Jensen's model of cotton in the growing areas of China using the data from the database of irrigation experiment in China, and the model had better performance in describing the relationship between yield and water consumption in different growth stages. Some researchers indicated the Jensen's model can be applied to simulate crop water production function in the pot experiments (Cui et al., 2015; Wang et al., 2014; Zou et al., 2014). But there are fewer studies about crop water production function of Kenaf.

In recent years, there are some studies about the response of Kenaf to irrigation treatment, but the responses of different Kenaf varieties in different regions to irrigation treatment and water demand (including physiological and ecological water demand) at different growth stages are not the same. Thus the objectives of this study were to investigate the effects of different irrigation levels at different growth stages of Kenaf on final yield and water use efficiency of hybrid and conventional varieties based on the genetic diversity and the difference in water absorption and utilization of Kenaf, and crop water production function of Kenaf was simulated by the Jensen's model, so as to provide a rational irrigation management for high yield cultivation of Kenaf.

2. Materials and methods

2.1. Experimental site and materials

Pot experiment was carried out in a greenhouse in Guangxi University, Nanning, south China (N 22°51′11″, E 108°17′27″). The experimental soil is latosolic red soil derived from Quaternary red earth. Soil pH was 5.0, organic matter 19.2 g/kg, available N (hydrolytic N, 1 mol/L NaOH hydrolysis) 77.6 mg/kg, available P (0.5 mol/L $NaHCO_3$) 21.1 mg/kg, available K (1 mol/L neutral NH_4OAc) 59.8 mg/kg and soil water content at field capacity 28% (on the mass basis).

Pot experiment was carried out in the plastic bucket (the upper diameter of 32 cm, the bottom diameter of 28 cm and the height of 28 cm), which filled with 20 kg air-dried soil after sieving. 12 seeds per pot were sown on May 29, 2012, and two uniform seedlings with the five leaves (about 10 cm high) were retained. The harvest date was October 7. Watering was stopped at two days before the harvest. After harvesting, all agronomic traits such as plant height were immediately measured.

Table 1
Orthogonal design of irrigation level at different growth stages of Kenaf. V: Variety, A: Irrigation level at the seedling stage, B: Irrigation level at the vigorous growth stage, C: Irrigation level at the flowering and fruiting stage, B × C: interaction of B and C, B × A: interaction of B and A, C × A: interaction of C and A. In varieties, 1 is Hongyou 2, and 2 is Fuhong 992. In irrigation level at different stages, 1 is high water level, 2 is middle water level and 3 is low water level.

Treatment	V	B	C	B × C	A	B × A	C × A	Blank
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

2.2. Experimental design and implement

Pot experiment included two Kenaf varieties (V), i.e. hybrid variety (Hongyou 2, V_1) and conventional variety (Fuhong 992, V_2), and three irrigation levels at the three growth stages, (1) high water level (A_1), middle water level (A_2) and low water level (A_3) at the seedling stage, and soil water content were respectively controlled at 60, 50 and 40% of field capacity, (2) high water level (B_1), middle water level (B_2) and low water level (B_3) at the vigorous growth stage, and soil water content were respectively controlled at 80, 70 and 60% of field capacity, and (3) high water level (C_1), middle water level (C_2) and low water level (C_3) at the flowering and fruiting stage, and soil water content were respectively controlled at 80, 70 and 60% of field capacity. Three irrigation levels at the three growth stages were shown in Table 1. Seedling stage refers to the period which plant height of Kenaf was less than 50 cm (15 days after the sowing), vigorous growth stage refers to the period which plant height of Kenaf was more than 50 cm without the flowering or budding, and flowering and fruiting stage refers to the period after the flowering or budding.

The interactions of variety, seedling stage, vigorous growth stage and flowering and fruiting stage were divided into three groups, (1) the interaction of different irrigation levels at two adjacent growth stages, i.e. B × C and B × A, (2) the interaction of different irrigation levels at two non-adjacent growth stages, i.e. C × A, and (3) the interaction of variety and growth stage, i.e. V × A, V × B and V × C. Group 1 is very likely, group 2 is likely, but group 3 is not likely to interact with each other. The problem should be complicated if all interactions are considered. To focus on the main effect and the interaction and reduce experimental workload, orthogonal test with replicates, unequal level and the existence of interaction was designed. In this study, the mixed orthogonal table L_{18} (2×3^7) was selected and shown in Table 1. The experiment had 18 treatments, and each treatment was replicated three times. The pots were randomly arranged. To reduce the effect of bucket position on the experimental result, the position of each bucket was randomly adjusted once a week. N fertilizer was applied with urea (N 46%), P fertilizer was applied with triple superphosphate (P_2O_5 46%) and K fertilizer was applied with potassium chloride (K_2O 60%). All the fertilizers were evenly mixed with soils at the commencement of the experiment.