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Water requirement characteristics and the optimal irrigation schedule for the growth, yield, and fruit quality of watermelon under plastic film mulching

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ABSTRACT

The challenge to sustainable agriculture under increasing water scarcity has led to the notion of water-saving irrigation. In this study, we designed a special closed cultural system which can avoid water loss from soil surface and soil leakage. By using this system, we determined that at least 117.5 kg water was required for the whole life of one watermelon and the proportion of water requirement in the seedling, flowering, expanding, and mature stage was 10, 15, 65, and 10%, respectively. The potentially maximum irrigation water use efficiency (iWUE) for watermelon cultivation was 42.1 kg m^{-3}. For watermelon cultivation under plastic film mulching, the optimal irrigation amount was 1800 m^3 hm^{-2} and the proportion of irrigation amount in the seedling, flowering, expanding, and mature stage was 10, 15, 65, and 10%, respectively. Under this irrigation schedule, the iWUE was 26.19 kg m^{-3}. These results are of great reference values for water management in watermelon production and indicate that there is still great potential for improving iWUE. Additionally, due to its better performance in arising soil temperatures, transparent film mulching is better to increase watermelon quality and yield than black film and grey-black film mulching in early spring cultivation.

1. Introduction

Water is one of the most important resource on which we live. Irrigated agriculture is the primary user of diverted water globally, reaching a proportion that exceeds 70% of the total, particularly in the arid and semi-arid zones (Fereres and Soriano, 2006; Wisser et al., 2008). However, distribution of rainfall due to global climate change and injudicious utilization of water resource by increasing human population have aggravated the frequency and severity of water deficit for crops in many areas (Bacon, 2004; Pachauri et al., 2015). For instance, in the north and northwest of China, which region accounts for half of the total area of China, but has less than 20% of total national available water resources, water shortage is severe and irrigation water use ratio is only about 40%, with a typical agricultural water use efficiency of about 0.46 kg m^{-3} (Deng et al., 2006). Thus, the challenge to sustainable agriculture under increasing water scarcity has led to the notion of water-saving irrigation and irrigation water use efficiency (iWUE) (Kijne et al., 2003).

Watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nakai] is one of the most economically important crops worldwide (Zhang et al., 2011). According to FAOSTAT (http://www.fao.org/), approximately 3.48 million hectares were planted with watermelon in 2014 all over the world, making it among the top five most consumed fresh fruits. Especially, China, with approximately 1.83 million hectares of watermelon cultivation in 2014, is the largest watermelon producer worldwide. Although originated from Africa, watermelon is a high water-consuming plant and its iWUE in many cultivating regions is low. According to Rashidi and Gholami (2008), the iWUE of watermelon vary greatly (2.70–14.33 kg m^{-3}) due to the different climates and water management practices. The main factor influencing iWUE is water loss via evaporation among plants and soil depletion. Thus, to determine the potential maximum iWUE of watermelon by avoiding invalid water loss can provide greatly valuable reference for improving the watermelon iWUE in field production.

Precise irrigation such as drip irrigation is an important approach to increase iWUE and has been widely used by producers, especially under protected cultivation. However, the optimal irrigation amount and frequency at different watermelon development stages are still obscure.

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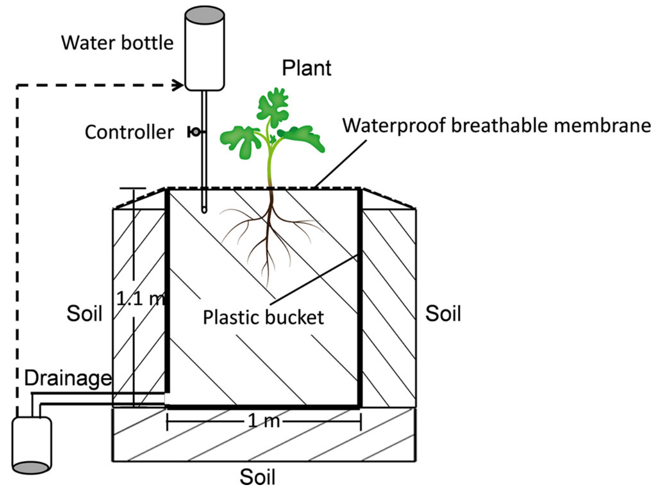

Fig. 1. A closed cultural system for watermelon cultivation to avoid water loss from soil surface and soil leakage.

Table 1
Irrigation amounts (kg plant^{-1}) in different stages of watermelon cultivated in a closed system.

Treatment	Seedling stage	Flowering stage	Expanding stage	Mature stage	Total irrigation amount
T1	4.25	6.38	27.62	4.25	42.5
T2	6.75	10.13	43.87	6.75	67.5
T3	9.25	13.88	60.12	9.25	92.5
T4	11.75	17.63	76.37	11.75	117.5
T5	14.25	21.38	92.62	14.25	142.5
T6	16.75	25.13	108.87	16.75	167.5

T1, T2, T3, T4, T5, and T6 means the irrigation amount of 42.5, 67.5, 92.5, 117.5, 142.5, and 167.5 kg water per plant, respectively.

In addition, the regulated deficit irrigation is a management strategy to reduce water use while maintaining farmers' net profits and this irrigation model has been studied in watermelon cultivation (Erdem and Yuksel, 2003; González et al., 2009; Kuşçu et al., 2015). Our previous study revealed the reasonable frequency of drip irrigation for watermelon cultivation in plastic greenhouse under regulated deficit irrigation (Liu et al., 2014).

Plastic mulching is another important approach to reduce water loss caused by evaporation and therefore may increase water available to plants (Lament, 1993). Soil mulching techniques have long been used in agriculture. Besides reducing water loss, plastic mulching can raise the soil temperature in early spring cultivation and thus promote faster crop development and earlier harvest. Recently, some researchers have studied the effects of different mulch material and mulch color on watermelon growth and revealed that film mulching enhanced the fruit quality, yield, and iWUE (Andino and Motsenbocker, 2004; Parmar et al., 2013; Rao et al., 2017). For watermelon cultivation in China, three plastic films including transparent film (TF), black film (BF), and grey-black film (GBF) are widely used. TF is more conducive to the increase of soil temperature, while black film and grey-black film can inhibit weed growth by reducing light penetration to the soil (Rao et al., 2017). Compared to BF, GBF can increase the light on the ground by reflection and drive aphids away. However, the effects of these three film mulches on watermelon growth, yield, and fruit quality are still unclear, especially under drip irrigation with different water amounts.

In our previous studies, we revealed the water requirement proportion and reasonable irrigation frequency for watermelon at different development periods under drip irrigation and film mulching (Ren, 2013; Liu et al., 2014). Basing on the previous results, we firstly analyzed the effects of different irrigation amounts on the growth, fruit quality and yield of watermelon with root in a closed system and demonstrated the potentially minimum water requirement for the whole life of one watermelon in this study. Then, we analyzed the effects of different irrigation amounts on the growth, fruit quality and yield of watermelon under different plastic film mulching. Our results determine the potentially minimum water requirement of watermelon and

Table 2
Effects of different irrigation amounts on the gas exchange and chlorophyll contents of watermelon with root in a closed system.

	Treatment	Chlorophyll content (mg g^{-1})	Pn (μmol m^{-2} s^{-1})	Gs (mmol m^{-2} s^{-1})	Ci (μmol mol^{-1})	Tr (mmol m^{-2} s^{-1})
SS	T1	3.35 ± 0.10a	22.80 ± 1.21a	0.67 ± 0.05a	333.4 ± 3.30bc	6.02 ± 0.06c
	T2	3.25 ± 0.08a	22.43 ± 1.38a	0.69 ± 0.02a	329.1 ± 2.08bc	5.98 ± 0.08c
	T3	3.23 ± 0.11a	21.6 ± 1.21ab	0.63 ± 0.02a	340.1 ± 2.57ab	6.12 ± 0.10bc
	T4	3.18 ± 0.09a	21.32 ± 0.33ab	0.68 ± 0.04a	339.0 ± 6.25ab	6.18 ± 0.09ab
	T5	3.18 ± 0.07a	21.17 ± 1.54ab	0.66 ± 0.03a	332.6 ± 2.64bc	6.31 ± 0.08a
	T6	2.95 ± 0.13b	20.28 ± 2.48b	0.63 ± 0.01a	342.60 ± 6.90a	6.35 ± 0.12a
FS	T1	3.38 ± 0.14b	21.20 ± 0.64c	0.71 ± 0.01b	308.67 ± 7.44a	6.01 ± 0.12b
	T2	3.4 ± 0.07ab	21.80 ± 0.54c	0.71 ± 0.01b	306.4 ± 12.06a	6.06 ± 0.04b
	T3	3.5 ± 0.16ab	23.28 ± 0.40b	0.72 ± 0.04ab	288.0 ± 5.90bc	6.24 ± 0.06a
	T4	3.60 ± 0.06a	25.68 ± 0.61a	0.76 ± 0.02a	279.07 ± 9.12c	6.26 ± 0.12a
	T5	3.59 ± 0.10a	26.13 ± 0.62a	0.73 ± 0.03ab	282.2 ± 5.02bc	6.32 ± 0.10a
	T6	3.4 ± 0.08ab	23.25 ± 0.53b	0.69 ± 0.02b	296.9 ± 5.39ab	6.36 ± 0.09a
ES	T1	0.82 ± 0.05c	×	×	×	×
	T2	0.97 ± 0.03c	×	×	×	×
	T3	3.91 ± 0.05b	28.73 ± 2.71a	0.77 ± 0.02a	274.33 ± 3.76a	7.32 ± 0.10b
	T4	4.11 ± 0.09a	30.25 ± 0.84a	0.75 ± 0.04a	271.57 ± 7.31a	7.53 ± 0.19ab
	T5	3.9 ± 0.21ab	29.98 ± 0.58a	0.78 ± 0.04a	264.97 ± 4.80a	7.63 ± 0.13a
	T6	0.99 ± 0.04c	×	×	×	×
MS	T1	0.33 ± 0.05b	×	×	×	×
	T2	0.41 ± 0.03b	×	×	×	×
	T3	2.35 ± 0.12a	17.25 ± 0.33b	0.45 ± 0.03a	328.03 ± 4.99a	6.65 ± 0.13a
	T4	2.34 ± 0.06a	18.08 ± 0.46a	0.49 ± 0.02a	323.10 ± 7.85a	6.63 ± 0.12a
	T5	2.27 ± 0.11a	12.53 ± 0.46c	0.46 ± 0.02a	326.70 ± 2.87a	6.65 ± 0.13a
	T6	0.30 ± 0.05b	×	×	×	×

×: No data due to the death of plant. T1, T2, T3, T4, T5, and T6 means the irrigation amount of 42.5, 67.5, 92.5, 117.5, 142.5, and 167.5 kg water per plant, respectively. SS, seedling stage; FS, flowering stage; ES, expanding stage; MS, mature stage.