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Effect of soil moisture-based furrow irrigation scheduling on melon (*Cucumis melo* L.) yield and quality in an arid region of Northwest China

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ABSTRACT

Water shortage and high irrigation rate has increased the need for appropriate irrigation scheduling to improve agricultural water use efficiency for food security in Northwest China. A two-year field experiment was carried out to investigate the response of melon (*Cucumis melo* L.) yield, quality and water productivity (WP) to various soil moisture levels with controlled furrow irrigation in the arid oasis region of Gansu Province. Soil water content (SWC) with values of 55% and 65% FC (field capacity) during blooming to fruit setting stage, and 45%, 55%, and 65% FC during fruit swelling stage, respectively, was considered as the lower limit for irrigation. Considering the fruit marketable yield, WP, and quality, an overall integrated index was developed and then used as an indicator to assess the appropriate irrigation scheduling. The overall integrated index value was computed by using the catastrophe progression method. Results showed that the melon yield (total, marketable and high quality yields), and vitamin C content were highly sensitive to lower SWC limits with value from 45% to 65% FC during fruit swelling stage. The treatment with lower SWC limit of 55% FC during blooming to fruit setting or fruit swelling stage was found without significant effect on melon yield and WP, and the treatment with lower SWC limit of 55% FC from blooming to swelling stage had negative impact on melon yield and vitamin C. Considering the overall integrated index values, the lower SWC limit of 55% and 65% FC was recommendable for furrow irrigation of melon crops during blooming to fruit setting and fruit swelling stages, respectively, in the arid oasis region of Northwest China.

1. Introduction

Water shortage is of great concern for crop production in the arid areas of Northwest China (Kang et al., 2004). Melon is one of the main horticultural and cash crops in the arid oasis region of Shiyang River basin, Gansu Province, Northwest China. The planting area of melon in China was 357,000 ha and 361,700 ha in 2007 and 2008, which was 3100 ha and 3900 ha in Gansu Province, respectively (Editorial Board of China Agriculture Yearbook, 2008, 2009). Furrow irrigation is commonly adopted for melon, and the irrigation quota is about 410 mm. Many studies indicated that water productivity (WP) in this area was very low due to the relatively high irrigation rate used by local farmers (Kang and Zhang, 2004). High irrigation rate might result in nitrogen leaching out of the root zone, which would be potential groundwater contaminants. Therefore, it is important to investigate the appropriate irrigation scheduling for melon crops in the study area.

To obtain high WP, one of the most commonly used methods is to reduce irrigation amount for the crops suffering from water stress at non-critical growth stages, and even at critical stages, without considerable yield loss. Previous researches showed that water stress to some extent in some growth stages was successful in increasing WP (Kirnak et al., 2005; Zeng et al., 2009; Cabello et al., 2009; Sharma et al., 2014) and improving fruit quality of melon (Lee and Kader, 2000; Sensoy et al., 2007; Sharma et al., 2014). Cabello et al. (2009) also reported that high WP of melon was obtained under the condition of moderate water stress. However, water

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stress at different crop growth stages has different effects on fruit quality. Fabeiro et al. (2002) stated that deficit irrigation applied during fruit setting and ripening stages can improve pulp sugar concentration in muskmelon. Wells and Nugent (1980) showed that maintaining high soil moisture during the fruit ripening stage can decrease the soluble solids concentration (SSC) of muskmelon. While Long et al. (2006) reported that water stress before or during harvest can significantly reduce the SSC of muskmelon fruit. The effects of water stress during different growth stages of melon on yield and fruit quality were reported inconsistently.

Several indexes have been used to evaluate the effect of irrigation on fruit quality, such as flesh thickness, flesh firmness, flesh ratio, mean fruit weight, total soluble solids (TSS), pH, sugar content, vitamin C (Vc), protein, and free amino acid (Hartz, 1997; Dogan et al., 2008; Cabello et al., 2009; Zeng et al., 2009; Sharma et al., 2014). However, it seems that few researches have been conducted on evaluation of overall fruit quality.

Overall fruit quality should be evaluated by quality evaluation methods and models owing to the fact that fruit quality is a fuzzy and relative term (Fisken, 1990), which is determined by many indexes, including sensory attributes, chemical and physical properties, shelf-life, etc. (Lester and Shellie, 1992). Molnár (1995) developed a model to evaluate overall fruit juice quality based on a weighted sum of individual quality parameters, while experts illustrated that the weighting factors led to the model without physical meaning. Furthermore, various methods were used to evaluate the fruit quality, such as the overall quality rating method, quality grading method, descriptive method (Costell, 2002) and multiple attribute decision-making approaches (Wang et al., 2011a). However, most of these available methods are subject to expert knowledge which has subjective quantification of assessing indicators.

The catastrophe progression method (CPM) proposed by Shi and Wu (1997), is a method of converting the multi-objective problem into a single-objective problem. Each objective index of the CPM is quantified without considering the weighting factor, while the relative importance of each objective index is considered (Wang et al., 2011b; Shi and Wu, 1997). The CPM has been successfully applied to various fields, such as groundwater resources and environmental risk assessment as well as land ecological security evaluation (Wang et al., 2011b; Su et al., 2011; Ahmed et al., 2015; Al-Abadi and Shahid, 2015). All of these researches indicated that the CPM not only can overcome the limitations of existing evaluation methods, but also can easily perform and obtain high reliability.

Most studies investigate only the responses of yield, WP and single fruit quality index to water conditions at different growth stages. Such relationships are difficult to use for obtaining an appropriate irrigation schedule that balances yield, WP and fruit quality. Therefore, the objective of this research is to investigate the effect of various soil moisture-based irrigation scheduling on melon yield, WP and fruit quality under furrow irrigation, and to develop an integrated method for evaluation of melons overall integrated index (OII) that balances marketable yield, marketable WP and fruit quality on the basis of the CPM, and thus obtain the appropriate irrigation scheduling for melon in the study area.

2. Materials and methods

The experiments were carried out during the growing seasons of 2008 and 2009 from May 8th to August 26th at the Shiyanghe Experimental Station For Water-saving in Agriculture and Ecology of China Agricultural University, situated in Wuwei City, Gansu Province of northwest China (102°50′ E, 37°52′ N, altitude 1581 m). The experimental site is located in a typical continental temperate climate zone with mean annual temperature of 8 °C, average annual sunshine duration of 3000 h, annual precipitation of 164.4 mm and mean annual pan evaporation of 2000 mm. The groundwater table is 40–50 m below the ground surface (Li et al., 2008).

Soils in the experimental site are sandy loam and silt loam at the depths of 0–30 cm and 30–120 cm, respectively. The profile bulk density is in a range of 1.44–1.58 g cm^{-3}, soil water content at field capacity ranges from 0.24 to 0.34 cm^3 cm^{-3} and it is in a range of 0.06-0.12 cm^3 cm^{-3} at wilting point. The soil physical properties of the experimental site are presented in Table 1.

2.1. Experimental design

Huanghemi-3 (*Cucumis melo* L.), a melon variety widely cultivated in Northwest China, was selected for the field trial study. The growth period of melon was divided into four growth stages, i.e. seedling, blooming to fruit setting, fruit swelling and ripening stages.

Irrigation water was applied to the field based on the lower soil water content (SWC) limits in the root zone. Each lower SWC limit corresponded to a percentage of field capacity (FC). Sensoy et al. (2007) stated that melon roots were mainly located within the top 40–50 cm of soil. Therefore, the top 0–50 cm soil layer was considered as the main root zone of melon in the following analysis. Refilling to field capacity was performed when the average SWC in the root zone approached the established lower SWC limits for irrigation. As shown in Table 2, three lower SWC limits, i.e., 45%, 55% and 65% FC, were considered to initiate irrigation at the fruit swelling stage. The lower SWC limit for irrigation was 55% FC during the other three stages, i.e., seedling, blooming to fruit setting and ripening stages. However, the SWC in the top 0–50 cm soil layer did not reach a threshold of 45% FC in 2009 due to different climatic conditions, four different treatments with lower SWC irrigation limits (55% FC and 65% FC during the blooming to fruit setting and swelling stages) were considered this season (Table 2). Treatments were arranged in randomized complete field plots, each treatment with three replicates. Each plot with an area of 40 m^2 (8 m × 5 m) included 6 rows. The spacing between rows and plants was 0.8 m and 0.5 m, respectively. The furrow and half of the ridge were mulched with transparent plastic film before seeding (Fig. 1). A buffer zone with space of 1.0 m was arranged in order to eliminate the water exchange between two adjacent plots. Irrigation water was applied in the furrows by using a 20 mm diameter hose with an attached flowmeter to record the application amount. Fertilizer was applied to the field before the ridge formed (Fig. 1). All treatments were fertilized with the same dose of 120 kg-N ha^{-1}. Melon plants were pruned above the fifth truss and the side shoots were also removed as they appeared. The pruning, pest and disease control were performed uniformly according to local farmers' best management practices.

2.2. Measurements

Meteorological variables including solar radiation, air temperature, humidity, wind speed and rainfall were recorded every 15 min with an automatic weather station (HOBO, Campbell Scientific Inc., USA) located 50 m away from the field plots. Daily average solar radiation, air temperature, reference evapotranspiration (ET_o) and precipitation at each growth stage in both seasons are presented in Table 3. ET_o was estimated by using the FAO 56 Penman-Monteith method (Allen et al., 1998).

Field capacity was measured by using the Wilcox method, a laboratory measurement method with undisturbed and saturated soil samples placed on air-dried and sieved soil samples. After reaching equilibrium, the water content of the undisturbed soil was considered as FC. Soil bulk density was determined by oven-dried soil cores at 105 °C and weighed, and the cores were obtained with rings.

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