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# Fruit yield and quality response of Newhall navel orange to different irrigation regimes and ground cover in Chongqing Three Gorges Reservoir area

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ABSTRACT

In order to reduce unwanted negative effect of frequent rainfall in spring and high-temperature in summer on fruit yield and quality of Newhall navel orange trees in Chongqing Three-Gorges Reservoir area. In this study, the influence of Tyvek® nonwoven materials ground cover (TC) and with different irrigation density 110% (ID110), 60% (ID60), and 0 (ID0) of the local evapotranspiration (ETc) on yield and fruit quality were evaluated during three consecutive years (2015–2017) in a commercial Newhall navel orange drip irrigated orchard. During spring frequent rainfall period, all TC treatments had a significant higher in leaf sucrose content and leaf starch content during flower bloom period due to their significantly increased the leaf $ACO_2$ exchange parameter compared to CK group. As a result, the highest in the number of fruit bearing (FBN) was obtained in TC + ID60 group due to its 84.6% and 13.5% higher the total flower number (TFN) than CK and TC + ID110 groups, respectively. However, the TC + ID110 and TC + ID0 groups had a significantly lower FBN due to their significantly 38.3% and 19.9% rate of dropped flowers (FLDR) compared to TC + ID60 group. During summer high-temperature period, the leaf water potential significantly decreased in order: TC + ID110, TC + ID60 and CK, TC + ID0, which resulted in the significant higher $ACO_2$ and transpiration rate in TC + ID110 and TC + ID60 groups, and significant lower $ACO_2$ and transpiration rate in TC + ID0 group. Consequently, there was a significant increase of total soluble solids, titratable acid, vitamin C in fruit internal quality and “a”, “b”, “a/b” value in fruit external quality, and a significant decrease of juice yield in fruit internal quality and fruit shape index, and weight per fruit with increasing water stress as compared to TC + ID110 group. In conclusion, TC + ID60 treatment can reduce the negative effect of frequent rainfall spring and high summer temperatures and improve the fruit yield and quality of Newhall navel oranges.

## 1. Introduction

The citrus production area and annual yield in China reached 2.63 million hectares and 38.39 million tons in 2016, respectively, both of which ranked the first in the world (FAOSTAT, 2018). However, previous studies have proved that the limited environmental factors were lack of sunshine, drought and lack of adequate soil moisture (Iwasaki, 1966). Although the annual rainfall in Chongqing Three Gorges Reservoir area is abundant with 295 mm, 482 mm, 279 mm and 63 mm of the average seasonal rainfall from 1960 to 2008 in spring, summer, autumn and winter, respectively, most citrus orchards encounter a significant unevenness of rainfall and loss of water due to their mountain terrains and landforms. Moreover, the Reservoir area encounters a frequent cloudy and rainfall weather in spring and prolonged high-temperature period in summer. Thus, the spring frequent cloudy and rainy weather (Bao et al., 2004) and seasonal drought (García-Tejero et al., 2012) have been important limited factors affecting the yield and quality of citrus in Chongqing three-gorges reservoir area.

To cope with unevenness of rainfall, deficit irrigation (DI) is an efficient way to achieve the goal of reducing irrigation water use (Fereres and Soriano, 2007). And the water-saving techniques such as drip irrigation, sprinkler irrigation, and plastic film mulching have been applied to improve the fruit quality and yield in the orchards (Stevens et al., 2012; Vélez et al., 2012). However, some researchers have

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proved that mild drought could increase the yield and fruit quality of citrus (Stagno et al., 2015) and grape (Fang et al., 2013), and severe drought stress would cause the plants to close the stoma, reduce leaf gas-exchange parameters (transpiration and $CO_2$ assimilation rates), and degrade photosynthetic pigments, which resulted in reducing yield and fruit quality (Anjum et al., 2011). Therefore, it is necessary for the guarantee of fruit production to understand the water demand of the plants before using water-saving techniques.

In addition, some previous studies have proved that the DuPont Tyvek® non-woven material applied to ground coverage in the maturity period of 'Hamlin' (an early maturing variety) and 'Valencia' (a late maturing variety) sweet orange trees with water stress treatment effectively delayed flowering and avoided young fruit loss during late-season mechanical harvesting without negative impacts on yield or fruit quality (Etxeberria and Parsons, 2003; Melgar et al., 2010). And these results were in agreement with our previous study that the soil mulching application of Tyvek® non-woven material in fall and winter efficiently reduced the negative influence on fruit quality of Wanzhou rose orange (a late maturing variety) by heavy rainfall and insufficient daylight in fall and winter, thereby improving the economic value (Jia et al., 2017). However, there are few studies on the effect of soil covering with deficient irrigation on the yield and quality of citrus with the aim to counteract the negative influence of spring frequent cloudy and rainy weather and summer seasonal drought.

Therefore, we evaluated the response of yield and fruit quality to ground coverage with different irrigation regimes in spring frequent rainfall and summer seasonal drought period on yield and fruit quality of citrus with the aim to reduce the influence of climate restricting factors on citrus production and provide a theoretical basis for improving the yield and quality in citrus orchards in Chongqing Three Gorges Reservoir area.

## 2. Material and methods

### 2.1. Experimental treatment

A total of 60 plants of 14-year-old Newhall navel orange (*Citrus sinensis* CV. Newhall) trees grafted on citrange [*C. sinensis* (L.) Osbeck × *P. trifoliata* (L.) Raf.], at a similar growth rate, were randomly selected in the Dagou orchard (Latitude, 29°45′51″ N; longitude, 106°22′21″ E; Altitude, 240 m above sea level) of Citrus Research Institute, Chinese Academy of Agricultural Sciences during three consecutive years of 2015, 2016 and 2017. During the experiment, seedcake was applied at 40.0 kg/tree in March and the compound fertilizer at 10.0 kg/tree in July. The pH value of the soil in the orchard was 6.3 ± 0.4, while the organic matter, available potassium, phosphorus, and nitrogen were14.8 ± 0.6 g/kg, 127.7 ± 8.6, 33.6 ± 3.9, and 64.3 ± 6.4 mg/kg, respectively.

From flower-bud differentiation period (FBDP) to fruit expansion period (FEP) during these three consecutive years, the soil was ground covered with DuPont Tyvek® nonwoven materials (Tyvek Cover-TC) in order to increase the lighting of citrus trees, and control the soil moisture by keeping rain out; the irrigation density (ID) was set at 110%, 60%, and 0 of the average seasonal local evapotranspiration from 1960 to 2008 with 185 mm, 292 mm, 142 mm and 72 mm in spring, summer, autumn and winter, respectively. The plants were irrigated every 14 days with 4 different treatments: control (CK: natural growth without TC), TC with sufficient irrigation (TC + ID110), TC with deficit irrigation (TC + ID60), and TC without irrigation (TC + ID0). Each treatment group comprised of 5 plants in triplicate.

### 2.2. Yield factor analysis

The number of dropped flowers during flowering stage and dropped fruits during 1st and 2nd physiological fruit-drop period (PFDP) were recorded as FLDN, 1st PFDN and 2nd PFDN for each plant as Fig. 1 shows, respectively, and the number of fruit bearing per tree during fruit maturity period (FMP) was recorded as FBN. Then, the number of total flowers (TFN) was calculated as the sum of FLDN, 1st PFDN, 2nd PFDN and FBN. Finally, the percentage of FLDN, 1st PFDN, 2nd PFDN and FBN to TFN was calculated as FLDR, 1st PFDR, 2nd PFDR and FBR, respectively (Zheng et al., 2017).

### 2.3. Fruit quality analysis

During FMP, 5 fruits were sampled from each direction of east, west, south, north, and center each tree. A total of 125 fruits from five trees each treatment were sampled for analyzing fruit internal and external quality.

Among these fruits, a total of 100 fruits were used to evaluate the parameters of internal quality analysis of total soluble solids (TSS), titratable acid (TA), vitamin C (Vc), juice yield, and edible rate according to the GB/T8210-2011 method (GB/T 8210, 2011) for the determination of fresh citrus fruits, and the ratio of TSS and TA (T/A) were estimated.

In addition, a total of 25 fruits were randomly selected and measured by a Vernier caliper for their longitudinal (ZD) and transverse diameters (HD), and the fruit shape index (FSI) was calculated as ZD/HD. The fruit color was evaluated by a CR-10 colorimeter (Konica Minolta, Japan). 3 points were randomly selected on the equatorial surface after white-board correction, and the a value (the color difference between red and green), b value (the color difference between yellow and blue), L value (lightness, the greater L value indicates higher brightness), and a/b value (the comprehensive index of fruit color, the greater a/b value indicates more reddish orange) were measured and calculated (Reig et al., 2016).

### 2.4. Soil moisture and leaf water potential monitoring

Soil at 20–40 cm depth around the canopy dripping line was sampled from FBDP to FEP, and its relative water content was measured using the oven drying method (Stanley et al., 2014). In addition, three leaves per tree were randomly selected in situ at 16:00 pm from FBDP to FEP on the sunny days from five trees on each treatment for analyzing the leaf water potential with a Psy-pro (Wescor, USA).

### 2.5. Detection of leaf gas exchange parameters

Gas exchange analysis was carried out using a portable photosynthesis system (Li-6400, Li-Cor, Lincoln, NE, USA) equipped with a large leaf chamber (6.0 $cm^2$). Both the leaf $CO_2$ exchange parameters ($ACO_2$) and transpiration rate determination were performed at 8:00 to 10:00 am on the selected sunny days during FBDP (January), 1st PFDP (April), 2nd PFDP (May), and FEP (July) in 2016 and 2017 (Zheng et al., 2016).

### 2.6. Starch and sucrose content measured

Thirty mature spring leaves from five trees each treatment were collected to determinate the sucrose and starch concentration during FBDP (January), 1st PFDP (April), 2nd PFDP (May), and FEP (July) in 2016 and 2017. 0.1 g of dry leaf samples were homogenized in a Precellys 24 homogenizer at 6500 rpm (Bertin Technologies, Montigny-le-Bretonneux, France) in a 2.5-mL tube containing 1 mL of distilled water with four metal beads. After homogenization, the homogenate was boiled for 10 min in a water bath, and then centrifuged in an Eppendorf AG Centrifuge-Model 5417C (swinging bucket rotor) for 2 min at 2500 rpm. The supernatant was used for starch and sucrose determination. Starch quantification was performed according to the $I_2$:KI method of Etxeberria and Gonzalez (unpublished protocol described by Rosales and Burns, (Rosales and Burns, 2011) by monitoring color change at 594 nm with rice starch (Sigma Aldrich, St. Louis, MO,