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Effects of deficit irrigation on yield and nutritional quality of Arabica coffee (*Coffea arabica*) under different N rates in dry and hot region of southwest China

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ABSTRACT

The objective of this study was to obtain water and nitrogen (N) management mode for water saving, high quality and proper yield of Arabica coffee in dry and hot region of southwest China. Taking full irrigation (FI) as the control, the effects of three deficit irrigation (DI) levels (DI_{80}, DI_{60} and DI_{40}, with irrigation amount of 80, 60 and 40% FI, respectively) in dry season on growth, yield, nutritional quality and water use efficiency (WUE) of Arabica coffee were investigated under three N rates (N_H: 140, N_M: 100 and N_L: 60 g N plant^{-1}) using field experiments from 2013 to 2015, and the comprehensive benefit of yield and nutritional quality was evaluated using the technique for ordering preferences by similarity to ideal solution (TOPSIS) method. Compared with FI, DI_{80} increased two-year averaged contents of protein, crude fat and chlorogenic acid in dry bean by 9.4, 26.0 and 12.5%, respectively, but reduced dry bean yield by 6.4%. DI_{60} and DI_{40} reduced dry bean yield and water use efficiency (WUE) greatly, but increased the contents of caffeine and crude fiber in dry bean. Compared with N_L, enhancing N rate increased dry bean yield, WUE, and the contents of protein and chlorogenic acid in dry bean by 32.9–42.6, 32.1–45.4, 5.9–9.7 and 7.0–12.6%, respectively, and N_M level had the largest dry bean yield, WUE and chlorogenic acid content in dry bean. FIN_M treatment had the largest two-year averaged dry bean yield of 5587.42 kg ha^{-1} and 31.8% higher than FIN_L treatment. $DI_{80}N_H$ treatment had the best comprehensive benefit of yield and nutritional quality. Compared with FIN_L treatment, $DI_{80}N_H$ treatment increased two-year averaged dry bean yield, WUE and the contents of protein and chlorogenic acid by 29.5, 42.7, 19.3 and 20.0%, respectively. Thus the treatment of high N (140 g plant^{-1}) and moderate deficit irrigation (irrigation amount was 80% of FI) was the suitable mode of water and nitrogen management for Arabica coffee, which could realize water-saving, high quality and proper yield of Arabica coffee simultaneously in the dry and hot region of southwest China.

1. Introduction

China is one of coffee-producing areas in Asia and mainly cultivates Arabica coffee, which requires warm and humid climate. The planting area and yield of Arabica coffee in Yunnan, southwest China were about 1.24×10^5 ha and 1.18×10^5 t in 2014, which accounts for the largest proportion of China (Huang and Li, 2008). Arabica coffee in Yunnan province has special quality character of being mellow but not bitter, fragrant but not strong and having a slight fruit acid taste. However, the dry and hot region in Yunnan has abundant sunshine and a warm winter, but little rainfall, large evaporation, long duration of dry season and poor soil fertility, which restrict high-efficient production of Arabica coffee. Flood irrigation is main irrigation method in local flatland Arabica coffee planting.

Deficit irrigation (DI) is a water-saving irrigation technique aiming to solve water scarcity and low water use efficiency (WUE). Now there are lots of DI experiments on pear (Samperio et al., 2015), peach (Faci et al., 2014), mango (Schulze et al., 2013), grape (Santesteban et al., 2011), tomato (Patanè et al., 2011), and coffee (Tesfaye et al., 2013). Previous studies have indicated that DI can save irrigation water, maintain or increase crop yield and improve quality simultaneously (Patanè et al., 2011; Santesteban et al., 2011). However, there were fewer studies about the effect of DI on coffee yield and quality. Water deficit decreases coffee WUE and numbers of flower and bean significantly (Liu et al., 2014b; Vaast

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et al., 2004), and reduces the height, crown width and trunk diameter (Chemura, 2014; Perdoná and Soratto, 2015; Sakai et al., 2015) and coffee yield (Sakai et al., 2015; Perdoná and Soratto, 2015). On the other hand, Tesfaye et al. (2013) indicated that compared to full irrigation, DI does not significantly reduce coffee yield, but improves overall quality in terms of raw appearance. However, it remains unknown about the effect of different DI levels on yield, quality and WUE of Arabica coffee.

Nitrogen (N) rate has significant effect on axillary bud number per branch, branch length and N uptake (Bruno et al., 2011; Nazareno et al., 2003; Tatiele et al., 2007), and enhancing N rate can increase coffee WUE and yield significantly (Liu et al., 2014a,b; Winston et al., 1992), but reducing N rate of 200–600 kg ha^{-1} did not decrease the yield of coffee bean. DaMatta et al. (2002) indicated that regardless of watering treatments, N increased water use efficiency through the changes in carbon assimilation with slight or no effect on stomatal behavior of coffee leaf. Liu et al. (2014b) indicated that there was significant positive correlation between total N uptake of young coffee tree and irrigation amount under N rate of 0–0.2 g kg^{-1}, but WUE and total N uptake firstly increased and then decreased with the increasing irrigation amount under N rate of 0.4–0.6 g kg^{-1}, and Arabica coffee had the highest WUE under higher water supply (65–75% field capacity) and middle N rate (0.4 g kg^{-1}). However, the effects of different water and N management strategies on coffee yield and quality need further investigation.

Technique for ordering preferences by similarity to ideal solution (TOPSIS) method evaluates relative superiority of each object by calculating relative closeness to positive ideal solution (Deng et al., 2000) and is widely applied in agricultural water-saving evaluation (Liu et al., 2014a; Wang et al., 2011). Wang et al. (2011) evaluated comprehensive quality of tomato under DI using TOPSIS method and proposed suitable irrigation scheduling. Liu et al. (2014a) established comprehensive evaluation mode of water-saving, high quality and high yield of greenhouse tomato using TOPSIS method to establish irrigation scheduling for water-saving and quality-regulating of greenhouse tomato. There are many interaction indices affecting coffee quality, but only single index is often used for coffee quality evaluation (Huang et al., 2012; Läderach et al., 2011). However, coffee comprehensive benefit can be only obtained by combing yield and many nutritional quality indices of coffee.

The objective of this study was to investigate the effect of DI on growth, yield, nutritional quality and WUE of Arabica coffee under different N rates, and establish an evaluation model for comprehensive benefit of coffee production and nutritional quality indices to seek for optimal supply model of water and N, so as to provide scientific basis for water and N management of Arabica coffee in dry and hot region of southwest China.

2. Materials and methods

2.1. Experimental site and materials

The field experiments were conducted from 2013 to 2015 in Lujiangba in Baoshan Yunnan, southwest China (latitude 21°59′N, longitude 98°53′E, 750 m altitude). The experimental site is in dry and hot region with average rainfall of 755.4 mm (80% of total rainfall from June to October), average annual evaporation of 2101.9 mm, average annual temperature of 21.3 °C, absolute maximum temperature of 40.4 °C, absolute minimum temperature of 0.2 °C, annual average sunshine hours of 2328 h and relative humidity of 71%.

Experimental field soil was a reddish brown sandy loam soil derived from old alluvium, and had organic matter content of 10–15 g kg^{-1}, total N content of 0.8–1.2 g kg^{-1}, total P content of 0.8–1.5 g kg^{-1}, available N content of 60–120 mg kg^{-1}, available P content of 5.0–20.0 mg kg^{-1}, available K content of 100–150 mg kg^{-1} in topsoil. Experimental trees were four-year-old Arabica coffee trees (Catimor P7963) with planting spacing and row spacing of 1 m and 1.5 m (333 trees ha^{-1}).

2.2. Experimental design and methods

In the experimental site, rainfall can meet water requirement of Arabica coffee during the rainy season (Cai et al., 2007), so irrigation treatment was only investigated in dry season (blossom and fruiting stages of coffee from February to May, maturity stage from November to January). Four irrigation levels and three nitrogen (N) rates were included in the experiment. This experimental plan yielded 12 treatments (i.e. 4 × 3), and each treatment was replicated three times. It had 36 plots and the area of each plot was 45 m^2 (9 × 5 m). Four irrigation levels included full irrigation (FI) and three deficit irrigation levels (DI_{80}, DI_{60} and DI_{40}, with irrigation amount of 80, 60 and 40% FI, respectively). Irrigation frequency was 7 days and irrigation date was postponed if rainfall. According to previous research (Cai et al., 2007), three N rates included high N (N_H, 140 g N $plant^{-1}$), middle N (N_M, 100 g N $plant^{-1}$) and low N (N_L, 60 g N $plant^{-1}$).

Irrigation dose in FI was determined by monthly averaged water consumption of local Arabica coffee (Chen et al., 1995) and actual effective rainfall in this area and can be calculated as Eq. (1).

$$I_i = (ET_{ci} \times n) - P_i \tag{1}$$

where I_i is irrigation amount of FI in i period (mm), ET_{ci} is average water consumption in i period (mm day^{-1}), n is time period (day), P_i is effective rainfall in i period (mm).

Surface drip irrigation was used with system working pressure of 0.1 MPa, installing a pressure compensating emitter on both sides of the capillary tube of each coffee tree and single emitter flow of 2.5 L h^{-1}. The equivalent urea was applied in mid-March and late-August, respectively, and KH_2PO_4 of 150 g $plant^{-1}$ was applied in mid-March. Fertilizer was uniformly applied to a 20 cm deep circular groove, 40 cm away from tree truck and then covered soil. Weeding was done monthly, pest and insect was controlled in early May, and there was no pruning of coffee tree. Effective rainfall accumulation and soil water budget during the experimental period were respectively shown in Figs. 1 and 2.

2.3. Plant sampling and measurements

Tree height and branch length were measured by mm ruler at the beginning of the experiment and at harvest (17 January 2014 and 26 January 2015), and trunk diameter in the east and north direction was measured using calipers (10 cm above the ground). Ten branches per tree with similar initial length were selected to measure their length continuously after labeling.

Coffee red cherries were harvested at the mature stage (from November to January) to measure fresh bean yield. Coffee cherries after peeling and fermentation were degummed, and finally the yield of dry bean was measured after natural dry in the sunshine.

The dry bean was used to measure various nutritional quality indices after grinding through 100 mesh sieve. The contents of caffeine and chlorogenic acid, total sugar, crude fiber, protein and crude fat were measured using high performance liquid chromatography (HPLC) method, anthrone colorimetry method, acid digestion method, Kjeldahl method and Soxhlet extraction method (Yu, 2001), respectively.

Groundwater recharge, runoff and deep leakage can be ignored because of deep groundwater level, little rainfall and shallow depth