Effect of Irrigation Amount on Flower Bud Growth and Fruit Set in Japanese Apricot ‘Nanko’

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Yield optimization of young Japanese ‘Nanko’ apricot (Prunus mume Siebold et Zucc.) trees requires adequate and timely irrigation. Here, different irrigation amounts (5, 10, 15, and 20 mm) were applied to three-year-old trees from July (initiation of flower bud differentiation stage) to March (fruit setting stage), when the pF meter reading was 2.7. Then, the effects on flower buds and fruit setting rate were assessed. Trees supplied with the 5 and 10 mm irrigation amounts experienced severe drought stress. Limited water supply reduced flower-bud growth and flower-bud number, possibly caused by several factors including inhibition of flower-bud differentiation in summer and abscission of immature buds just before anthesis. Limited irrigation did not inhibit complete flower formation, except under the 5 mm irrigation treatment, but flower size and fruit-setting rate were negatively affected. These findings indicated that insufficient irrigation caused poor flower formation and low fertility. Combined, these effects explained the observed yield reduction and all irrigation treatments, except for the 20 mm one, severely affected productivity. Based on these results, we recommend that the amount of water applied to young Japanese apricot trees from flower-bud differentiation to fruit set should be no less than 20 mm to achieve adequate flower bud growth and a high fruit-setting rate for high fruit yield.

Key Words: carbohydrate, differentiation, drought stress, flower bud, leaf water potential, yield.

Introduction

The cultivated area and yield of Japanese apricot in Wakayama Prefecture are the largest in the country (MAFF, 2018), with ‘Nanko’ being the most frequently cultivated variety. In many orchards in this region, trees are over 30 years old and are already showing a significant decline in yield. In such orchards, trees are usually cut down sequentially and replaced by one- or two-year-old trees. From a management point of view, it is important to start harvesting fruit as soon as possible after planting nursery trees.

Most of the cultivated land occupies steeply sloped hills where rainwater drains easily. Nevertheless, water is a scarce resource. Hence, Japanese apricot trees in local orchards quite often experience growth and yield reduction in low rainfall years. Young apricot trees in particular show less tolerance to drought stress than mature ones. In Wakayama Prefecture, low rainfall during spring and summer has become a frequent occurrence that poses a great threat to fruit yield and tree productivity. Therefore, it is very important to determine the minimal irrigation requirements to obtain profitable fruit yields, especially from young trees.

Previous studies have shown that drought stress inhibits stem and root growth (Tsuchida et al., 2011), as well as the allocation of carbohydrates to these organs (Tsuchida and Yakushiji, 2017), in Japanese apricot trees. However, the effects of reduced water supply on the growth of flower buds and fruit yield remain poorly understood.

Generally, flower bud differentiation in Japanese apricot trees occurs in summer, after harvest (Hanaoka et al., 1980). Problems with flower bud development have been associated with the occurrence of water deficit. Thus, for example, a significant reduction in flowering and fruit yield was observed in plum trees in the growing season following severe water stress treatment implemented post-harvest (Johnson et al., 1994; Torrecillas et al., 2000).
Carbohydrates are essential substrates for respiration and growth of fruits (DeJong and Goudriaan, 1989), and ultimately crop productivity (Ho, 1988). The carbon resources needed to support flower development in apricot trees do not result from the photosynthetic activity of the current year, as the leaves have not yet emerged; therefore, they are stored either in the vegetative tissues or in the flower bud itself during the previous growing season (Oliveira and Priestley, 1988; Rodrigo et al., 2000). However, information regarding the characteristics of carbohydrate accumulation in the flower buds of the Japanese apricot under drought stress conditions is scarce.

Here, we report the effects of different amounts of irrigation water post-harvest on flower-bud development, flower morphology, and subsequent fruit set of young Japanese apricot trees to determine the minimum requirement to guarantee a profitable fruit yield.

Materials and Methods

Plant material, growing conditions, and irrigation regimes

Three-year-old Japanese apricot ‘Nanko’ trees planted in 60-L pots filled with brown forest soil in an unheated greenhouse at the Japanese Apricot Laboratory in Minabe, Wakayama Prefecture (33°82’N, 135°35’E, 134 m a.s.l.) were used as experimental plant material. Four groups, each consisting of three trees, were categorized by irrigation sheet treatment with 4, 3, 2, and 1 L of water treatments representative of 20, 15, 10, and 5 mm of rainfall, respectively. The amount of irrigation water was calculated by multiplying the soil surface area of the pot (2000 cm²) and the allocated rainfall amount. This irrigation treatment was conducted from July 18, 2018 (initiation of flower bud differentiation stage) to March 25, 2019 (fruit setting stage). A DIK-8333 pF meter (Daiki Rika Co., Ltd., Japan) to monitor soil moisture was set 20 cm deep, at 20 cm from the trunk of the trees irrigated with 20 mm. Irrigation was applied when the pF meter reading was 2.7, as the pF range from 2.7 to 3.0 is considered the point of capillary continuity rupture, a clear indication that soil water is no longer readily available for plants to absorb (Horino et al., 1996).

Leaf water potential

Pre-dawn leaf water potential was determined using a DIK-7002 pressure chamber (Daiki Rika) at 5:00 a.m. on July 18, just before the start of the experiment, and again on August 14 in mid-summer when drought stress can be easily observed.

Analysis of flower bud dry weight growth

Flower buds were sampled monthly from October 3, 2018, to January 22, 2019, 22 days before full bloom (i.e., 80% flowering). Ten to 20 flower buds were sampled from approximately 10 cm long spurs on one main branch. Spurs with this size show high fruit productivity (Hasebe, 1988). Sample flower buds were dried under forced air at 80°C for two days, and then the flower bud dry weight (DW) was measured and averaged for analysis.

Carbohydrate analysis in flower buds

Dried flower buds sampled on January 22 were ground to a fine powder. Approximately 0.1 g of powder was heated in 80% EtOH for 15 min at 80°C and centrifuged at 1000 × g. The supernatant was designated as the soluble sugar fraction. This treatment was repeated three times. Then, the residue was suspended in 80% EtOH at 20°C and centrifuged, and the supernatant was added to the soluble sugar fraction. This treatment was repeated twice, and the residue was dried under forced air at 80°C overnight and then suspended in 0.7 N HCl for 2.5 h. The residue was removed by filtration, and the filtrate was designated as the starch fraction. Soluble sugar and starch fractions were added with 0.3 N Ba(OH)₂ and 5% ZnSO₄ for the protein to congeal prior to its removal by filtration. The total sugar concentration in the soluble sugar and the starch fractions was estimated by the phenol-sulfuric acid method (Chaplin, 1986) using glucose as a standard. Briefly, 1 mL of the diluted sample was added to 5 mL of sulfuric acid and 1 mL of 10% phenol solution. Then, absorbance at 490 nm was measured in a V-500 spectrophotometer (JASCO Co., Ltd., Japan) to determine carbohydrate concentration.

Flower bud induction

Flower bud setting number and nodes of all spurs on another main branch were determined on February 7, 2019. Then, the number of flower buds per 100 nodes was calculated.

Malformed flowers and fruit set

The numbers of complete and imperfect flowers (without pistils) at full bloom were counted for 70–80 flowers on February 12, 2019. Then, the complete flower rate was calculated for the various irrigation treatments, except for the 5 mm irrigation treatment. In the latter case, anthesis did not occur at all throughout the duration of the experimental period. Flowers on the main branches were pollinated sequentially, as anthesis occurred, from February 8 to 22, 2019, with pollen of Japanese apricot ‘NK14’, using a small paintbrush. The number of set fruits was counted on March 25, 2019, after unfertilized fruits had dropped following foliar bud sprouting (March 15, excluding the 5 mm treatment that did not sprout). The fruit set rate was then calculated as the percentage of set fruits relative to the total number of flowers.

Statistical analysis

Data on flower set number and carbohydrate content
in flower buds, as well as arcsine transformation of the data on the rates of complete flower and fruit set were analyzed for statistical significance by Tukey’s multiple-range test.

**Results**

**Leaf water potential**

Leaf water potential was approximately −0.85 MPa in all the experimental trees just before the start of the experiment on July 18 (Fig. 1). It remained at the same level through August 14 in leaves of trees under the 20 mm irrigation-sheet treatment, but declined to −1.20, −1.68, and −2.35 MPa, over the same period in trees under the 15, 10, and 5 mm water treatments, respectively.

**Flower bud growth**

The flower bud DW remained constant at approximately 1 mg in all irrigation treatments until November 9 (Fig. 2), increasing to 10.5 mg by January 22 under the 20 mm irrigation water treatment, which was the maximum DW recorded for any treatment, and an over 10 fold increase relative to original weight. This was followed by 10 mm (9.5 mg) and 15 mm (8.5 mg) irrigation treatments. In contrast, the flower bud DW increase reached only 3.8 mg on the same date under the 5 mm irrigation treatment, the smallest increase among all treatments tested, and only a 4-fold increase from the original weight over the time interval considered, whereas the increase exceeded 10-fold for the 20 mm treatment.

**Carbohydrate accumulation in the flower buds**

The ratio of soluble sugar to starch concentration was nearly 1.0 across irrigation treatments (Fig. 3). The total carbohydrate concentration for all irrigation treatments was around 0.18 mg·g⁻¹DW. Thus, there were no significant differences in total carbohydrate concentration in the flower buds between treatments.

Total carbohydrate content in the whole flower buds decreased slightly with decreasing irrigation amount. For the 20, 15, and 10 mm irrigation amounts, the total carbohydrate contents were 2.00, 1.50, and 1.66, respectively, whereas in the 5 mm irrigation treatment the content was 0.67 mg, the lowest level of all the treatments (Fig. 4).

**Number of flower buds**

The flower-bud setting rate decreased as the irrigation amount was reduced (Fig. 5). The numbers of flower buds were 35, 20, 17, and 5 in the 20, 15, 10, and 5 mm irrigation treatments, respectively.

**Malformed flowers and fruit set**

The complete flower rate was determined to be 98–100% in the 20, 15, and 10 mm irrigation treatments, but was assumed to be 0% in the 5 mm treatment because in this case anthesis did not occur throughout the
Flower size at full bloom (February 12) notably increased with increasing irrigation amounts (Fig. 6). The fruit setting rate decreased with decreasing irrigation amounts. On March 20, the fruit setting rates in the 20, 15, 10, and 5 mm treatments were 8.5, 5.2, 2.3, and 0%, respectively (Fig. 7). The fruit setting numbers per 100 nodes calculated by multiplying the fruit setting rate (Fig. 7) and flower bud setting numbers per 100 nodes (Fig. 5) in the 20, 15, 10, and 5 mm treatments were 3.2, 1.1, 0.3, and 0, respectively (data not shown).

**Discussion**

The experiments reported here were conducted to clarify the effects of different amounts of irrigation water post-harvest on flower bud development and morphology and subsequent fruit set in young Japanese apricot trees. This was done to determine the optimal quantity required to guarantee a profitable fruit yield.

Leaf water potential decreased with decreasing water supply (Fig. 1) and was −1.68 and −2.35 MPa in the 10 and 5 mm water treatments, respectively. Tsuchida and Yakushiji (2017) showed that a leaf water potential below −1.5 MPa reduced the rate of photosynthesis. Therefore, apricot trees administered the 10 mm and 5 mm water treatments suffered from severe drought stress and inhibited carbohydrate production during the summer. Several studies have shown that in citrus the level of non-structural carbohydrates may limit flower formation (Ogaki et al., 1963; Goldschmidt and Golomb, 1982; Lovatt et al., 1988). Bridget et al. (2001) suggested that water availability is an important determinant of floral initiation. Flower bud differentiation in Japanese apricot trees occurs in summer, after harvest (Hanaoka et al., 1980). Indeed, prolonged periods of soil dryness during summer are known to affect apricot trees by reducing the number of differentiated flower buds, thereby delaying the time to differentiation of many flower buds, and retarding the rate of bud de-
velopment (Brown, 1952; Brown and Abi-Fadel, 1953) and consequently their drop (Hendrickson and Veihmeyer, 1950). Apricot flower bud drop occurs mainly during the swollen bud stage, just before bloom (Legave et al., 1982). Torrecillas et al. (2000) showed that withholding irrigation immediately after harvest for one and a half months significantly reduced fruit yield the following year. These facts support our results that a reduced irrigation amount reduces the flower bud number (Fig. 5).

The results for the differences in flower size on February 12 between the 20 mm, 15 mm, and 10 mm irrigation treatments (Fig. 6) were typical, the flower sizes being smaller with decreasing irrigation, which contrasted with the results for flower bud weight on January 22 (Fig. 2). The fruit setting rate also notably decreased with decreasing irrigation amounts (Fig. 7). These results are similar to observations by Rodrigo and Herrero (2002), who reported that small flowers showed lower fruit-set rates, suggesting a strong relationship between flower size and fruit set. Considering that there was a little difference in carbohydrate content in the flower buds on January 22 between the 20 mm, 15 mm, and 10 mm irrigation amounts (Fig. 4), it appears that flower growth and fruit set were controlled more by the irrigation amount than by carbohydrate content.

Indeed, fruit abscission may be affected by assimilates produced by the new leaves sprouting in March, and this hypothesis should be clarified by further investigation.

In conclusion, decreased water irrigation reduced flower bud numbers and inhibited fruit setting, thereby reducing yield. Fruit setting numbers per 100 nodes in the 20, 15, 10, and 5 mm treatments were 3.2, 1.1, 0.3, and 0, respectively. This suggests that an irrigation amount less than 15 mm produces a small yield, and that 20 mm of irrigation water is necessary for young Japanese apricot trees (3-year-old) to achieve adequate flower bud growth and fruit set. This investigation used potted trees, and therefore the ideal water amount for apricot tree growth and carbohydrate requirements: Reevaluation of the Kraus-Kraybill hypothesis and flowering in citrus. Proc. 6th Intl. Citrus Congr. 1: 475–483.

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