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Changes of Tree Growth and Fruit Quality of "Yumi" Peach under Long-Term Soil Water Deficit

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Abstract

Purpose: This paper presents the effects of soil drought stress during the growing season and pre-harvest period on tree growth and fruit quality of "Yumi" peach, an early season cultivar. **Methods:** Soil drought stresses were treated with four levels of -30, -50, -60, and -70 kPa during long term (LT) and short term (ST). For LT treatments, soil water was controlled for nine weeks from May 1 to July 5, which was assumed as the full growing season. For ST treatments, soil water was controlled for four weeks from June 10 to July 5, which was assumed as the pre-harvest season. Tree growth and leaf photosynthesis were measured, and fruit characteristics such as fruit weight and diameter, soluble solid and tannin contents, and harvest date were investigated. **Results:** Soil water deficit treatments caused a significant reduction in tree growth, leaf photosynthesis, and fruit enlargement. LT water stress over -60 kPa during the full growing season caused significant reduction in tree growth, including shoot length, trunk girth, leaf photosynthesis, and fruit enlargement. ST water stress over -60 kPa during the pre-harvest period also induced significant reduction in leaf photosynthesis and fruit enlargement, while tree growth was not reduced. In terms of fruit quality, water stress over -50 kPa significantly reduced fruit weight, increased soluble solid and tannin contents, and delayed harvest time in both LT and ST treatments. **Conclusions:** As a result, it is assumed that LT water stress over -60 kPa can reduce both tree growth and fruit enlargement, whereas ST water stress over -50 kPa can reduce fruit enlargement without reducing tree growth. From an agricultural perspective, moderate water deficit like -50 kPa treatments could have positive effects, such increased fruit soluble solid contents along with minimal reduction in fruit size.

Keywords: Drought, Fruit enlargement, Photosynthesis, *Prunus persica*, Water stress

Introduction

The Intergovernmental Panel on Climate Change has recently reported that the unpredictable intensity and frequency of abiotic stresses such as drying, high temperature, low temperature, salt, and flooding are the biggest contributors to crop loss (Parry et al., 2007). In the face of global deficit in water resources, drought stress is one of the most important factors that threaten the preservation of food resources. Drought stress affects the plants at any phenological or developmental stage when water deficit occurs from the morphological level to molecular level (Farooq et al., 2009). However, the intensity of drought stress is very difficult to predict because it is influenced by many factors such as rainfall frequency, distribution, amount of evaporative demand, and soil water retention (Wery et al., 1994).

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Peaches, which are grown at average annual temperatures of 12-15°C, are known to be relatively tolerant to drought compared to other temperate fruit trees. Nevertheless, long-term droughts exceeding four weeks in May and June have been occurring more frequently in peach cultivation areas owing to unseasonable weather in recent years. Thus, it is necessary to develop strategies to cope with such drought conditions. Sufficient drought stress in peaches and grapes has been reported to improve fruit quality (Chaves et al., 2007; Kobashi et al., 2000). However, sever drying stress is known to lower the quality of the fruit by further increasing the acidity rather than the sugar content of the orange (Pérez-Pérez et al., 2009). Thus, short-term drought in the summer can have a positive effect on peach tree growth and fruit quality but long-term drought is expected to have a negative impact.

Although the problem of long-term drought can be resolved by water supply facilities, more efficient soil water management is needed to improve fruit quality by considering water use efficiency. However, there is little research on changes in tree growth and fruit quality in response to drought stress in peaches because it is very difficult to accurately control soil water levels throughout the drought stress treatment.

This study was performed to investigate the changes in tree growth and fruit quality of "Yumi" cultivar grown under different soil water deficit conditions in large pots, and under soil water control conditions in a rainproof plastic house. This information provide a better understanding of efficient water management to cope with long-term drought in peach orchards.

Materials and Methods

Plant materials and plant management

Five-year-old "Yumi" peach trees were used in this study. They were cultivated at the experimental orchard of the National Institute of Horticultural and Herbal Science in Wanju-gun, Jeollabuk-do. The peach trees were planted in large pots to exclude the effects of soil water around the rhizosphere and were cultivated in a rainproof plastic house to exclude the influence of rainfall (Fig. 1). When the interior temperature of the plastic house exceeds 30°C during the growing season from May to August, forced ventilation was provided with a ceiling ventilator to suppress the temperature rise.

Figure 1. Appearance of five-year-old "Yumi" peach trees cultivated under different soil water deficit conditions throughout the experimental period in the greenhouse in 2017.

Large plastic pots with a length of 2.0 m, width of 1.0 m, height of 0.8 m, and volume of 1.6 m^3 were used in this study. In order to exclude the effects of temperature rise in the rhizosphere, the potted peach trees were planted at a depth of 0.8 m in the soil.

In March 2015, two-year-old peach trees were planted and grown in a central-leader-type training system with a 70° slope for two years in the large pots; and the present study began in 2017. The amount of fertilizer applied each year was based on the standard amount of applied fertilizer. All the data were obtained from three individual trees per treatment.

Soil water treatment

In order to investigate tree growth and fruit quality of "Yumi" peaches under soil water deficit, soil water treatments were conducted for two periods divided into long-term soil water deficit conditions (LT) during full season, and short-term soil water deficit conditions (ST) at pre-harvest. Soil water potentials were set at four levels: -30, -50, -60, and -70 kPa. The soil water in the pot was monitored by tensiometers (Irrometer R, Irrometer Co., CA, USA) installed at a depth of 30 cm (Figs. 2 and 3).

LT treatments were set from May 1 to July 14, considering that the flowering date of "Yumi" peach trees is April 10 and their harvest date is July 1. ST treatment was set from June 10 to July 5. Fruit enlargement of early maturing peaches such as "Yumi" is divided into three periods: the primary enlargement period, temporary nucleus hardening period, and secondary enlargement

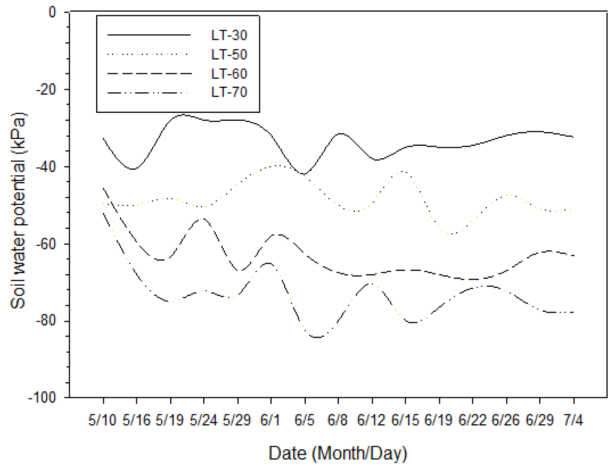

Figure 2. Soil water potential changes under long-term soil water deficit conditions (LT) treated for nine weeks from May 1 to July 5 in 2017.

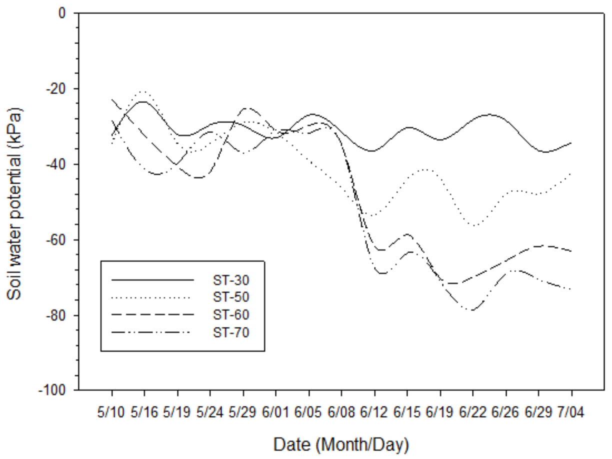

Figure 3. Soil water potential changes under short-term soil water deficit conditions (ST) treated for four weeks from June 10 to July 5 in 2017.

period after the stone-hardening stage. Hence, the starting point of water treatment was June 10, just before the secondary enlargement period. And, the flowering date of "Yumi" was April 4 in this experiment, which was three days earlier than that of outdoors.

Investigation of tree growth and fruit characteristics

The growth of trunk girth was investigated at 0.1 m height from the ground on March 10 and July 14. Number of shoots and shoot length were measured on July 14. In order to evaluate fruit characteristics according to soil water levels, fruits were harvested at the ripening stage of each treatment. Soluble solid contents were measured using a digital refractometer (PAL-1, Atago, Japan). Total acidity was measured by titrating 0.1 N sodium hydroxide solution and calculated as malic acid content. Tannin content was analyzed using the method of Makkar (2003). All experiments were repeated three times with randomized complete block design.

Photosynthesis measurement

Photosynthesis measurements were performed on June 20 using a photosynthetic measurement system (LI-6400, Li-Cor, NE, USA). The measurements were conducted after setting the chamber temperature to 30°C and the light source to 1500 mmol·m^{-2}·s^{-1} photosynthetically active radiation. The photosynthetic rate of leaves showed large variations according to light conditions. To reduce the influence of light conditions, we measured separately sun and shade leaves. The photosynthetic values were measured when CO_2 fixation speed was stable after approximately 40 s from the start of the measurement.

Statistical analysis

Statistical differences were assessed using analysis of variance with the SAS 9.4 software package (SAS Institute Inc., Cary, NC, USA). Mean differences were established by Duncan's multiple range tests.

Results and Discussion

Changes in tree growth by long-term and short-term soil water deficit treatments

Observations of tree growth changes according to different soil water levels during LT treatment (Table 1) show that the greater the soil water deficiency, the

Table 1. Changes in growth of five-year-old "Yumi" peach trees affected by long-term soil water deficit conditions (LT) treated for nine weeks from May 1 to July 5 in 2017

Soil water potential (kPa)	Shoot length (cm)	No. of shoots	Trunk girth growth (cm)
-30	41.0a[z]	97a	2.00a
-50	38.2ab	90ab	1.95a
-60	35.0b	86b	1.45b
-70	35.3b	77c	1.10b

[z]Different letters within columns indicate significant differences among the treatments according to Duncan's multiple rage test ($p \leq 0.05$).

greater the decrease in tree growth. The average shoot length and number of shoots decreased at -50, -60, and -70 kPa treatments compared to those at -30 kPa treatment. The average shoot length and number of shoots at -30, -50, -60, and -70 kPa treatments were 41.0, 38.2, 35.0, and 35.3 cm; and 97, 90, 86, and 77, respectively. The growth of trunk girth significantly declined at -70 kPa but was not significant at -30, -50, and -60 kPa treatments. The growth of trunk girth at -70 kPa was 1.10 cm, while those at -30, -50, -60 kPa were 2.0, 1.95, and 1.45 cm, respectively. In addition, the photosynthetic ability of leaves was remarkably reduced with the decrease in soil water levels during the LT treatment period (Fig. 4).

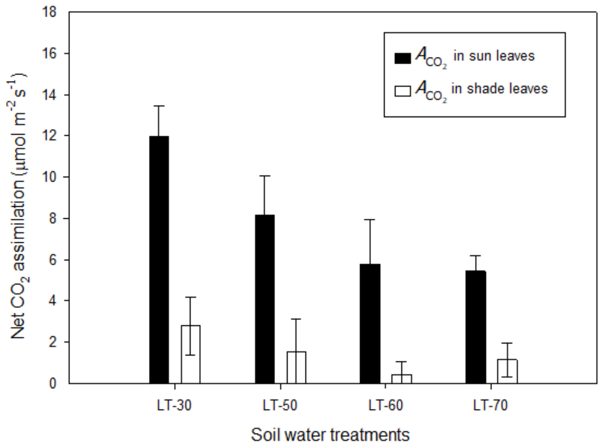

Figure 4. Net CO_2 assimilation (measured on June 20) of five-year-old "Yumi" peach leaves affected by long-term soil water deficit conditions (LT) treated for nine weeks from May 1 to July 5 in 2017.

Table 2. Changes in growth of five-year-old "Yumi" peach trees affected by short-term soil water deficit conditions (ST) treated for four weeks from June 10 to July 5 in 2017

Soil water potential (kPa)	Shoot length (cm)	No. of shoots	Trunk girth growth (cm)
-30	41.3a^z	102a	1.98a
-50	39.7a	102a	1.88a
-60	38.7a	94a	1.93a
-70	37.9a	89a	1.68a

^{z}Different letters within columns indicate significant differences among the treatments according to Duncan's multiple rage test ($p \leq 0.05$).

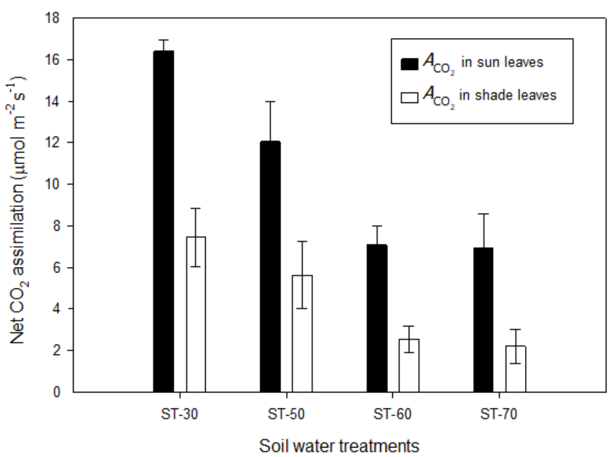

Figure 5. Net CO_2 assimilation (measured on June 20) of five-year-old "Yumi" peach leaves affected by short-term soil water deficit conditions (ST) treated for four weeks from June 10 to July 5 in 2017.

On the other hand, during ST treatment, there was no significant difference between -30, -50, -60, and -70 kPa treatments in terms of the average shoot length, number of shoots, and trunk girth (Table 2). However, the photosynthetic ability of leaves declined significantly with decrease in soil water levels (Fig. 5).

The long-term soil water deficit conditions during the full season significantly reduced the tree growth of "Yumi" peaches, including the average shoot length and number of shoots (Table 1). However, there was no significant difference in tree growth between the short-term soil water deficit conditions during the pre-harvest season (Table 2). Peaches are generally known to be more tolerant to drought stress than other fruit trees. As a result of this experiment, the appearance of peach trees also showed some withering phenomenon at -60 and -70 kPa during LT treatment, whereas during ST treatments, there were no apparent differences between treatments. However, the photosynthesis ability of the leaves was remarkably reduced in both LT and ST treatments (Figs. 4 and 5).

Changes in fruit quality by long-term and short-term soil water deficit treatments

The results of the analysis of fruit characteristics according to different soil water levels during LT treatment (Table 3) show that fruit weights at -30, -50, -60, and -70 kPa were 238, 203, 176, and 150 g, respectively. In addition, the longitudinal and equatorial diameters of fruits at -30, -50, -60, and -70 kPa were 69.7, 63.8, 62.2, and 58.5 mm; and 79.4, 74.9, 69.3, and 66.2 mm, respectively. The observation of fruit enlargement shows that the equatorial diameters of fruits were extended first in the early fruit enlargement stage, and then longitudinal diameters of fruits were predominantly

Table 3. Characteristics of fruits harvested from five-year-old “Yumi” peach trees affected by long-term soil water deficit conditions (LT) treated for nine weeks from May 1 to July 5 in 2017

Soil water potential (kPa)	Diameter of fruit		Fruit weight (g)	Soluble solid content (Bx)	Total acidity (%)	Tannin content (g/kg)	Harvest (Date)
	Longitudinal (mm)	Equatorial (mm)					
-30	69.7a^z	79.4a	238a	12.5b	0.23a	0.58c	June 29
-50	63.8b	74.9b	203b	12.8b	0.26a	0.59c	July 3
-60	62.2b	69.3c	176c	13.4ab	0.29a	1.09b	July 5
-70	58.5c	66.2c	150d	13.7a	0.32a	1.23a	July 5

^{z}Different letters within columns indicate significant differences among the treatments according to Duncan’s multiple rage test ($p \leq 0.05$).

Table 4. Characteristics of fruits harvested from five-year-old “Yumi” peach trees affected by short-term soil water deficit conditions (ST) treated for four weeks from June 10 to July 5 in 2017

Soil water potential (kPa)	Diameter of fruit		Fruit weight (g)	Soluble solid content (Bx)	Total acidity (%)	Tannin content (g/kg)	Harvest (Date)
	Longitudinal (mm)	Equatorial (mm)					
-30	73.0a^z	79.6a	236a	11.8b	0.12b	0.43c	June 29
-50	70.0a	77.0ab	216b	13.1a	0.13b	0.52c	July 3
-60	65.6b	73.0b	196c	13.3a	0.25b	0.69b	July 5
-70	64.4b	68.4c	173d	13.8a	0.35a	0.92a	July 5

^{z}Different letters within columns indicate significant differences among the treatments according to Duncan’s multiple rage test ($p \leq 0.05$).

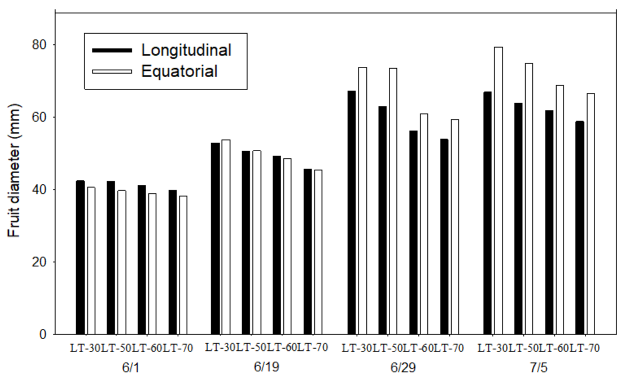

Figure 6. Fruit enlargement patterns of five-year-old “Yumi” peach trees affected by long-term soil water deficit conditions (LT) treated for nine weeks from May 1 to July 5 in 2017.

extended in the late fruit enlargement stage. Finally, equatorial diameters of fruits surpassed the longitudinal diameters about 15 days before harvest (Fig. 6). Soluble solid content at soil water deficit treatments of -30, -50, -60 kPa were 12.5, 12.8, 13.4, and 13.7 Brix, respectively, and these increased with the intensity of soil water deficit. However, the difference in total acidity between the treatments was marginal. Harvest dates were July 3 at -50 kPa treatment, and July 5 at -60 and -70 kPa treatments, compared to June 29 at 30 kPa. Thus, harvest dates were delayed by four to six days. Tannin contents were higher at -60 and -70 kPa treatments compared to the other treatments.

The analysis of fruit characteristics according to different soil water levels during ST treatment (Table 4) show that fruit weights at -30, -50, -60, and -70 kPa were 236, 216, 196, and 173 g, respectively. In addition, the longitudinal and equatorial diameters of fruits at -30, -50, -60, and -70 kPa were estimated as 73.0, 70.0, 65.6, and 64.4 mm; and 79.6, 77.0, 73.0, and 68.4 mm, respectively. The longitudinal and equatorial diameters of fruits were lower at -50, -60, and -70 kPa than at -30 kPa. It is known that equatorial diameters of fruits generally increase significantly in the late fruit enlargement stage. With soil water deficit treatments, the equatorial enlargement of fruit was retarded by water stress (Fig. 7). Soluble solid content for the soil water deficit treatments of -30, -50, -60, and -70 kPa were 11.8, 13.1, 13.3, and 13.8 Brix, respectively, and these increased with intensity of soil water deficit. In addition, total acidities increased with increasing of soil water deficit. The harvest dates were June 29 at -30 kPa, July 3 at -50 kPa, and July 5 at -60 and -70 kPa treatments. Thus, harvest days at -50, -60, and -70 kPa were delayed by four to six days compared to that at -30 kPa. Similar to LT treatment, tannin contents were higher at -60 and -70 kPa treatments.

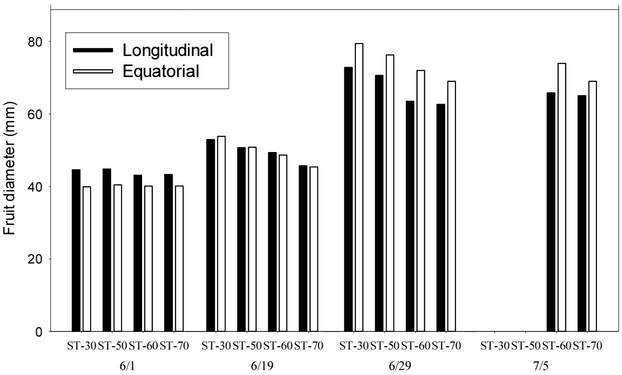

Figure 7. Fruit enlargement patterns of five-year-old "Yumi" peach trees affected by short-term soil water deficit conditions (ST) treated for four weeks from June 10 to July 5 in 2017.

Fruit quality showed significant differences according to soil water levels in both LT and ST treatments (Tables 3 and 4). The excess or deficit state of soil water affected the quality of the fruit (Mills et al., 1997). Low soil water level induced drought stress in plants and inhibited fruit enlargement and fruit weight of *Citrus unshiu* and *Aronia melanocarpa*. It also reduced yields by reducing fruit size and weight (Chae et al., 2007; Hyun et al., 1993; Won et al., 2017). In this study, the increased soil water deficit in both LT and ST treatments suppressed fruit enlargement and reduced the size and weight of fruits. In addition, low soil water conditions negatively affected the photosynthetic ability of the leaves (Figs. 4 and 5), and the reduction in leaf photosynthetic rate seemed to affect the fruit enlargement suppression. Some studies reported that when drought stress was increased by water deficit, the size of peach and blueberry fruits decreased (Glass et al., 2005; Rahmati et al., 2015).

The soluble solid content and acidity of fruits were affected by weather factors such as temperature, light, and rainfall during the growing period, and depend on cultivation techniques such as soil water management (Marguery and Sangwan, 1993). When drought stress was applied, the soluble solid content of blackberries increased (Naumann and Wittenburg, 1980); in the case of *Citrus unshiu*, the soluble solid content and acidity increased (Hyun et al., 1993). It has also been reported that when sufficient water was supplied to grapes, the yield increased but sugar content decreased (Morris et al., 1983). In this study, both LT and ST water stress decreased fruit size and increased soluble solid content and total acidity, although the extent of these effects varied according to the severity of drought stress.

Grapes have been reported to have increased tannin content when water is lacking at maturity (Bucchetti et al., 2011). Our results also indicate that the tannin content of fruits increased with increasing drought stress in both LT and ST treatments (Tables 3 and 4). Generally, it has been reported that the tannin content of fruits declines owing to the insolubility of fruit tannin as fruits reach maturation (Salunkhe et al., 1968). Therefore, the shortage of soil water could inhibit fruit enlargement as well as delay fruit maturity and tannin insolubility.

Conclusions

Although peaches are known to be relatively tolerant to drought stress compared to other fruit crops, there was a significant reduction in tree growth, leaf photosynthesis, and fruit enlargement with soil water deficit treatments. LT water stress (nine weeks) over -60 kPa during the full growing season caused significant reduction in tree growth, including shoot length, trunk girth, leaf photosynthesis, and fruit enlargement. ST water stress (four weeks) over -60 kPa during the preharvest period also caused a significant reduction in leaf photosynthesis and fruit enlargement, although tree growth was not reduced. With regard to fruit quality, water stress over -50 kPa significantly reduced fruit weight, increased soluble solid and tannin contents, and delayed harvest time in both LT and ST treatments. As a result, it is assumed that LT water stress over -60 kPa can reduce both tree growth and fruit enlargement, while ST water stress over -50 kPa during the preharvest season can reduce fruit enlargement without reducing tree growth. From an agricultural perspective, moderate water deficit like -50 kPa treatments could have positive effects, such as increased fruit soluble solid contents along with a minor reduction in fruit size.

Conflict of Interest

The authors have no conflicting financial or other interests.

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