Europ.J.Hort.Sci., **78** (2). S. 67–75, 2013, ISSN 1611-4426. © Verlag Eugen Ulmer KG, Stuttgart

Deficit Irrigation in Nectarine: Fruit Quality, Return Bloom and Incidence of Double Fruits

A. Thakur and Z. Singh
(Curtin Horticulture Research Laboratory, Department of Environment and Agriculture, School of Science and International Institute of Agri-Food Security (IIAFS), Curtin University, Western Australia, Australia)

Summary

Deficit irrigation (DI) at phenological stages less sensitive to water stress (pit hardening and post-harvest stage) influenced fruit quality, plant growth, return bloom and incidence of double fruits in nectarines. Four irrigation levels: control irrigation (CI), DI 75 (75 % of CI), DI 58 (58 % of CI) and DI 33 (33 % of DI) were applied in 'Spring Bright' and 'Summer Bright' nectarines during pit hardening and post-harvest stages. DI 58 and DI 33 treatments resulted in development of intense red fruit colour and early maturity in 'Spring Bright'. DI 33 improved fruit colour in 'Summer Bright', soluble solids concentrations (SSC) and SSC/acid ratio in both cultivars. DI 33 treatment decreased glucose and fructose at harvest in 'Spring Bright' and increased glucose in 'Summer Bright'. DI 58 and DI 33 treatments improved the levels of total phenolics, antioxidant capacity, ascorbic acid and carotenoids in the fruit of both cultivars with acceptable fruit weight in comparison to CI. DI 33 treatment significantly increased the total anthocyanin content in fruit peel and reduced water sprout length in both cultivars. In subsequent season, the DI 58 and DI 33 treatments increased flower density in 'Spring Bright' and incidence of double fruit in either cultivar. Conclusively, DI improved fruit colour, SSC/acid ratio and nutraceutical levels; and reduced water sprout length. Further, it increased flower density and double fruits in the subsequent season.

Key words. deficit irrigation – fruit colour – rheological properties – nutraceuticals

Introduction

The reduction in availability of fresh water for horticulture use throughout the world necessitates better irrigation scheduling in fruit crops (Rouphael et al. 2008). Peach and nectarine having an annual production of 20.32 million tonnes from 1.56 million ha (Fao 2010) are often grown in arid regions, where irrigation water is a limiting factor. In peach, crop yield, fruit size and quality are highly dependent on irrigation (Naor 2006).

The success in breeding of low chill and early maturing nectarine cultivars with intense red fruit skin led to an enormous increase in their cultivation in many countries viz. USA, France, Italy, South Africa, Australia, Brazil, Mexico, China, Japan and India. The production in non-traditional subtropical regions with mild winters is usually associated with poor fruit quality. The majority of low-chill stone fruits including peach and nectarines have very low sugar levels (George et al. 2005). Aromatic compounds, relative amounts of specific sugars, texture, and acidity are very important components of peach and nectarine quality. However, sweetness is an overriding factor in the eating quality of nectarines (Genard and Souty 1996) and consumer prefers fruits with high sugar and low acid levels (Wu et al. 2003).

In peach and nectarines, fruit growth exhibits a double sigmoid growth pattern. The slow fruit growth phase during pit hardening is the most appropriate stage for deficit irrigation (Naor 2006). Deficit irrigation (DI) has been employed in peach and nectarine to control vegetative growth, maximising water use efficiency and improving fruit quality (Gelly et al. 2004, Pliakoni et al. 2010). Recently, there is resurgence in the use of DI in fruit crops, however, the focus has been shifted from controlling excessive vegetative growth to improving fruit quality (Stefanelli et al. 2010). Besides saving water, DI during pit hardening has been reported to reduce vegetative growth, sustain yields with improvement in fruit quality (Behboudian et al. 2011). DI increased total sugars, sucrose and sorbitol in nectarines (Thakur and Singh 2012). DI also improved SSC in peach (Sotiropoulos et al. 2010, Lopez et al. 2011). DI improved sweetness, juiciness and intensity of flavor thus improving sensory quality and consumer acceptance in peach (Vallverda et al. 2012).

The peach and nectarine fruits are good sources of polyphenols. The strong antioxidant potential of polyphenol compounds enriches the fruit with health-promoting properties. DI has been reported to enhance the concentration of bioactive compounds in peach and nectarine fruits (BUENDÍA et al. 2008, PLIAKONI et al. 2010). DI is thus a powerful tool to increase the concentration of these phytochemicals in fruit which in turn increase their sensory and nutritional quality.

In subtropical regions, early maturing peach cultivars are harvested early in summer and there is a potential for post-harvest water saving (CONEJERO et al. 2011). However, severe post-harvest water stress may have detrimental effects on flowering and fruit set in the following season. The main disadvantage of post-harvest DI in peach is a higher incidence of double fruits (JOHNSON and PHENE 2008) because high air temperature occur during the bud development stage affecting next season's fruit (BEPPU et al. 2001). Hence, it is surmised that the effects of DI will vary under different climatic conditions.

It was hypothesized that DI at phenological stages less sensitive to water stress (pit hardening and post-harvest stages) may influence fruit quality, shoot growth, return bloom and incidence of double fruits in nectarines. The effects of different levels of DI during pit hardening on fruit colour, texture, weight, SSC concentration levels of different sugars and organic acids, phenolics, antioxidant, carotenoids, anthocyanin and ascorbic acid at harvest in 'Spring Bright' and 'Summer Bright' nectarines were investigated. Additionally, the effects of DI treatments during pit hardening and post-harvest stages on shoot growth, carbohydrates: nitrogen ratio, return bloom, fruit set and incidence of double fruits was also studied.

Materials and Methods

Plant material and experimental conditions

Two experiments were conducted, during 2010–11 season, on 'Spring Bright' and 'Summer Bright' cultivars of nectarine (*Prunus persica* Batsch var. nectarina) at Casuarina Valley Orchard, Karagullen, Perth Hills (Lat. 31° 57' S; Long. 115° 50' E; and 294 m asl), Western Australia having a dry summer subtropical climate. Six-year old nectarines trees on 'Nemaguard' rootstock, having 0.50 rooting depth, had been planted 2.4 m between trees and 4.5 m between rows in an east-west row direction. The orchard soil was gravelly in a sandy or loamy matrix with more than 1.2 m depth. The experiment was laid out as a randomized complete block design, with four replications. Two trees were treated as an experimental unit. The details of the DI treatments are presented in Table 1. The cultivars were harvested at commercial harvest; the 'Spring Bright' was harvested at 93 DAFS (days after fruit set; 50 % shucks off) and 'Summer Bright' at 105 DAFS. Fruits were randomly harvested from inner and outer parts of the central canopy of the experimental trees for determining fruit qualityvanalysis.

DI treatments were applied during pit hardening and again after harvest to evaluate their effects on shoot growth, and flowering intensity, fruit set and incidence of double fruits in the following season. The initiation of pit hardening was judged with a slight increase in difficulty of cutting through the pit near to distal end of the fruit with a sharp knife. The irrigation levels during the post-harvest stage are presented in Table 1. Before DI application during pit hardening, all the experimental trees received uniform irrigation at ETc 114 % for 10 days. The crop water use was calculated by using the equation: $ET_c = ET_0 \times Kc$. Where, the FAO Penman-Monteith ET_0 was calculated from the data from an automatic weather station at the experimental site and Kc is the crop coefficient. The Kc values were 0.7 from the start of irrigation in mid spring till the end of pit hardening (DI period) and 1.2 during the fruit growth and maturation. The values were adapted from KRIEDMANN and GOODWIN (2003). Kc value of 0.8 was used during the post-harvest DI period (DICHIO et al. 2007). All the experimental plot trees were surrounded by guard trees receiving the same irrigation treatment. The level of irrigation was varied by using different regulated micro-sprinklers (Regulated Micro Sprinkler, Netafim Supernet, Tel Aviv, Israel) with flow rates varying from 20–60 $L\ h^{-1}$ $tree^{-1}$.

Stem water potential

The mid-day stem water potential (Ψ_{stem}) was determined using a pressure chamber (3000; Soil Moisture Equipment Corp., Santa Barbara, CA, USA). The leaves were enclosed in a plastic bag covered with aluminium foil for 120 minutes and Ψ_{stem} was determined between 11.00 to 13.00 solar time. Ψ_{stem} was recorded from 8 days after DI started to one week before fruit harvest and again during the postharvest stage.

Fruit quality

Fruit colour, texture, soluble solids concentration (SSC), titratable acidity (TA). The fruit skin colour was recorded using a HunterLab ClourFlex 45°/0° Spectrophotometer (Hunter Associates Inc, Reston, VA, USA) from four equatorial regions of the fruit with the 15 mm diameter port. The data were expressed as chroma (C*) and hue angle (h°). Fruit texture was determined from two peeled sides of each fruit using a texture analyser (TA plus; AMETEK Lloyd Instruments Ltd, Hampshire, UK) interfaced to a computer with Nexygen® software. Magness-Taylor probe (5/16 inches) with a 500N load cell was used to puncture the peeled fruit at a crosshead speed of 100 mm min^{-1} to 7.5 mm depth. SSC was determined with an infrared digital refractometer (Atago-Palette PR 101, Atago Co. Ltd., Tokyo, Japan) at 20 °C. TA was determined by titrating

Table 1. Details of deficit irrigation (DI) treatments applied during pit hardening and post harvest stage in nectarine cv. 'Spring Bright' and 'Summer Bright'.

	'Spring Bright'	'Summer Bright'
DI during pit hardening		
DI period	40 to 65 DAFS[1]	36 to 68 DAFS
FAO Penman-Monteith ET_0 during DI period	120.3 mm	142.9 mm
Rainfall during DI period	13.4 mm	13.4 mm
Irrigation levels during DI		
Control Irrigation (CI)	114 % ETc (Commercial Irrigation)	100 % ETc
DI 75	85 % ETc	75 % ETc
DI 58	66 % ETc	58 % ETc
DI 33	38 % ETc	33 % ETc
Fruit growth and maturation period	66–93 DAFS	69–105 DAFS
ETo during fruit growth and maturation	145.0 mm	204.9 mm
ETc during fruit growth and maturation	128 % ETc (Commercial Irrigation)	100 % ETc
Average fruit load tree^{-1}	320	235
DI during postharvest period		
DI period	100–174 DAFS	118–170 DAFS
FAO Penman-Monteith ET_0	398.9 mm	356.0 mm
Rainfall during postharvest DI	30.0 mm	12.2 mm
Control Irrigation (CI)	105 % ETc	107 % ETc
DI 75	79 % ETc	80 % ETc
DI 58	61 % ETc	62 % ETc
DI 33	35 % ETc	35 % ETc
Crop load (Fruits/tree)	320	235

[1] Days after fruit set

the juice (10 mL) against 0.1 N NaOH solution to an end-point pH of 8.2 using phenolphthalein as an indicator.

Determination of sugars and organic acids. The sugars and organic acids were determined using a high-performance liquid chromatography (HPLC) analysis as described by Singh et al. (2009). The concentrations of different sugars and organic acids were determined at harvest.

Total phenolics, ascorbic acid, carotenoids and antioxidants. Total phenolics were determined from fruit tissue with the Folin-Ciocalteu reagent based method (Singleton et al. 1999). Ascorbic acid and total carotenoids in fruit skin and flesh tissue were determined with the methods described by Khan et al. (2008). Antioxidant capacity in fruit skin and flesh was estimated by using the method of Brand-Williams et al. (1995) with some modifications described by Khan et al. (2008).

Determination of total anthocyanin. The concentration of total anthocyanin was determined according to Whale et al. (2008). The concentration of total anthocyanin was calculated using the molecular weight 449.2 g mol^{-1} and molar extinction coefficient of 23900 L cm^{-1} mol^{-1} for cyanidin −3-*O*-glucoside and expressed as mg 100g^{-1}.

Vegetative growth

The vegetative growth was measured by recording the growth of water-sprouts, fruiting shoots and internodal length from the experimental trees at end of pit hardening, after fruit harvest and after the termination of postharvest DI. There was no significant difference in vegetative growth parameters over the three stages hence, the data recorded only after the termination of postharvest DI is presented.

Return bloom, fruit set, incidence of double fruits and C:N ratio

One secondary branch was selected on six trees (three on each side) and numbers of flower buds were counted at bloom stage. The number of fruits set and double fruits were counted at 30 d after full bloom (DAFB). Flower density on the fruiting shoots was also determined and expressed as the number of flowers per 1 m length of one-year-old shoots. The nitrogen and carbon for C:N ratio was determined from fine powder of one year old shoots having diameter of 4 to 5 mm using an Automated Nitrogen Carbon Analyzer ANCA-S1 (Europa Scientific Ltd., Crewe, UK).

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using statistical software MSTATC. The mean separation was done using least significant difference (Fisher's LSD) at $P \leq 0.05$ following significant F test. All the assumptions of analysis were checked to ensure validity of statistical analysis.

Results

Fruit Colour

DI treatments (DI 58 and DI 33) significantly decreased the Chroma (C*) and hue angle (h°) values in cultivar 'Spring Bright' (Table 2). In 'Summer Bright', only DI 33 lowered the C* values. It suggests intense colour development in 'Spring Bright' nectarines with DI 58 and DI 33; and with DI 33 in 'Summer Bright'. The decrease in C* with DI 58 and DI 33 in 'Spring Bright'; and DI 33 in 'Summer Bright' shows the development of darker red colour in these treatments. The significant decrease in h° also confirms more intense red colour development in 'Spring Bright' with DI 58 and DI 33. DI 75 had no significant effect on the fruit colour in either cultivar.

Table 2. Effect of deficit irrigation (DI) treatments on fruit colour, fruit weight, rheological properties, SSC, sugars and organics acids in nectarine cv. 'Spring Bright' and 'Summer Bright'.

	'Spring Bright'					'Summer Bright'				
	CI	DI 75	DI 58	DI 33	LSD	CI	DI 75	DI 58	DI 33	LSD
Fruit Colour										
C*	42.9 ab	43.2 a	38.6 bc	36.0 c	4.45	43.3 a	43.2a	42.4 a	38.9 b	2.90
h°	31.3 a	31.3 a	27.5 b	27.1 b	3.33	30.9 a	30.6 a	29.9 a	28.7 a	NS
Fruit weight (g)	118.9 a	116.1 a	109.1 b	98.4 b	11.52	113.5 a	109.6 ab	108.9 b	103.4 b	6.32
Rheological properties										
Firmness (N)	36.65 a	35.02 a	24.67 b	18.57 b	9.77	35.88 a	33.86 a	30.17 a	29.75 a	NS
Cohesiveness	0.14 a	0.05 a	0.06 a	0.13 a	NS	0.046 a	0.028 a	0.045 a	0.037 a	NS
Springiness (mm)	3.44 a	2.75 ab	2.96 ab	2.34 b	1.07	3.29 a	2.41 ab	2.64 ab	2.13 b	1.12
Chewiness (N mm)	15.08 a	5.89 a	6.25 a	6.21 a	NS	5.85 a	2.84 b	3.99 ab	2.69 b	2.88
Adhesiveness (N mm)	2.89 a	2.09 a	2.51 a	2.56 a	NS	1.04 a	1.47 a	1.61 a	1.31 a	NS
SSC, sugars and organic acids										
SSC (%)	9.1 b	9.2 b	9.3 b	10.3 a	0.94	10.3 b	10.5 ab	10.7 a	10.8 a	0.4
Acidity (%)	0.70 a	0.68 ab	0.64 b	0.65 b	0.05	0.73 a	0.70 bc	0.71 ab	0.69 c	0.03
SSC/acid ratio	13.0 b	13.5 b	14.5 ab	15.8 a	1.87	14.1 b	15.0 ab	15.1 a	15.7 a	0.91
Sucrose (g $100g^{-1}$)	6.5 bc	6.1 c	6.7 ab	7.2 a	0.1	6.8 b	6.6 b	7.2 ab	7.7 a	0.8
Glucose (g $100g^{-1}$)	0.7 a	0.5 b	0.5 b	0.3 c	0.1	0.3 b	0.3 b	0.5 a	0.6 a	0.1
Fructose (g $100g^{-1}$)	1.3 a	1.1 b	1.1 bc	1.0 c	0.1	1.5 a	1.5 a	1.5 a	1.7 a	0.1
Sorbitol (g $100g^{-1}$)	0.4 ab	0.3 ab	0.3 b	0.4 a	0.1	0.3 b	0.3 c	0.2 d	0.6 a	0.1
Total Sugar (g $100g^{-1}$)	8.7 ab	8.2 b	8.6 ab	8.9 a	0.7	8.9 bc	8.7 c	9.4 b	10.5 a	0.8
Total Sugar (g $fruit^{-1}$)	10.3 a	9.5 ab	9.4 ab	8.8 b	1.4	10.1 b	9.5 b	10.3 ab	10.9 a	0.8
Malic acid (g $100g^{-1}$)	0.5 a	0.5 a	0.4 a	0.4 a	NS	0.5 a	0.5 a	0.5 a	0.5 a	NS
Citric acid (g $100g^{-1}$)	0.3 a	0.3 a	0.3 a	0.3 a	NS	0.5 a	0.4 ab	0.4 b	0.5 a	0.1

The means followed by same letters across the rows do not differ significantly at $P \leq 0.05$.

Fruit weight

DI 58 and DI 33 significantly reduced fruit weight in 'Spring Bright' (8.20 and 17.22 %, respectively) and 'Summer Bright' (4.20 % and 8.88 %, respectively), but DI 75 showed no negative effects on fruit weight (Table 2). Except for the average fruit weight of 98.42 g observed in DI 33 treatment in 'Spring Bright', more than 100 g fruit weight was recorded in all the treatments in both cultivars. In both cultivars, the fruit weight was above the minimum acceptable standards (> 85 g) for the best quality 'Extra Class' grade as per EU Regulation 543/2011 (Anonymous 2011).

Rheological properties

In 'Spring Bright', DI 58 and DI 33 significantly decreased firmness of the fruit at harvest (Table 2). The lowest firmness (18.67 N) was recorded in DI 33 which was followed by DI 58 (24.67 N). DI 33 also decreased springiness in cultivar 'Spring Bright' but, it had no effect on cohesiveness, chewiness and adhesiveness. In cultivar 'Summer Bright', DI treatments had no significant effect on firmness, adhesiveness and cohesiveness. However, the springiness and chewiness were decreased with DI 33.

SSC, sugars and acids

In 'Spring Bright', the highest SSC level (10.30 %) was recorded in DI 33 (Table 2) whereas, the SSC levels in DI 58 and DI 75 did not differ from CI (9.07 %). In 'Summer Bright', DI 33 led to the highest SSC level (10.83 %) which did not differ significantly from DI 58. The SSC level and SSC/acid ratio in DI 33 and DI 58 was significantly higher than CI. DI treatments did not significantly affect the titratable acidity in either cultivar. The data presented in Table 2 also shows that DI 33 resulted in the highest total sugar $100g^{-1}$ fruit in both cultivars ($8.90\ g\ 100g^{-1}$ in 'Spring Bright' and $10.50\ g\ 100\ g^{-1}$ in 'Summer Bright'). However, in comparison to CI, DI 58 and DI 33 increased total sugar $100g^{-1}$ fruit in 'Summer Bright' but, in 'Spring Bright', DI 33 and DI 58 had no significant effect. On fruit basis, severe deficit irrigation treatments also increased total sugar $fruit^{-1}$ in 'Summer Bright' but, decreased in 'Spring Bright' (Table 2). Severe DI levels decreased glucose and fructose levels in 'Spring Bright' but increased them in 'Summer Bright'. DI 75 had no significant effect on the total sugars and sucrose levels. DI had no significant effect on malic and citric acid levels in either cultivar.

Total phenolics, antioxidant capacity, ascorbic acid, carotenoids and anthocyanin

DI 75 had no significant effect on most of the biochemical properties measured; however, it increased total phenolics in the skin of 'Spring Bright' fruit (Table 3). DI 58 and DI 33 increased the levels of phenols, ascorbic acid, antioxidants, carotenoids and anthocyanin in both cultivars

Table 3. Effect of deficit irrigation (DI) treatments on total phenols, antioxidant content, ascorbic acid and anthocyanins in nectarine cv. 'Spring Bright' and 'Summer Bright'. * Chlorogenic acid equivalent, # Ascorbic acid equivalent.

	'Spring Bright'					'Summer Bright'				
	CI	DI 75	DI 58	DI 33	LSD	CI	DI 75	DI 58	DI 33	LSD
Total phenolics (mg $100g^{-1}$ CAE*)										
Flesh	19.2 b	20.6 ab	21.8 a	21.5 a	1.45	17.8 b	18.5 ab	20.9 a	20.8a	2.90
Peel	104.5 c	105.2 c	108.2 b	111.5 a	1.33	81.4 c	86.5 b	89.1 b	97.6 a	2.90
Antioxidant capacity (mg $100g^{-1}$ AAE#)										
Flesh	55.1 a	54.5 a	54.0 a	53.3 a	NS	53.9 a	53.8 a	53.7 a	54.6 a	NS
Peel	104.1 c	104.5 c	107.4 b	111.5 a	2.73	101.3 b	103.7 b	104.5 b	111.0 a	5.50
Ascorbic acid (mg $100g^{-1}$)										
Flesh	5.1 a	4.9 a	5.04 a	5.0 a	NS	4.0 b	4.8 ab	5.2 a	5.2 a	0.90
Peel	19.3 c	22.4 c	25.9 b	29.9 a	3.25	14.1 b	15.7 b	19.7 a	20.1 a	3.50
Total carotenoids (mg $100g^{-1}$)										
Flesh	0.069 b	0.070 b	0.087ab	0.100 a	0.02	0.061 a	0.051 a	0.057 a	0.063 a	NS
Peel	0.293 b	0.271 b	0.454 a	0.478 a	0.04	0.272 c	0.278bc	0.316 b	0.392 a	0.04
Total anthocyanin (mg $100g^{-1}$)										
Peel	25.7 b	25.9 b	25.4 b	33.4 a	7.36	27.1 b	27.1 b	29.2 ab	32.6 a	3.90

The means followed by same letters across the rows do not differ significantly at $P \leq 0.05$.

but, the effects were more pronounced for fruit peel than for flesh (Table 3). DI 58 and DI 33 treatments increased phenols in peel and flesh; and ascorbic acid in peel of either cultivar. DI 33 significantly increased the antioxidant capacity, carotenoids and total anthocyanin content in the fruit peel of both cultivars. Anthocyanin was not detected in fruit flesh due to absence of red streak in the flesh.

Vegetative growth, return bloom, fruit set and double fruits

DI 33 significantly reduced water sprout length in both cultivars (Table 4). The waterspouts and fruiting shoots attained maximum length up to the end of pit hardening stage. There were no significant differences in the length of water sprouts and fruiting shoots from the end of pit hardening until the end of post-harvest DI (data not included). Hence, the differences in the vegetative growth following DI appear to be an effect of DI during the pit hardening stage. DI had no significant effect on flower density in ‘Spring Bright’ and fruit set in either cultivar (Table 4). DI 58 and DI 33 increased flower density in ‘Summer Bright’. DI 58 and 33 resulted in significant increase in the incidence of double fruits (Table 4). The nitrogen content tended to decrease and C:N ratio tended to increase in shoots from trees with DI treatments.

Discussion

The development of more intense red colour in nectarine cultivars following DI 58 and DI 33 treatments may be due to higher anthocyanins in fruit skin (Table 3) following higher light penetration into tree canopy due to reduction in vegetative growth (Table 4). DI (35 % ETc) applied at pit hardening stage has been reported to result in the development of more reddish colour in the skin of peach fruit (Gelly et al. 2004). Probably, water stress induced endogenous levels of abscisic acid in plant may have induced anthocyanin biosynthesis (Deis et al. 2011). It may also be argued that the increase in anthocyanin concentrations with DI may be due to higher sucrose accumulation following DI (Table 2). High tissue solute potentials were associated with low or undetectable levels of expression of anthocyanin biosynthesis genes in immature green grapes, while decrease in solute potential following higher sugar accumulation showed high correlation with increase in expression of anthocyanin biosynthesis genes during berry colour development (Castellarin et al. 2011).

The decrease in fruit weight with DI 58 and DI 33 might be due to delay in the recovery of plants from water stress (Girona et al. 2005). Deficit irrigation during pit hardening in early maturing peach cultivars has adverse effects on fruit size due to shorter period from fruit set to harvest (Conejero et al. 2011). The decrease in fruit diameter and not fruit length (data not included) may be responsible for the decrease in fruit weight with DI 33 in ‘Spring Bright’. The differences in recovery pattern of water stress in plants after the resumption of CI (Fig. 1A, B) as discussed above may also be responsible for the decrease in fruit size with severe deficit irrigation treatment. The higher ethylene production and respiration rates in severe DI treatment (data not included) suggest early fruit maturity consequently decreased firmness of ‘Spring Bright’ fruit with DI 58 and DI 33 at harvest. Peach fruits from DI (50 % of ETc) have been reported to loose firmness very quickly in storage (Pliakoni and Nanos 2010). However, DI treatments had no significant effect on firmness in ‘Summer Bright’. This shows that the delay in the recovery from water stress on resumption of CI after pit hardening stage (Fig. 1A) might have affected the early maturing cultivar ‘Spring Bright’ differently than the mid-season cultivar ‘Summer Bright’.

Table 4. Effect of deficit irrigation (DI) treatments on vegetative growth, flower density (flowers m^{-1}), fruit set (%), double fruits (%) and C:N ratio in nectarine cv. ‘Spring Bright’ and ‘Summer Bright’.

	‘Spring Bright’					‘Summer Bright’				
	CI	DI 75	DI 58	DI 33	LSD	CI	DI 75	DI 58	DI 33	LSD
Watersprout length (cm)	55.0 a	45.4 ab	44.9 ab	40.4 b	10.3	48.2 a	47.3 ab	40.3 ab	39.2 b	8.3
Fruiting shoot length (cm)	25.9 a	24.9 a	22.8 a	22.0 a	NS	26.5 a	25.5 a	21.6 b	22.3 b	3.0
Internodal length (mm)	32.4 a	34.4 a	33.9 a	31.7 a	NS	30.7 a	30.3 a	29.8 a	27.8 b	1.4
Flower density (flowers m^{-1})	34.8 a	36.9 a	39.8 a	39.0 a	NS	41.3 b	40.2 b	52.1 a	52.9 a	7.1
Fruit set (%)	81.1 a	86.3 a	82.5 a	79.5 a	NS	83.4 a	85.0 a	87.0 a	83.8 a	NS
Double fruit (%)	2.5 b	1.8 b	11.0 a	14.4 a	0.8	0.0	1.1 b	5.1 a	4.3 a	0.7
Nitrogen (%)	0.98 a	0.94 a	0.90 a	0.92 a	NS	1.42 a	1.23 a	1.24 a	1.26 a	NS
Carbon (%)	46.30 a	45.84ab	45.28 b	45.90ab	0.9	46.03 a	45.85 a	45.43 a	45.59 a	NS
C:N ratio	47.88 a	49.02 a	50.26 a	50.40 a	NS	33.20 a	37.55 a	36.92 a	36.33 a	NS

The means followed by same letters across the rows do not differ significantly at $P \leq 0.05$.

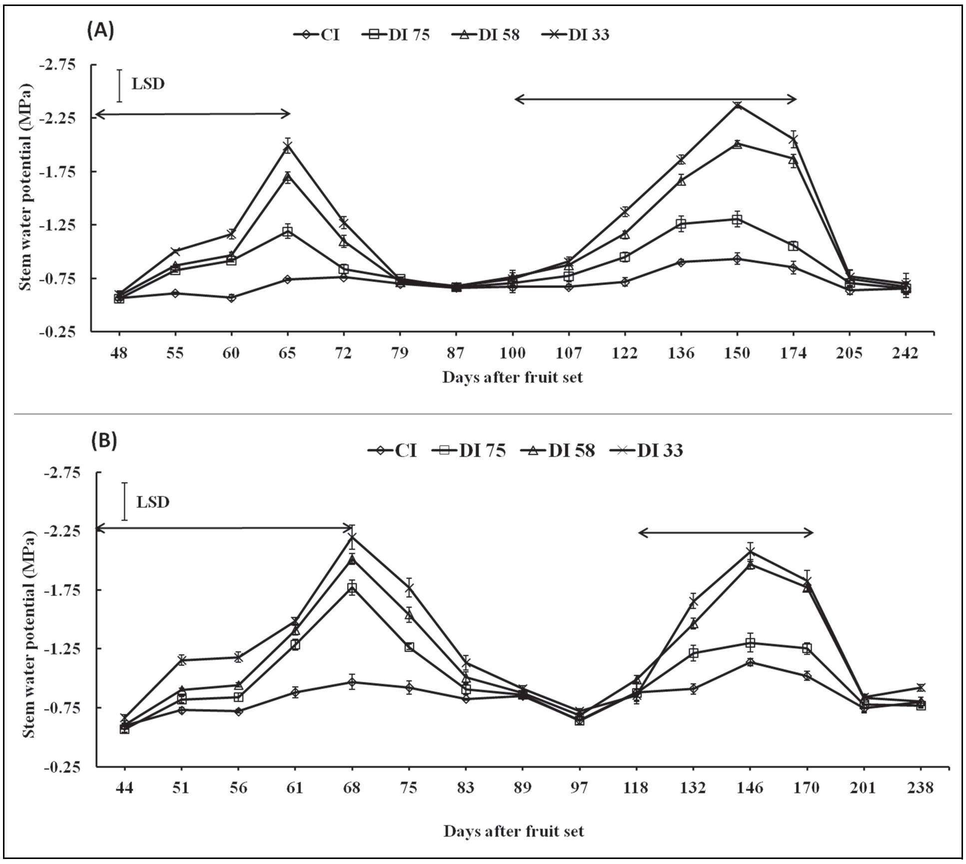

Fig. 1. Effect of DI at pit hardening and postharvest stages on stem water potential in 'Spring Bright' (A) and in 'Summer Bright' (B). The double arrow lines show the periods of deficit irrigation. Vertical bars represent S.E. and are not visible when the values are smaller than the symbol.

Sugars are the major component of SSC along with organic acids, amino acids and soluble pectins. The improvement in SSC with DI 58 and DI 33 may be due to increase in accumulation of total sugars 100 g^{-1} fruit and sucrose in fruits of both cultivars (Table 2). DI (50 %) has been reported to increase SSC at harvest in peach (Pliakoni and Nanos 2010). DI 58 and DI 33 also improved SSC/acid ratio (Table 2) which is an indicator of improvement of consumer acceptance in peach (Crisosto and Crisosto 2005). The improvement in SSC/acid ratio indicates an improvement in sweetness and other organoleptic parameters which lead to better sensory quality and consumer acceptance in peach (Lopez et al. 2011).

The increase in total sugar 100 g^{-1} fruit and total sugar $fruit^{-1}$ with severe deficit irrigation (DI 58 and DI 53) in 'Summer Bright' may be ascribed to increased sucrose and sorbitol levels (Table 2). Severe deficit irrigation had no significant effect on total sugar 100 g^{-1} fruit but, decreased total sugar $fruit^{-1}$ in 'Spring Bright' (Table 2). This suggests concentration of sugars following reduction in fruit size as discussed by Stefanelli et al. (2010). This may also be due to decrease in glucose and fructose in DI 33 (Table 2). Significantly higher fruit respiration rates (data not presented) were recorded in 'Spring Bright' nectarine at harvest with severe deficit irrigation which might have led to reduction in glucose and fructose in this cultivar. The sucrose arrives in fruit via phloem where some is hydrolysed by invertase enzyme into glucose and fructose. The increase in sucrose levels with deficit irrigation may be due to decrease in the hydrolysis of sucrose which is suggested by reduction in glucose and fructose (Table 2). Sucrose is also synthesised by sucrose synthase from glucose and fructose. The reduction in glucose and fructose levels with DI in 'Spring Bright' may be due to their conversion into sucrose as reported by Jacob et al. (2006).

DI has been reported to increase total phenolic compounds in nectarines (Pliakoni et al. 2010). Buendía et al. (2008) have reported that the DI strategies had a greater influence on the biochemical properties of peel tissue rather than the flesh in peach. They suggested that water stress activated phenolic compounds biosynthesis associated with an increase in the activity of L-phenylalanine ammonia lyase (PAL) in the peel of fruit following DI. Decrease in vegetative growth (Table 4) might have increased light interception leading to the observed increases in phenolic compounds and anthocyanins. Contrary to the findings of Buendía et al. (2008), DI (DI 58 and DI 33) increased levels of ascorbic acid and carotenoids in both cultivars. DI has been reported to improve ascorbic acid in jujube (Cui et al. 2008). The level of carotenoids has been reported to be approximately 60 per cent lower in grapes from irrigated vines in comparison to non-irrigated vines in soils with low water retention capacity (Oliveira et al. 2003).

Application of DI significantly reduced the vegetative growth as the pit hardening stage, coincides with the slow fruit growth and active vegetative growth phase in peach. The significant reduction in Ψ_{stem} during pit hardening in both cultivars (Fig. 1 A, B) due to reduction in irrigation levels and low water storage capacity of the gravel in sandy or loamy matrix soil might have resulted in reduction in vegetative growth. In high density orchards, one of the major effects of DI is reduction of vegetative growth (GOODWIN and BOLAND 2002). The increase in flower density with DI 33 in either cultivar may be due to a decrease in internodal length of fruiting laterals (Table 4) following water stress during pit hardening (Fig. 1 A, B). Severe postharvest water stress as observed with DI 58 and DI 33 in either cultivar during the bud development period (Fig. 1 A, B) has been reported to increase the occurrence of double fruits in nectarines (NAOR et al. 2005) and peach (JOHNSON and PHENE 2008). However, the maximum incidence of double fruits in 'Spring Bright' (14 %) and 'Summer Bright' (5 %) is relatively low in comparison to some other reports (NAOR et al. 2005). These doubles can be easily removed during regular thinning operations.

DI improved fruit colour, SSC, SSC/acid ratio, phenolics, total sugar, antioxidant capacity, ascorbic acid, anthocyanin and carotenoids in nectarines. It decreased water sprout length and increased flower density and double fruits in the following season. In conclusion, DI (DI 58 and DI 33) can be successfully applied in irrigating nectarines without having much effect on fruit size and improved levels of nutraceuticals in the fruit.

Acknowledgements

We are grateful to Professor Hossein Behboudian for suggestions to improve the manuscript. Anirudh Thakur acknowledges Punjab Agricultural University, Ludhiana, India for granting leave and financial support. We thank Mr. John Cassoti, Casuarina Valley Orchard, Karragullen, Perth Hills and Mr. David Gibb, Waterwise Coordinator, Perth Region NRM for supporting the research. The technical help rendered by Ms. Susan M. Petersen is also duly acknowledged.

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Received 08/30/2012 / Accepted 11/12/2012

Addresses of authors: Anirudh Thakur (present address), Department of Fruit Science, Punjab Agricultural University, Ludhiana 141 004, India, e-mail: anirudhthakur@pau.edu, Zora Singh (corresponding author), Curtin Horticulture Research Laboratory, Department of Environment and Agriculture, School of Science and International Institute of Agri-Food Security (IIAFS), Curtin University, GPO Box U1987, Perth, 6845, WA, Australia, e-mail (corresponding author): z.singh@curtin.edu.au.