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Fruit Quality Attributes and their Interrelationships of 'Braeburn' Apple in Response to Deficit Irrigation and to Crop Load

Wechselwirkung von Mangelbewässerung und Fruchtbehang auf die Qualitätseigenschaften von Äpfeln der Sorte 'Braeburn'

Bussakorn S. Mpelasoka[1)], M. H. Behboudian[1)] and S. Ganesh[2)]
([1)]Institute of Natural Resources (INR 433), College of Sciences, Massey University, Palmerston North, New Zealand and [2)]Institute of Information Sciences and Technology, College of Sciences, Massey University, Palmerston North, New Zealand)

Summary

Information on the interaction between irrigation and crop load on fruit quality other than fruit size is lacking for apple. We investigated this interaction on various fruit quality attributes individually and collectively for 'Braeburn' apple during the growing season of 1998/99. Irrigation treatments were commercially irrigated control and deficit irrigation applied throughout the season. Crop load treatments were commercial crop load (CCL) having six fruit per cm^2 of trunk cross-sectional area and light crop load (LCL) having four. There was no interaction between irrigation and crop load on individual fruit quality attributes or on collective fruit quality when various quality attributes were considered together. This was true both at harvest and after storage. Deficit irrigation improved fruit quality at harvest in terms of increased firmness, total soluble solids (TSS), total sugar concentration (TSC), and dry matter concentration. There was an irrigation effect on collective fruit quality both at harvest and after storage. Reduced crop load improved fruit quality at harvest in terms of increased firmness, TSS, TSC, and density. The LCL fruit had a higher ($P < 0.1$) weight loss during storage and a higher ($P < 0.1$) incidence of bitter pit after storage than did the CCL fruit. There was a crop load effect at harvest but not after storage on collective fruit quality. A tendency of increased weight loss and incidence of bitter pit during storage in light crop load may limit its application, especially if fruit are destined for long storage.

Zusammenfassung

Abgesehen von der Fruchtgröße fehlen Informationen zu Wechselwirkungen zwischen Bewässerung und Fruchtbehang auf die Qualitätseigenschaften von Äpfeln. In einem Versuch in Neuseeland mit der Sorte 'Braeburn' wurde daher der Einfluß dieser Wechselwirkung auf einzelne Fruchtqualitätsmerkmale sowie die Gesamtqualität untersucht. Eine Mangelbewässerung während der gesamten Vegetationsperiode wurde mit einer praxisüblichen Bewässerung verglichen. Der Fruchtbehang war entweder praxisüblich (6 Früchte pro cm^2 Stammquerschnittsfläche – CCL) oder leicht (4 Früchte pro cm^2 Stammquerschnittsfläche – LCL). Sowohl bei der Ernte als auch nach viermonatiger Lagerung wurde keine Wechselwirkung zwischen Bewässerung und Fruchtbehang auf einzelne Qualitätsmerkmale der Früchte noch auf die Gesamtqualität festgestellt. Mangelbewässerung führte zu einer besseren Fruchtqualität zum Erntezeitpunkt durch eine Erhöhung der Fruchtfestigkeit und höhere Gehalte an löslichen Kohlenhydraten, Gesamtzucker und Trockenmasse. Mangelbewässerung beeinflußte die Gesamtfruchtqualität sowohl zur Ernte als auch nach der Lagerung. Verringerung des Fruchtbehanges verbesserte die Fruchtqualität zum Erntetermin durch erhöhte Fruchtfestigkeit und -dichte und höhere Gehalte an löslichen Kohlenhydraten und Gesamtzucker. Allerdings hatten Früchte von leichter tragenden Bäumen nach der Lagerung einen höheren ($P < 0.1$) Gewichtsverlust und einen höheren ($P < 0.1$) Anteil an Früchten mit Stippigkeit im Vergleich zum praxisüblichen Fruchtbehang. Der Fruchtbehang beeinflußte die Gesamtqualität zur Ernte aber nicht nach der Lagerung. Eine Verringerung des Fruchtbehangs ist angesichts der Tendenz zu höherem Gewichtsverlust und erhöhtem Anteil an Stippigkeit nicht zu empfehlen.

Introduction

Deficit irrigation (DI), if applied judiciously, saves water, decreases vegetative growth and therefore pruning costs, reduces leaching of biocides into ground water, and may improve fruit quality (BEHBOUDIAN and MILLS 1997). One possible disadvantage of DI is a reduction in fruit size especially if severe water deficit is allowed to develop during rapid fruit growth. This effect of DI could be counteracted by reducing crop load (NAOR et al. 1997). Information on interaction of irrigation and crop load on fruit quality other than fruit size is lacking for apple. This information is needed to determine whether reduced crop load can be integrated with DI in order to maximise the beneficial effects of DI in apple production. However, there is some information on the effects of crop load and DI, applied separately, on apple fruit quality. Reduced crop load increased firmness (ELGAR et al. 1999; JOHNSON 1994) but also increased the incidence of physiological disorders such as 'Brae-

burn' browning disorder (ELGAR et al. 1999; TOUGH et al. 1998) and bitter pit (TOUGH et al. 1998; VOLZ et al. 1993; FERGUSON and WATKINS 1992). Deficit irrigation applied either early or late in the growing season improved 'Braeburn' quality in terms of increased firmness, TSS, and sugar concentration both at harvest and after storage (MPELASOKA et al. 2000). Fruit weight loss, one of the serious causes of fruit deterioration during storage, decreased in DI apple fruit (KILILI et al. 1996; MPELASOKA et al. 2000). There are no published data for crop load effect on this aspect. Little is also known about effects of crop load or DI on incidence of water core, a physiological disorder that has become significant in 'Braeburn' since the 1997/98 growing season (CLARK and RICHARDSON 1999).

The aim of this study was to investigate the interaction of irrigation and crop load on various individual fruit quality attributes. The interaction on collective behavior of various quality attributes was also explored.

Materials and Methods

The study was carried out during the 1998–99 growing season at Massey University Fruit Crop Unit, Palmerston North (lat. 40° 2' S, long. 175° 4' E), New Zealand. The area has a humid temperate climate with an average annual rainfall of 960 mm. The orchard soil is a Manawatu fine sandy loam. The structure and water retention properties of this soil can be found in CLOTHIER et al. (1977). Ten-year-old 'Braeburn' apple trees (5 m between rows, 3 m within rows) on MM 793 rootstock were divided into four blocks of eight trees. Each block had two plots of four trees and each plot was divided into two sub plots of two trees. There were at least two guard trees in between each plot. Commercially irrigated control (CI) and deficit irrigation (DI) treatments were randomly applied to each plot within each block. The CI trees were drip irrigated to maintain soil moisture at or close to field capacity. Soil in the DI plots was covered with clear polythene from 12 days after full bloom (DAFB) to exclude rain. Full bloom occurred on October 20, 1998. The DI trees were irrigated twice late in the growing season when volumetric soil water content (θ) became lower than 0.15 $m^3 m^{-3}$. Commercial crop load (CCL) and light crop load (LCL) treatments were randomly applied to each sub plot within each plot. Trees were hand-thinned at 38 DAFB to leave either 6 or 4 fruit per cm^2 of trunk cross-sectional area, representing CCL and LCL, respectively.

Volumetric soil water content (θ) was measured at a depth of 400 mm using time domain reflectometry (TDR) equipment (model 1502 C; Tektronix Inc., Redmond, Ore., USA). Two pairs of TDR probes were installed around the middle of each sub plot, one on each side of the row, at a distance of 500 mm from the tree trunk. Midday leaf water potential (Ψ_l) was measured between 1200 and 1300 hr on two fully expanded sunlit leaves per sub plot using a Scholander pressure chamber.

After harvest, fruit of similar sizes were picked from the outer portion around the middle height of the canopy for quality assessments. The assessments at harvest were performed on 16 fruit per replicate. The assessments included measurements of density, skin colour, soluble sugars, internal ethylene concentration (IEC), flesh firmness, starch pattern index (SPI), total soluble solids (TSS), titratable acidity (TA), dry matter concentration (DMC), and incidence of physiological disorders. Assessments after storage were made after seven-day shelf-life at 20 °C following 17 weeks at 0 °C on eight fruit per replicate. The assessments included skin colour, IEC, flesh firmness, SPI, TSS, TA, and incidence of physiological disorders. Fruit weight loss was determined from 24 fruit per replicate. Individual fruit weight was monitored during 17 weeks at 0 °C and fruit weight loss was calculated as percent reduction from initial weight.

Fruit density was determined as fruit mass per unit volume. Fruit volume was calculated from fruit diameter assuming that fruit were spherical. Fruit weight was determined using an analytical balance (Mettler PM4800, Greifensee, Switzerland). Fruit diameter was determined using a Cranston Fruit Gauge (Cranston Machinery Co., Oregon, USA). Fruit skin colour was determined as hue angle (H^o) on two positions of each fruit, red-blushed and background green colour, using a portable tristimulus chromameter (CR-200, Minolta, Osaka, Japan). Fruit IEC was determined from gas samples drawn from the core cavity of each fruit while submerged under water. The 1-ml gas samples were analysed using a gas chromatograph (Shimadzu GC-4B PTF; Seisakusho Ltd, Kyoto, Japan). Flesh firmness was determined on two positions, red blushed and unblushed portion areas, at the equator of each fruit using a press-mounted Effegi penetrometer (model FT 327, Alfonsine, Italy) with an 11.1-mm head (HARKER et al. 1996). Fruit SPI was determined by dipping cross-sectional fruit halves for 30 sec in an iodide solution (8.8 g potassium iodide and 2.2 g iodine l^{-1}). Hydrolysis of starch was rated on the scale of 0 (100 % starch) to 6 (no starch). Fruit TSS and TA were determined from fruit juice produced by a domestic juicer. Fruit TSS was determined using a hand held refractometer with automatic temperature compensation (ATC-1 Atago, Tokyo, Japan). Fruit TA was determined by titration of fruit juice against 0.1 N sodium hydroxide, using an automatic titrator (Mettler DL21, Greifensee, Switzerland) equipped with a Mettler DG111 pH electrode, to an endpoint pH of 7.1 (malic acid). Concentrations of sucrose, glucose, fructose, and sorbitol, the four major soluble sugars in the apple fruit (CHAN et al. 1972), were measured using a Waters high-performance liquid chromatography (HPLC) system (Waters, Milford, MA, USA) as detailed by MILLS et al. (1994). Total sugars concentration (TSC) was calculated as the sum of these sugars. Water core incidence was rated as none, acceptable, slight, or severe according to the water core chart of the New Zealand Apple and Pear Marketing Board (ENZA).

Results were analysed using the Statistical Analysis System (SAS) software Version 6.2 (SAS Institute, Cary, NC, USA). Data of individual attributes were subjected to analysis of variance (ANOVA) as a split plot design with irrigation treatment as main plot and crop load as sub plot. Comparisons of means were done using t-tests. When there was no interaction between irrigation and crop load, only results of the main effect, 'irrigation' and 'crop load' are presented. When interactions between irrigation and crop load were observed, results

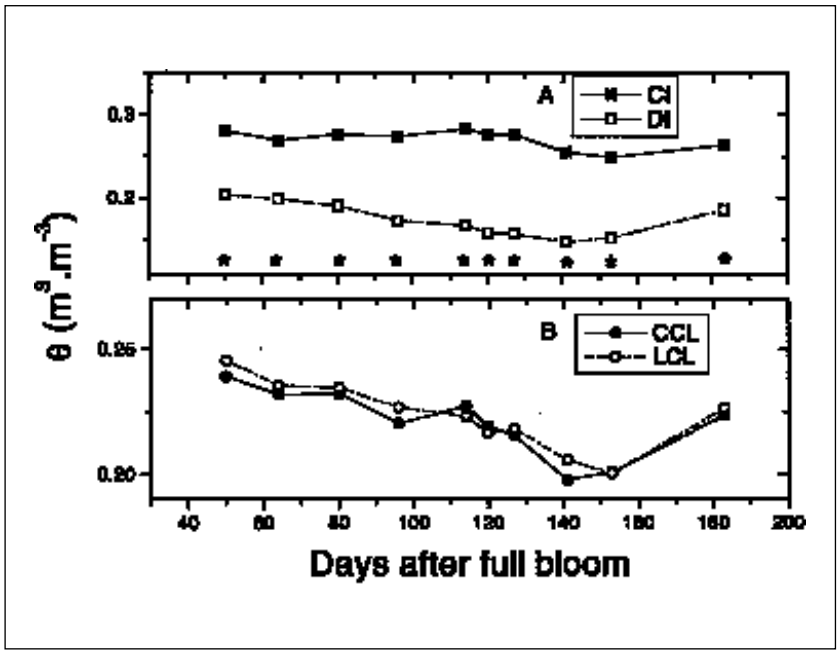


Fig. 1. Volumetric soil water content (θ) during the growing season for 'Braeburn' apple under different irrigation (A) and crop load (B) treatments. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load. Asterisks represent significant differences ($P < 0.05$).
Bodenwassergehalt (θ) *während der Wachstumsphase der Apfelsorte 'Braeburn' für verschiedene Bewässerungsbehandlungen (A) und Fruchtbehänge (B). Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang. Mit einem Stern versehene Werte sind von signifikantem Unterschied (P < 0.05).*

for irrigation treatments were also analysed and compared separately for each crop load and those for crop load treatments were made separately for each irrigation treatment.

A multivariate analysis of variance (MANOVA) was carried out on fruit quality at harvest and after storage using data from individual trees. Canonical variate analysis (CVA) was carried out within the context of MANOVA to explore the differences within each group. Fruit quality attributes included in multivariate analysis were skin colour, density, DMC, firmness, TA, and TSS at harvest; and skin colour, firmness, TA, TSS, and incidence of physiological disorders after storage.

Results

There was no interaction between irrigation and crop load on θ. Values of θ in DI plots were lower than those in CI plots throughout the season starting from the first measurement on 50 DAFB (Fig. 1A). There was no difference in θ between the two crop load treatments (Fig. 1B). Midday Ψ_l in DI became lower than in CI from 70 DAFB (Fig. 2A) and tended to be lower in CCL than in LCL but the differences were significant only in five occasions (Fig. 2B). Interactions between irrigation and crop load on Ψ_l were observed during mid and late season when Ψ_l values were similar in CCL and LCL under CI but were lower in CCL under DI (data not shown). Values of Ψ_l for DI were generally lower than those for CI for both crop loads except at 101 DAFB when DI and CI had similar Ψ_l for the LCL treatment (data not shown).

There was interaction between irrigation and crop load on yield and mean fruit weight. Fruit yield per tree was the same in CI and DI for both crop loads (Table 1). Mean fruit weight was lower in DI than in CI for CCL but DI and CI had similar values for LCL (Table 1). Fruit yield per tree was lower in LCL than in CCL under both irrigation treatments (Table 1). Mean fruit weight was higher in LCL than in CCL under DI but was the same under CI (Table 1).

Table 1. Interactions of irrigation and crop load treatments on yield and on mean fruit weight (MFW) for 'Braeburn' apple. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load. Comparisons of irrigation treatment were done at each crop load treatment and comparisons of crop load treatments were done under each irrigation treatment. For each treatment pair, values along the column followed by different letters are significantly different at $P < 0.05$.
Wechselwirkungen von Bewässerung und Fruchtbehang auf Ertrag und Gewichtsdurchschnitt (MFW) der Apfelsorte 'Braeburn'. Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang. Vergleiche von Bewässerungsbehandlungen wurden für jeden Fruchtbehang und von den verschiedenen Fruchtbehängen für jede Bewässerungsbehandlung gezogen. Für jedes Behandlungspaar sind die Werte, die mit verschiedenen Buchstaben versehen sind von signifikantem Unterschied (P < 0.05).

Treatment		Yield (kg/tree)	MFW (g)
		Irrigation treatments	
At CCL	CI	72.1 a	206.1 a
	DI	60.6 a	182.8 b
At LCL	CI	50.3 a	222.6 a
	DI	49.1 a	217.0 a
		Crop load treatments	
Under CI	CCL	72.1 a	206.1 a
	LCL	50.3 b	222.6 a
Under DI	CCL	60.6 a	182.8 b
	LCL	49.1 b	217.0 a

There was no interaction between irrigation and crop load treatments on any individual quality attribute either at harvest or after storage. At harvest, DI fruit were firmer and had higher TSC, TSS, and DMC than CI fruit (Table 2). Fruit skin colour (Table 2), TA, density, IEC, and SPI were similar for CI and DI (data not

Table 2. Flesh firmness, total sugar concentration (TSC), total soluble solids (TSS), dry matter concentration (DMC), density, and background skin colour (H, °) at harvest for 'Braeburn' apple. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load. For each main effect, 'irrigation' and 'crop load', values across the row followed by different letters are significantly different at $P < 0.05$.
Fruchtfleischfestigkeit, Gesamtzuckerkonzentration (TSC), lösliche Kohlenhydrate (TSS), Trockenmasse (DMC), und Hintergrund Hautfarbe (H, °) der Apfelsorte 'Braeburn' während der Erntezeit. Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang. Für jede Auswirkung von Bewässerung und Fruchtbehang sind die Werte, die mit verschiedenen Buchstaben versehen sind von signifikantem Unterschied (P < 0.05).

Fruit attributes	Irrigation treatments		Crop load treatments	
	CI	DI	CCL	LCL
Firmness (N)	90.2 b	92.8 a	90.6 b	92.3 a
TSC (mg g^{-1} FW)	84.9 b	89.2 a	85.2 b	88.9 a
TSS (%)	11.8 b	12.3 a	11.9 b	12.2 a
DMC (mg g^{-1})	118.3 b	121.1 a	118.7 a	120.7 a
Density (g cm^{-3})	0.88 a	0.88 a	0.87 b	0.89 a
Unblush (H, °)	97.9 a	98.8 a	101.2 a	95.5 b

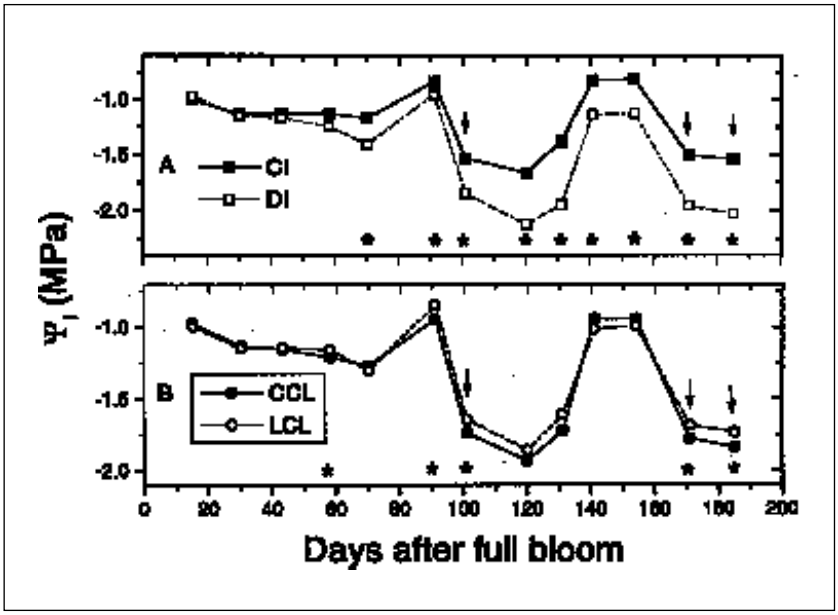


Fig. 2. Midday leaf water potential (Ψ_l) for 'Braeburn' apple under different irrigation (A) and crop load (B) treatments. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load. Asterisks represent significant differences ($P < 0.05$). Arrows indicate existence of interactions between irrigation and crop load.
Mittägiges Blattwasserpotential (Ψ_l) der Apfelsorte 'Braeburn' für verschiedene Bewässerungsbehandlungen (A) und Fruchtbehänge (B). Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang. Mit einem Stern versehene Werte sind von signifikantem Unterschied (P < 0.05). Pfeile zeigen die Wechselwirkungen zwischen Bewässerungsbehandlung und Fruchtbehang an.

shown). Flesh firmness, TSC, TSS, and density at harvest were higher in LCL than in CCL but crop load did not affect DMC (Table 2), IEC, TA, and SPI (data not shown). Hue angle on the red blush skin portion was similar for CCL and LCL fruit (data not shown) but LCL fruit had lower hue angle on the green background skin portion than CCL fruit (Table 2). Water core was observed only in two fruit, one from a CCL tree under CI and the other from a LCL tree under DI. No incidence of other physiological disorders was observed at harvest.

Cumulative weight loss during 17 weeks at 0°C was higher ($P < 0.1$) in CI than in DI but only on one occasion (Fig. 3A). The LCL fruit had higher weight loss than CCL fruit ($P < 0.1$) throughout 17 weeks at 0°C (Fig. 3B).

After storage, the SPI value reached the maximum (SPI = 6) for all fruit. Flesh firmness, TA, and skin colour were similar for DI and CI fruit (data not shown) but DI fruit had higher TSS and IEC than CI fruit. The values of TSS (%, $LSD_{0.05}$ = 0.4) were 13.4 and 14.1 and of IEC (µl l^{-1}, $LSD_{0.05}$ = 109.9) were 412.0 and 526.7 for CI and DI fruit, respectively. No incidence of water core was observed after storage. Incidence of bitter pit was higher in LCL than in CCL ($P < 0.1$). Percentage of fruit with bitter pit ($LSD_{0.05}$ = 5.84) was 6.25 and 1.56 for LCL and CCL, respectively. The LCL and CCL fruit were similar for all other quality attributes measured after storage (data not shown).

In univariate analysis a single response of each attribute is considered at one time whereas in multivariate analysis response of interrelationships among many quality attributes is considered (MANLY 1994). We attempted to explore the interrelationships among various quality attributes in response to irrigation and crop load. There was no interaction between irrigation and crop load on fruit quality either at harvest or after storage when various quality attributes were considered collectively (collective fruit quality). There were significant effects (Wilks' Lambda statistic: $P < 0.05$) of irrigation and crop load on collective fruit quality at harvest.

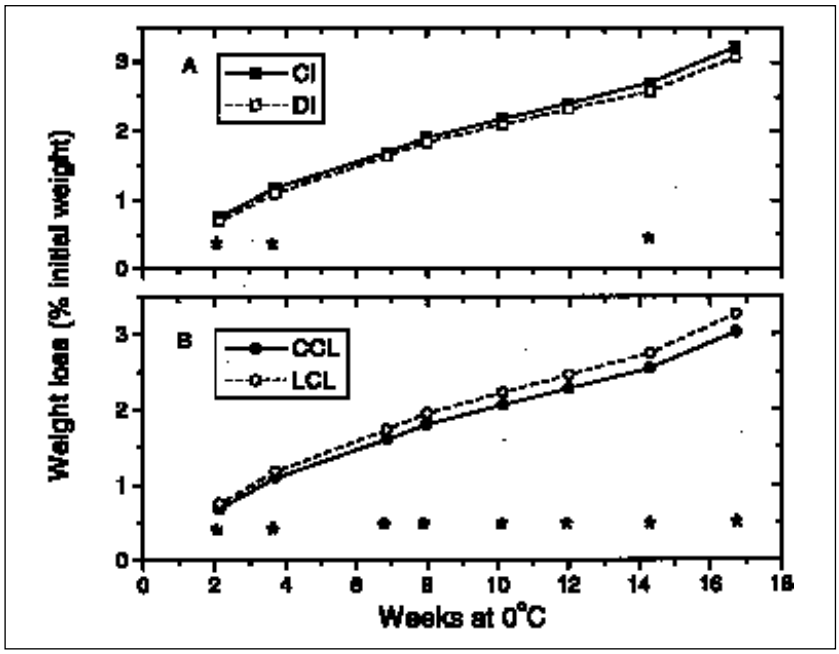


Fig. 3. Cumulative weight loss at 0 °C for 'Braeburn' apple under different irrigation (A) and crop load (B) treatments. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load. Asterisks represent significant differences ($P < 0.1$).
Anwachsender Gewichtsverlust bei 0 °C für verschiedene Bewässerungsbehandlungen (A) und Fruchtbehänge (B). Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang. Mit einem Stern versehene Werte sind von signifikantem Unterschied ($P < 0.1$).

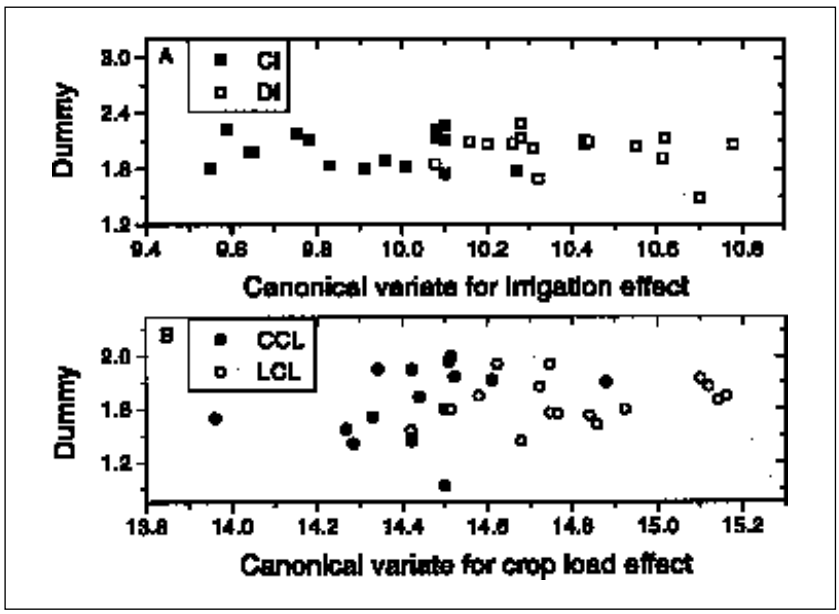


Fig. 4. Plots of canonical scores for irrigation effect (A) and for crop load effect (B) on collective fruit quality at harvest for 'Braeburn' apple under different irrigation and crop load treatments. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation. Crop load treatments were: CCL = commercial crop load and LCL = light crop load.
Diagramme der Werte der Wirkungen von Bewässerung (A) und Fruchtbehängen (B) zur Erntezeit der Apfelsorte 'Braeburn' für verschiedene Bewässerungsbehandlungen und Fruchtbehänge. Für Bewässerung und Fruchtbehänge gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung; CL = praxis-üblicher Fruchtbehang und LCL = leichter Fruchtbehang.

Canonical variate analysis determines linear functions of several attributes that maximally separate the groups of apple fruit while keeping the variation within groups as small as possible. These linear functions are called canonical variates (MANLY 1994). Because there were only two levels of irrigation treatments and two levels of crop load treatments, differences between CI and DI or between CCL and LCL could be accounted for by only one canonical variate. The values of the canonical variates for each individual are called canonical scores (MANLY 1994). Plots of canonical scores associated with canonical variates showed grouping along the sole canonical variate for irrigation effect (Fig. 4A) as well as for crop load effect (Fig. 4B). After storage, there was still an irrigation effect (Wilks' Lambda statistic: $P < 0.05$) on collective fruit quality but there was no difference between CCL and LCL on collective fruit quality. The plot of canonical scores associated with canonical variates again showed grouping along the sole canonical variate for irrigation effect (Fig. 5).

Discussion

An effect of crop load on Ψ_l tended to be dependent on soil water availability with decreased Ψ_l in CCL under DI but crop load had no effect on Ψ_l under well-watered conditions. This is consistent with other findings in peach (BERMAN and DEJONG 1996) and in 'Golden Delicious' apple (NAOR et al. 1997).

Since DI fruit had higher DMC than CI fruit, the lower fruit TSC and TSS in CI could be due to dilution effect. The firmer fruit in DI than in CI could be be-

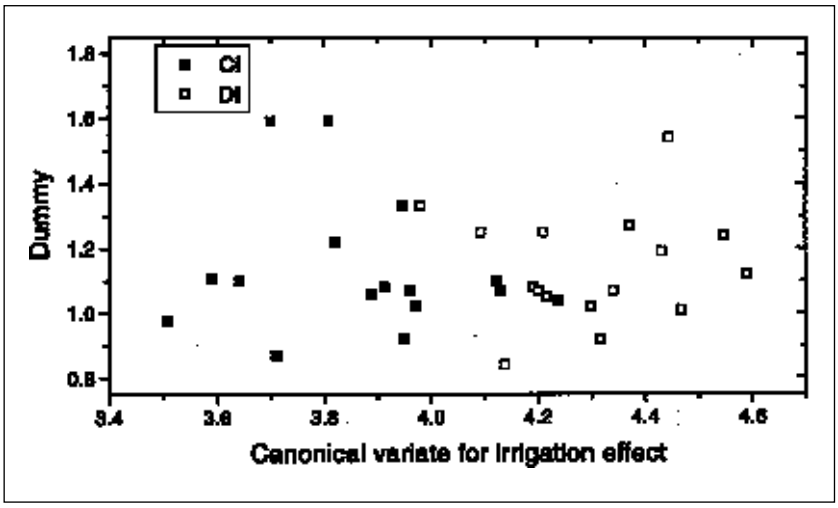


Fig. 5. Plot of canonical scores for irrigation effect on collective fruit quality after storage for 'Braeburn' apple under different irrigation treatments. Irrigation treatments were: CI = commercially irrigated control and DI = deficit irrigation.
Diagramme der Werte der Wirkung der Bewässerung auf die Gesamtfruchtqualität nach der Lagerung der Apfelsorte 'Braeburn' für verschiedene Bewässerungsbehandlungen. Für Bewässerung gilt: CI = praxis-übliche Bewässerung und DI = Mangelbewässerung.

cause of decreased cellular hydration in the former. Increased firmness with light crop load in 'Cox's Orange Pippin' apple was also observed by JOHNSON (1994) and in 'Braeburn' apple by TOUGH et al. (1998). Research findings on crop load effects on fruit TSS have been inconclusive. TOUGH et al. (1998) observed higher TSS in 'Braeburn' apple from light cropping trees whereas OPARA and TADESSE (2000) found no consistent effect of crop load on TSS for 'Pacific Rose' apple. Sugars are the major component of soluble solids (WILLS et al. 1997). Higher TSS in LCL than in CCL in this research is in agreement with higher total sugar concentration in LCL. Inconsistent findings in crop load effects on fruit TSS from different experiments could be due to differences in times of thinning, differences in cultivars, and differences in levels of crop load.

The LCL fruit had more yellow background skin colour because they had lower hue angle on the green background skin portion than CCL fruit (Table 2). JOHNSON (1995) observed more yellow background skin colour and an earlier increase in IEC in 'Cox's Orange Pippin' apple from thinned trees. He therefore suggested that fruit from thinned trees were more advanced in maturity than fruit from unthinned trees. Background skin colour is often used as a maturity index because, as fruit mature, background skin colour changes from green to yellow through chlorophyll degradation and unmasking of carotenoids (GORSKI and CREASY 1977). In this research, however, LCL and CCL fruit had similar maturity based on IEC and SPI. Fruit skin colour is determined by several factors such as light interception, temperature, and fruit nutrients especially nitrogen (DAUGAARD and GRAUSLUND 1999). High nitrogen level enhances chlorophyll retention hence retarding yellow background colour development (MAGNESS et al. 1940). Vegetative growth is generally more vigorous with lighter crop load which may lead to less nitrogen availability to the fruit. Shoot growth was greater in LCL than in CCL in this experiment (data not shown). However, fruit nitrogen was not measured here for a definite conclusion.

Irrigation treatments appeared to have little effect on weight loss in this experiment although fruit weight loss during storage was reported to be lower in DI than in CI fruit in other studies (KILILI et al. 1996; MPELASOKA et al. 2000). Differences in the degree of water deficit could have contributed to inconsistencies in findings from different studies. A 6% loss in fruit weight after harvest results in shrivel and loss of marketability (HATFIELD and KNEE 1988). A tendency of increased fruit weight loss in LCL may be a disadvantage especially for fruit destined for long storage.

In canonical variate analysis, characteristic vector of each attribute indicates how much each attribute contributes to the difference along the canonical variate (MANLY 1994). The difference in collective fruit quality at harvest between CCL and LCL was mainly due to the difference in fruit density because the characteristic vector of density was by far the highest compared to those of other attributes. The characteristic vector was 13.0 for density and the second highest characteristic vector was –2.6 for TA. Density was not measured after storage, hence, was not included in collective fruit quality after storage. This could be the reason for similar collective fruit quality after storage between CCL and LCL.

Deficit irrigation improved fruit quality at harvest in terms of increased firmness, TSS, TSC, and DMC. Reducing crop load from the commercial level by one third improved fruit size under DI but not under commercial irrigation. Reduced crop load also increased firmness, TSS, TSC, and density at harvest. However, a tendency of increased weight loss during storage and higher incidence of bitter pit after storage in light crop load may limit its application to increase fruit size under DI especially for fruit destined for long storage. Further studies should be carried out to confirm these results.

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Anschrift der Verfasser: Bussakorn S. Mpelasoka and M. H. Behboudian (corresponding author), Institute of Natural Resources (INR 433), College of Sciences, Massey University, Palmerston North, New Zealand, e-mail: m.behboudian@ messey.ac.nt and S. Ganesh, Institute of Information Science, College of Sciences, Massey University, Palmerston North, New Zealand.