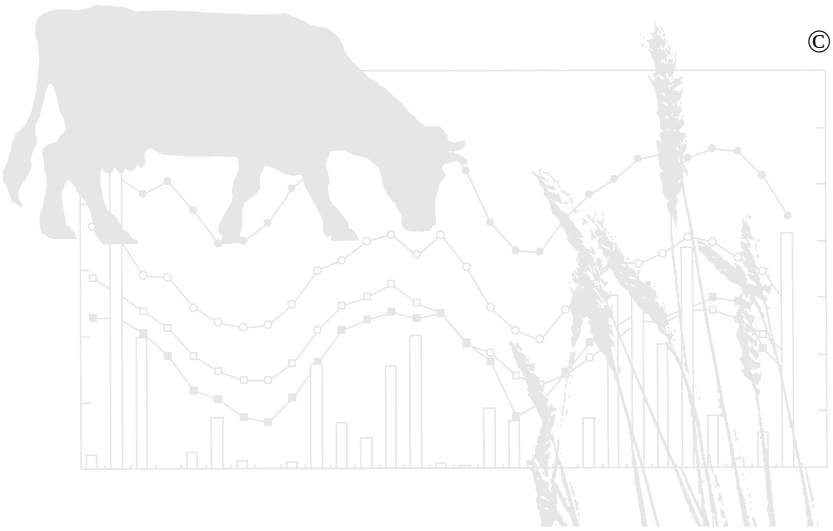
CSIRO PUBLISHING

Australian Journal of Experimental Agriculture

Volume 37, 1997



… a journal publishing papers (in the soil, plant and animal sciences) at the cutting edge of applied agricultural research

www.publish.csiro.au/journals/ajea

All enquiries and manuscripts should be directed to
Australian Journal of Experimental Agriculture
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood
Vic. 3066
Australia

Telephone: 61 3 9662 7614
Facsimile: 61 3 9662 7611
Email: chris.anderson@publish.csiro.au
lalina.muir@publish.csiro.au

Published by
CSIRO PUBLISHING
in co-operation with the
Standing Committee on Agriculture and Resource Management (SCARM)

Diagnostic leaf nutrient standards for low-chill peaches in subtropical Australia

D. O. Huett[A], *A. P. George*[B], *J. M. Slack*[A] *and S. C. Morris*[C]

[A] NSW Agriculture, Tropical Fruit Research Station, PO Box 72, Alstonville, NSW 2477, Australia.
[B] Queensland Department of Primary Industries, Maroochy Horticultural Research Station, PO Box 5083, Sunshine Coast Mail Centre, Nambour, Qld 4560, Australia.
[C] NSW Agriculture, Agricultural Research Institute, Wollongbar, NSW 2477, Australia.

Summary. A leaf nutrient survey was conducted of the low-chill peach cultivars, Flordaprince (October maturing) and Flordagold (mid November–early December maturing) at 3 commercial sites in both northern New South Wales and southern Queensland. Recently mature leaves from the middle third of a current season's fruiting lateral (spring flush) were sampled at stone hardening and 2-weeks postharvest and of a non-fruiting lateral at maturity of the summer flush (after summer pruning) during the 1992–93 and 1993–94 seasons. At an additional site in New South Wales (Alstonville), leaf nutrient concentrations were also determined on cv. Flordagem (early November maturing) at 2-week intervals during both seasons. Soil (0–30 cm) chemical determinations were conducted at all sites at 2-weeks postharvest.

Seasonal trends in leaf nutrient composition were associated with a leaf age–maturity effect. As flush leaves matured during spring, and as mature leaves aged after hardening of the summer flush, nitrogen (N) concentration declined and calcium (Ca) concentration increased. Nitrogen and Ca concentrations increased when young leaves produced from the summer flush were sampled. Time of sampling produced the most consistently significant ($P<0.05$) main effects on leaf nutrient concentration. The 2-week postharvest period was selected as a convenient time to sample—when leaves were of a consistent age and maturity, and the effect of crop load on tree nutrient reserves was still present.

Paclobutrazol, which reduces vegetative growth in stonefruit, was applied to all Queensland sites and, as a consequence, mid lateral leaves contained higher ($P<0.05$) Ca, magnesium (Mg) and chloride (Cl) and lower ($P<0.05$) N and phosphorus (P) concentrations than leaves from New South Wales sites. State effects can therefore be interpreted as paclobutrazol effects. Cultivar effects ($P<0.05$) occurred for many leaf nutrients, however, at the 2-week postharvest sampling, concentrations were sufficiently similar to combine as a narrow adequate concentration range for both cultivars. The diagnostic adequate leaf nutrient concentrations were within the range developed for high-chill peaches (Leece *et al.* 1971) with the exception of lower Ca, lower Mg for New South Wales (both cultivars), lower iron for Flordaprince (both states), higher P for Flordaprince in New South Wales and higher manganese values for Queensland (both cultivars).

Regression analyses were conducted between leaf and fruit nutrient concentrations and soil chemical properties. The only consistent result demonstrated that as the soil Ca:Mg ratio increased, leaf Mg concentration decreased exponentially ($P<0.001$), indicating that the practice of heavy annual agricultural limestone or gypsum applications in the absence of Mg fertiliser, which had been adopted by several growers in the survey, is associated with lower leaf Mg concentrations.

Introduction

Leaf nutrient standards for stonefruit in Australia were developed from surveys of (later maturing) high-chill cultivars in commercial orchards around northern Victoria and southern New South Wales (Leece *et al.* 1971; Leece 1972; Taylor and Van den Ende 1972; Leece and Barkus 1974; Leece and Gilmore 1974). Low-chill cultivars, which expanded into subtropical areas during the early 1980s, now dominate production in Australia. They were bred at the University of Florida, Gainesville, and are harvested from October–mid December. Under these conditions, they are vegetatively more vigorous and fruit 2–3 months earlier than higher chill cultivars growing in more temperate climates.

Tentative leaf standards for low-chill, Florida-grown peaches differ for most nutrients (Crocker and Williamson 1993) compared with high-chill standards (Leece *et al.* 1971). The growth retardant, paclobutrazol reduces vegetative vigour of low-chill stonefruit (George *et al.* 1993) and is used in commercial orchards to reduce

10.1071/EA96040

pruning costs. Treatment with paclobutrazol reduces leaf potassium (K) and increases leaf calcium (Ca) and magnesium (Mg) concentrations (Allan *et al*. 1993), which also suggests that current high-chill stonefruit diagnostic leaf nutrient standards are not appropriate for low-chill cultivars where trees are treated with paclobutrazol.

This study was undertaken to produce adequate leaf nutrient concentration standards for low-chill peach cultivars where the effects of some of the major variables, time of sampling, season, the use of paclobutrazol and cultivar, could be considered.

Materials and methods

Leaf nutrient survey

A leaf nutrient survey was conducted of peach orchards in northern New South Wales and southern Queensland over 2 seasons, 1992–93 and 1993–94. One orchard in New South Wales was located at Mangrove Mountain on the Central Coast and the others were located on the Far North Coast. The orchards in Queensland were located in the south east of the state around Gympie, Nambour and Toowoomba. The 2 main cultivars, Flordaprince (October maturing) and Flordagold (mid November–early December maturing) were represented at 3 sites in each state (Table 1).

Trees at all sites in Queensland had been collar drenched with paclobutrazol to control tree growth (George *et al.* 1993) according to commercial practice.

Seasonal leaf nutrient patterns

An orchard at Alstonville was sampled every 2 weeks commencing 4 September 1992 to 17 February 1993 and a final sample was taken on 15 April 1993. Leaf sampling was repeated in the following season commencing 1 September 1993 at 2-week intervals to 11 May 1994. The Flordagem cultivar (early November maturing), which is intermediate in maturity date between Flordaprince and Flordagold, was used at Alstonville.

Low-chill stonefruit are vegetatively vigorous with a major flush commencing in early spring with new leaves produced through to mid summer. Much of the old fruiting wood is removed during the summer pruning. A second flush which arises from lateral buds occurs in summer after which these leaves harden off and eventually senesce. Apart from the initial flush in September when all leaves are immature, leaves sampled from the middle third of a fruiting lateral from late September (after stone hardening) through to mid December, represent recently mature leaves of similar physiological age. Young leaves are sampled in January from the summer flush.

Table 1. Location, soil type and cultivars used in the leaf and soil nutrient survey, 1992–94

Site	State	Locality	Soil type	Flordaprince	Flordagold
1	NSW	Alstonville	Krasnozem	+	+
2	NSW	Wollongbar	Krasnozem	+	+
3	NSW	Wollongbar	Krasnozem	+	
4	NSW	Mangrove Mtn	Podzolic		+
5	Qld	Gympie	Podzolic	+	
6	Qld	Nambour	Podzolic	+	
7	Qld	Glasshouse Mtns	Podzolic	+	
8	Qld	Kumbia	Krasnozem		+
9	Qld	Crows Nest	Podzolic		+
10	Qld	Grantham	Sandy loam		+

Tree selection

Healthy, high-yielding trees were selected and fertiliser rates at all sites except Alstonville exceeded nutrient removal (leaf, lateral and fruit). For a crop yield of 25 t/ha, nutrient removal was measured (kg/ha) at 46 nitrogen (N), 5 phosphorus (P), 54 K, 14 Ca and 5 Mg (Slack *et al*. 1996). The Alstonville site was fertilised on 3 February 1993 with 2.8 t/ha fine agricultural lime, 41 kg/ha N as urea, 18 kg/ha P as single superphosphate and 35 kg/ha K as muriate of potash. On 11 May 1993, 200 kg/ha magnesium oxide was applied. Irrigation was regularly scheduled at all sites to maintain soil moisture tension within the tree line at no less than –30 cb at a depth of 30 cm.

Trees at all sites were dormant pruned in winter and summer pruned in early January each year.

Sampling procedure

Leaf. In an area of about 0.5 ha, 4 subplots of 25 trees from each site were sampled by removing 4 leaves from the middle third of the current season's, fruit-bearing shoots for the stone hardening and postharvest sampling at a height of 2 m from each tree (Leece 1972). Following summer pruning, leaves were sampled from new flush growth. These leaves were immediately stored in a cooled container then at 4ºC before washing. Leaves were rinsed in 0.1% non-ionic detergent for 1 min followed by consecutive rinses for 1 min in deionised water. Samples were then dried in a forced air oven at 70ºC for 24 h.

About 20 mature fruit were sampled from each site, washed and dried as for leaves in preparation for nutrient determination.

Samples were individually removed from the oven and immediately ground using a cyclone sampling mill to pass through a 1 mm sieve to give a particle size <0.3 mm. A representative 20 g subsample was stored in a sealed container pending nutrient analyses.

Soil. Composite samples were taken at the 2-week postharvest leaf sampling stage from each of the 4 subplots per site. This corresponded to mid–late November for Flordaprince and early December for Flordagold, a difference of 3 weeks. Depending on the uniformity of each site, between 2 and 25 soil cores from a depth of 0–30 cm were sampled within the irrigated

area and about 1.5 m from the base of trees within each subplot. Datum trees were marked and soil cores were taken from identical locations in consecutive years.

Samples were immediately air-dried directly in the sun for 6 h and stored at –20ºC before nutrient analyses.

Nutrient determinations

Both soil and leaf nutrient determinations were conducted at the commercial laboratory of Incitec Ltd, Brisbane.

Leaf N was determined on a Kjeldahl digest in concentrated sulfuric acid plus selenium catalyst for 3 h measuring colorimetrically in a segmented flow analyser. Total P, sulfur (S), K, Ca, Mg, sodium (Na), copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) and boron (B) were determined on a nitric acid digest and measured using an inductively coupled plasma argon emission spectrometer (ICP AES). The precision of leaf nutrient analyses was checked by including standard reference material every tenth sample as apple leaves obtained from the United States Department of Commerce, National Institute of Standards and Technology, Gaithersburg, Maryland.

Soil samples were further dried at 40ºC for 48 h in a forced air oven where air had been scrubbed of ammonia by passing through sulfuric acid. Samples were then ground to pass through a 2 mm sieve before chemical analyses. A 1:5 soil:water dilution was used for pH, electrical conductivity, chloride (Cl) and nitrate-N determinations. Anions were measured colorimetrically in a segmented flow analyser. Bicarbonate-P was measured by the method of Colwell (1963). Potassium, Ca, Mg and Na were extracted by neutral normal ammonium acetate (Black 1965), Cu, Zn, Mn and Fe by DTPA (Lindsay and Norvell 1978), and B by mannitol and calcium chloride (Cartwright *et al.* 1983). Nutrients were measured on an ICP AES.

Statistical analyses

A mixed linear model was fitted to each leaf nutrient variable. For this analysis, state, stage of harvest, cultivar and all their interactions were considered fixed effects. Year effects were fitted as random terms in the model as inferences were required for any year. Other random terms were fitted to correspond to the survey stratification of block within variety within farm within state. A similar model was fitted to the soil nutrient variables but no stage of harvest term was used.

The models were fitted in GENSTAT 5 using the restricted maximum likelihood procedures (Payne 1987). Wald tests for statistical significance of the fixed effects and generalised least squares estimates of cultivar, stage of harvest and state means were calculated.

Sodium values were not analysed because they consisted only of values of 0.01 or 0.02.

Results

Seasonal leaf nutrient concentration, Alstonville

Sampling of Flordagem trees commenced before the oldest leaves had fully expanded (early September) and leaf concentrations of N, K, Ca, P and Mg during the 1992–93 and 1993–94 seasons are presented in Figures 1 and 2 respectively.

There were a few consistent seasonal changes in leaf nutrient concentration. Leaf N concentration declined during September, the major vegetative growth flush period, and during March and April after the summer flush had hardened off. Leaf Ca concentration decreased sharply in January each year, when summer flush leaves were sampled, then increased during March and April after the flush had hardened off.

Most leaf trace element concentrations were relatively stable throughout the year (data not shown). Copper concentrations increased during summer and autumn in both years.

Survey leaf nutrient concentrations

Main effects and interactions were measured. The most consistent significant (P<0.05) main effects were for stage of sampling (N, S, P, Ca, Mg, Cl, Zn, Mn) followed by state (N, P, K, Ca, Mg, Cl, Mn, B) and cultivar (P, K, Ca, Fe, Al, B). Adequate leaf nutrient standards need to be defined for a specific sampling

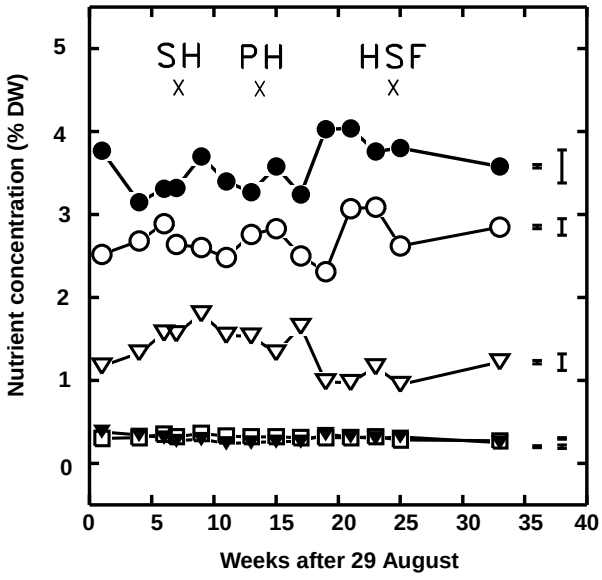


Figure 1. Nitrogen (●), K (○), Ca (▽), P (▼) and Mg (□) concentrations in youngest fully expanded leaves of Flordagem peach during the 1992–93 season. SH, stone hardening; PH, postharvest; HSF, hardening of summer flush. Vertical bars indicate minimum and maximum standard errors for the means.

Table 2. Leaf nutrient concentrations at stone hardening (SH), 2-weeks postharvest (PH) and hardening of summer flush (HSF) where state and cultivar main effects are significant (P<0.05)

At the postharvest stage, not all comparisons are significantly different (P = 0.05)

Harvest stage	Cultivar	NSW	Qld	l.s.d. (P = 0.05)
		Potassium (%)		
SH	Flordagold	2.58	2.56	
	Flordaprince	2.68	2.33	
PH	Flordagold	2.45	2.38	0.22
	Flordaprince	2.49	2.48	
HSF	Flordagold	2.51	2.11	
	Flordaprince	2.74	2.46	
		Calcium (%)		
SH	Flordagold	1.37	1.50	
	Flordaprince	1.40	1.31	
PH	Flordagold	1.40	1.87	0.23
	Flordaprince	1.39	1.69	
HSF	Flordagold	1.49	1.99	
	Flordaprince	1.38	1.58	
		Phosphorus (%)		
SH	Flordagold	0.33	0.30	
	Flordaprince	0.32	0.31	
PH	Flordagold	0.26	0.20	0.04
	Flordaprince	0.29	0.23	
HSF	Flordagold	0.24	0.17	
	Flordaprince	0.25	0.22	
		Boron (mg/kg)		
SH	Flordagold	42	41	
	Flordaprince	44	40	
PH	Flordagold	38	33	6
	Flordaprince	43	39	
HSF	Flordagold	36	32	
	Flordaprince	48	39	

Table 3. Leaf nutrient concentrations at stone hardening (SH), 2-weeks postharvest (PH) and hardening of summer flush (HSF) where state effects only are significant (P<0.05)

At the postharvest stage, not all comparisons are significantly different (P = 0.05)

Harvest stage	NSW	Qld	l.s.d. (P = 0.05)
	Nitrogen (%)		
SH	3.88	4.05	
PH	3.58	3.07	0.16
HSF	3.52	2.91	
	Magnesium (%)		
SH	0.36	0.51	
PH	0.35	0.60	0.03
HSF	0.37	0.61	
	Chlorine (%)		
SH	0.04	0.06	
PH	0.05	0.10	0.02
HSF	0.06	0.11	
	Manganese (mg/kg)		
SH	87	207	
PH	104	261	82
HSF	124	293	

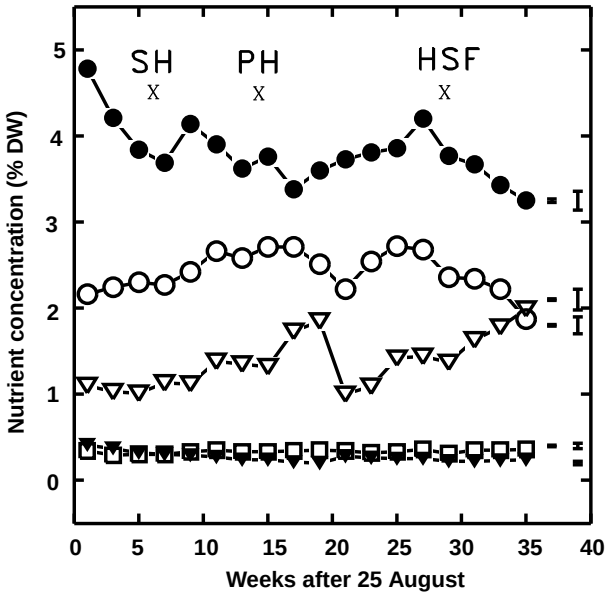


Figure 2. Nitrogen (●), K (○), Ca (▽), P (▼) and Mg (□) concentrations in youngest fully expanded leaves of Flordagem peach during the 1993–94 season. SH, stone hardening; PH, postharvest; HSF, hardening of summer flush. Vertical bars indicate minimum and maximum standard errors for the means.

stage to simplify nutrient monitoring. The 2-week postharvest stage was selected as an easily identifiable practical time when crop load effect on tree nutrient reserves was still present.

Table 2, the sampling x cultivar x state table, was used to derive adequate nutrient concentrations and to select values for the postharvest stage. Where both cultivar and state main effects were present (P<0.05), 4 values (2 cultivars x 2 states) were selected. Where only state main effects were present (P<0.05), adequate values for each state were derived from the stage of

Table 4. Leaf nutrient concentrations (mg/kg) at stone hardening (SH), 2-weeks postharvest (PH) and hardening of summer flush (HSF) where cultivar effects are significant (P<0.05)

At the postharvest stage, not all comparisons are significantly different (P = 0.05)

Harvest stage	Flordagold	Flordaprince	l.s.d. (P = 0.05)
	Iron		
SH	81	61	
PH	132	72	39
HSF	99	88	
	Aluminium		
SH	5	2	
PH	38	10	26
HSF	28	9	

Table 5. Adequate leaf nutrient concentrations (± 95% confidence interval), 2-weeks postharvest for low-chill Flordagold (FG) and Flordaprince (FP) peaches

Nutrient	NSW	Qld
Nitrogen (%)	3.58 ± 0.11	3.07 ± 0.11
Potassium (%)	2.38–2.49 ± 0.15	2.38–2.49 ± 0.15
Phosphorus (%)	0.26 ± 0.03 (FG), 0.29 ± 0.03 (FP)	0.20 ± 0.03 (FG), 0.23 ± 0.03 (FP)
Sulfur (%)	0.19 ± 0.01	0.19 ± 0.01
Calcium (%)	1.39–1.40 ± 0.16	1.87 ± 0.16 (FG), 1.69 ± 0.16 (FP)
Magnesium (%)	0.35 ± 0.02	0.60 ± 0.02
Chloride (%)	0.05 ± 0.01	0.10 ± 0.01
Sodium (%)	0.011	0.011
Copper (mg/kg)	9.4 ± 1.5	9.4 ± 1.5
Iron (mg/kg)	132 ± 28 (FG), 73 ± 28 (FP)	132 ± 28 (FG), 73 ± 28 (FP)
Zinc (mg/kg)	30 ± 2	30 ± 2
Manganese (mg/kg)	104 ± 58	261 ± 58
Boron (mg/kg)	38 ± 4 (FG), 43 ± 4 (FP)	33 ± 4 (FG), 39 ± 4 (FP)
Aluminium (mg/kg)	38 ± 19 (FG), 10 ± 19 (FP)	38 ± 19 (FG), 10 ± 19 (FP)

sampling x state table (Table 3) for the postharvest stage. Where cultivar main effects only were present (P<0.05), adequate values for each cultivar were derived from the stage of sampling x cultivar table (Table 4) for the postharvest stage. Where cultivar and state effects were absent (P>0.05), the mean value for the postharvest stage is presented.

Cultivar and state main effects were present for leaf K, Ca, P and B concentrations. The 4 values were obtained from the stage of sampling x cultivar x state table (Table 2) to represent adequate values for the 2-week postharvest stage. State effects only were present for leaf N, Mg, Cl and Mn concentrations and 2 values were obtained from Table 3. Cultivar effects only were present for leaf Fe and aluminium (Al) concentration and 2 values were obtained from Table 4.

Adequate leaf nutrient concentrations for the 2-week postharvest sampling stage obtained from the above tables are summarised in Table 5. Cultivar and state values were similar for K and a range has been presented. New South Wales cultivar values were similar for Ca and a range has been presented.

State effects were present for 7 of the 14 variables and included cultivar effects (P<0.05) for 3 of these variables as well as for 2 additional variables. Leaf N, P, and B concentrations were higher for New South Wales while leaf Ca, Mg and Mn concentrations were higher for Queensland.

Table 6. Soil chemical properties (0–30 cm), 2-weeks postharvest for Flordagold and Flordaprince peaches in New South Wales and Queensland

Soil property	Flordagold	Flordaprince	l.s.d. (P = 0.05)
pH	5.8	6.3	0.3
Nitrate-N (mg/kg)	12.6	17.8	7.4
Sulfur (mg/kg)	242 (NSW), 74 (Qld)	171 (NSW), 39 (Qld)	116
Phosphorus (Colwell) (mg/kg)	74	65	21
Potassium [cmol(+)/kg]	0.86	0.86	0.29*
Calcium [cmol(+)/kg]	5.93	8.09	1.95
Magnesium [cmol(+)/kg]	1.41	2.31	1.47
Sodium [cmol(+)/kg]	0.18	0.18	0.12*
Chloride (mg/kg)	21 (NSW), 32 (Qld)	48 (NSW), 20 (Qld)	18
Aluminium [cmol(+)/kg]	0.10	0.10	0.16*
CEC [cmol(+)/kg]	8.65	11.52	3.28
Elect. cond. (dS/m)	1.67 (NSW), 0.63 (Qld)	1.67 (NSW), 0.63 (Qld)	0.61
Copper (mg/kg)	8.4	8.4	5.6*
Zinc (mg/kg)	9.9	9.9	12.1*
Manganese (mg/kg)	8.7 (NSW), 32.0 (Qld)	8.7 (NSW), 32.0 (Qld)	17.5
Iron (mg/kg)	142 (NSW), 54 (Qld)	94 (NSW), 163 (Qld)	74
Boron (mg/kg)	0.31	0.31	0.18*

* 95% confidence interval.

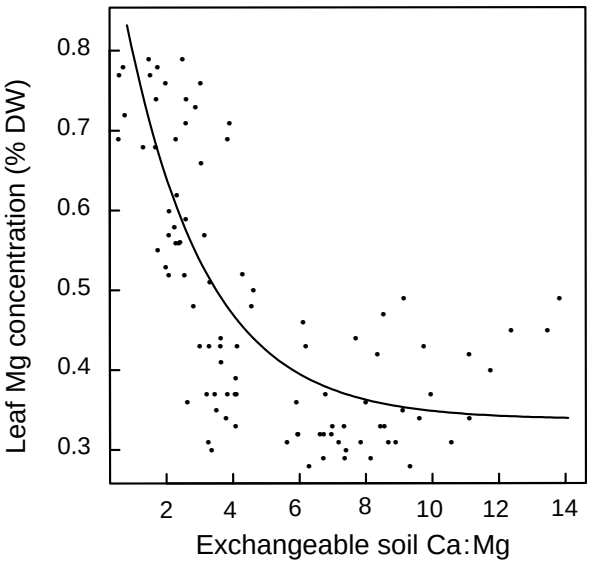


Figure 3. Regression between leaf Mg concentration (y) and exchangeable soil Ca : Mg ratio (x), 2-weeks postharvest from survey sites during the 1992–93 and 1993–94 seasons. The general model is $y = a + br^x$, where a = 0.33 (± 0.02), b = 0.69 (± 0.08), r = 0.65 (± 0.05) (R^2 = 0.60; P<0.001).

Soil chemical properties

Cultivar effects (P<0.05) were present for 9 of the 17 variables and included state effects (P<0.05) for 3 of these 9 variables as well as for 2 additional variables (Table 6).

Flordaprince sites had higher soil nitrate-N, pH, exchangeable Ca and Mg, but lower S and P levels than Flordagold.

Leaf, fruit nutrient composition v. *soil chemical properties*

Only 1 consistent significant regression (P<0.05) was recorded and this was between leaf Mg concentration and exchangeable soil Ca : Mg ratio (Fig. 3). An exponential model provided the best fit for the 2 season's data. Leaf Mg concentration was very responsive to a soil Ca : Mg ratio <4, was moderately responsive to Ca : Mg ratios of 4–8 and was unresponsive to a Ca : Mg ratio >8.

Discussion

The consistent stage of sampling effect on leaf nutrient concentration for low-chill stonefruit in the present study confirms the importance of the general principle in diagnostic leaf nutrient analyses of nominating a specific sampling time (Reuter and Robinson 1986). Leece and Gilmore (1974) demonstrated seasonal trends in leaf nutrient concentrations for high-chill stonefruit with a 4–6-week period immediately preharvest (January and February) when the rate of change in nutrient concentration was least, and as a consequence, this was nominated as an appropriate diagnostic sampling period. The seasonal changes in leaf nutrient composition for low-chill stonefruit were not as pronounced as those for high-chill stonefruit. In comparing 3 nutrients which showed a distinct seasonal change for the high-chill cv. Golden Queen, N and K declined from 3.8 to 2.8% and from 2.7 to 1.7% respectively, and Mg increased from 0.56 to 0.92% (Leece and Gilmore 1974) whereas the maximum comparable change for cv. Flordagem was N 3.58 to 3.25%, K 2.86 to 1.87%, and Mg 0.27 to 0.36%.

Where the effect of leaf age on nutrient composition was studied with a range of vegetable crops (e.g. cabbage, Huett and Rose 1989), the most consistent effects were a decline in N and an increase in Ca concentration as leaves aged. Flordagem leaf Ca concentration increased during September and October as leaves aged. The decline in leaf Ca concentration in late January confirms that younger leaves were being sampled. Recently mature leaves sampled at this stage were younger leaves from recent flush growth after summer pruning had removed older flush growth. A decline in leaf N and K and an increase in Ca and Mg concentration occurred over the entire season for high-chill stonefruit (Leece and Gilmore 1974), suggesting a leaf ageing effect.

Stage of sampling effects were detected for most leaf nutrient concentrations and we recommend the 2-week postharvest period as a diagnostic leaf sampling time. It is well separated from the spring and summer flushes and leaves of a consistent age and maturity can be sampled. Nutrient demand of fruit near maturity is more likely to be reflected in a reduction in leaf nutrient composition if trees are under nutrient stress. Fruit compete effectively with other tree components for nutrients (and carbohydrates) to the extent of reducing vegetative growth (Huett 1996).

The diagnostic leaf analysis standards developed for high-chill stonefruit are based on a review of 39 published nutrition studies with slight modification following a 2 year survey by Leece *et al.* (1971). There are no previously published data for low-chill stonefruit representing diagnostic levels apart from tentative values for Florida presented by Crocker and Williamson (1993). The high-chill leaf nutrient surveys were not designed to enable state, cultivar and stage of sampling effects to be tested (Leece *et al.* 1971; Leece and Gilmore 1974; Leece and Barkus 1974), in contrast to the present study, and therefore ranges of values were presented for low-chill stonefruit as diagnostic adequate standards to cover all main effects. We have presented single values (± confidence interval) where significant state or cultivar effects were present. Cultivar and state effects were detected although many values did not differ greatly at 2-weeks postharvest. Many values have been combined to provide a range, consistent with the approach used for high-chill stonefruit.

The current survey produced a narrower range of adequate leaf nutrient concentrations for low-chill stonefruit than for high-chill stonefruit (Leece *et al*. 1971). The concentrations of N, K, S, Cu, Zn, Na and Cl for low-chill were generally within the high-chill range. Lower Ca, and Mg in New South Wales (both cultivars), lower Fe for Flordaprince (both states), higher P for Flordaprince in New South Wales and higher Mn values in Queensland (both cultivars) were recorded for low-chill stonefruit. There were also differences between the low-chill Florida optimum range where K (1.10–2.00%) was well below the current survey values (2.38–2.49%).

Higher leaf Ca and Mg and lower N and P concentrations in Queensland than New South Wales are consistent with a paclobutrazol effect in Queensland. Higher leaf Ca and Mg concentrations were measured in Flordaprince peach following paclobutrazol application (Allan *et al.* 1993). Paclobutrazol reduces vegetative vigour by reducing internode length and leaf number (Steffens *et al.* 1985). The effect on leaf nutrient concentration in the present study suggests that older leaves were sampled at 2-weeks postharvest in Queensland compared with New South Wales. The effect of state on adequate leaf nutrient concentrations should be interpreted as a paclobutrazol effect rather than a state effect, and different standards are required for N, P, Ca, Mg, Cl, Mn and B.

Unexpected results were the frequent cultivar effects and the absence of state effects for soil chemical properties (Table 6). Results suggest that heavier rates of N, Ca and Mg and lower rates of S and P fertilisers were applied to Flordaprince than Flordagold orchards. However, grower fertiliser records indicated a similar immediate fertiliser history unless differences occurred during the establishment phase of the orchard. New South Wales orchards were, all but one, located on krasnozem soils whereas many Queensland sites had sandy loam topsoils, thus a contrast in soil chemical properties may have been expected.

Only one consistent significant ($P<0.05$) regression could be detected between soil chemical properties and leaf or fruit nutrient composition which indicates that fruit trees will tolerate a wide range of soil chemical properties before a response can be detected in leaf and fruit nutrient composition. Tree crops have large nutrient reserves in roots and branches and are well buffered against the external nutrient supply (Huett 1996). Soils used for low-chill stonefruit production are moderately acid and annual lime or gypsum applications (about 2 t/ha) have been a regular part of fertiliser practice. The Ca : Mg uptake by stonefruit is about 3 (Slack *et al*. 1996) suggesting that this would be an appropriate soil nutrient ratio. About two-thirds of the sites in the survey exceeded this ratio reaching 12 at 1 site. At a soil Ca : Mg ratio of about 3, leaf Mg concentration is very responsive and corresponds to 0.54%. The low New South Wales Mg concentration (0.35%) may reflect a history of heavy Ca fertiliser application. Annual applications of lime without Mg amendment will cause a soil Ca : Mg imbalance and could lead to Mg deficiency.

While diagnostic leaf analysis standards have been developed for most horticultural crops (Reuter and Robinson 1986), and this study fills the void for low-chill peaches (and probably nectarines), their value in rectifying an inappropriate fertiliser program is limited. Tree crops have relatively large nutrient reserves and low nutrient uptake rates compared with vegetable crops (Huett 1996) where leaf nutrient analyses are very useful in diagnosing nutrient inadequacies. We recommend that soil chemical determinations should be used in conjunction with leaf nutrient analyses and fertiliser history to determine future fertiliser strategies. Crop nutrient removal for a 25 t/ha low-chill peach orchard was measured (kg/ha) at 46 N, 5 P, 54 K, 14 Ca and 5 Mg (Slack *et al*. 1996). This is an appropriate starting point for determining fertiliser rates.

Acknowledgments

We thank Glenn Smith and Bob Nissen for providing technical support and Ms Sandra Hardy who collected plant and soil samples from the Mangrove Mountain site. Incitec Ltd contributed substantial funding by conducting chemical analyses on soil and plant material. Funding was also provided by the Northern Rivers Stonefruit Growers Association and the Horticultural Research and Development Corporation.

References

Allan, P., George, A. P., Nissen, R. J., Rasmussen, T. S., and Morley-Bunker, M. J. (1993). Effects of paclobutrazol and phenological cycling of low-chill 'Flordaprince' peach in subtropical Australia. *Scientia Horticulturae* **53**, 73–84.

Black, C. A. (1965). 'Methods of Soil Analysis.' Part II. (American Society of Agronomy Inc.: Madison, Wisconsin, USA.)

Cartwright, B., Tiller, K. G., Zarcinas, B. A., and Pounier, L. R. (1983). The chemical assessment of the boron status of soils. *Australian Journal of Soil Research* **21**, 321–32.

Colwell, J. D. (1963). The estimation of the phosphorus fertiliser requirement of wheat in southern New South Wales by soil analysis. *Australian Journal of Experimental Agriculture and Animal Husbandry* **3**, 190–8.

Crocker, J. E., and Williamson, J. G. (1993). Peaches and nectarines in Florida. Florida Cooperative Extension Service, University of Florida, Circular 299–3, Gainesville.

George, A. P., Nissen, R. J., and Rasmussen, T. (1993). Effects of postharvest topping, autumn cincturing and paclobutrazol on growth, yield and fruit quality of low chill nectarine cv. Sundowner in subtropical Australia. *Australian Journal of Experimental Agriculture* **33**, 353–62.

Huett, D. O. (1996). Prospects for manipulating the vegetative–reproductive balance in horticultural crops through nitrogen nutrition: a review. *Australian Journal of Agricultural Research* **47**, 47–66.

Huett, D. O., and Rose, G. (1989). Diagnostic nitrogen concentrations for cabbages grown in sand culture. *Australian Journal of Experimental Agriculture* **29**, 883–92.

Leece, D. R. (1972). Diagnostic leaf analysis for stonefruit. 1. Errors associated with standard and simplified sampling procedures. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12**, 315–22.

Leece, D. R., and Barkus, B. (1974). Diagnostic leaf analysis for stone fruit 3. Nutritional status of peach orchards. *Australian Journal of Experimental Agriculture and Animal Husbandry* **14**, 828–34.

Leece, D. R., Cradock, F. W., and Carter, O. G. (1971). Development of leaf nutrient concentration standards for peach trees in New South Wales. *Journal of Horticultural Science* **46**, 163–75.

Leece, D. R., and Gilmore, A. R. (1974). Diagnostic leaf analysis for stonefruit. 2. Seasonal changes in the leaf composition of peach. *Australian Journal of Experimental Agriculture and Animal Husbandry* **14**, 822–7.

Lindsay, W. L., and Norvell, W. A. (1978). Development of a D.T.P.A. soil test for zinc, iron, manganese and copper. *Journal of the Soil Science Society of Agronomy* **42**, 421–8.

Payne, R. W. (1987). 'Genstat 5 Reference Manual.' (Oxford University Press: Oxford.)

Reuter, D. J., and Robinson, J. B. (1986). 'Plant Analysis: an Interpretation Manual.' (Inkata Press: Melbourne.)

Slack, J. M., Huett, D. O., and George, A. (1996). Fertilising low-chill stonefruit. A guide to nutrient management of low-chill peaches and nectarines in Australia. NSW Agriculture.

Steffens, G. L., Wang, S. Y., Faust, M., and Byun, J. K. (1985). Growth, carbohydrate, and mineral element status of shoot and spur leaves and fruit of 'Spartan' apple trees treated with paclobutrazol. *Journal of the American Society of Horticultural Science* **110**, 850–5.

Taylor, B. K., and van den Ende, B. (1972). Leaf analysis survey of Pullar's cling peach trees in northern Victoria: correlations between leaf nutrient status and tree performance in two years. *Australian Journal of Experimental Agriculture and Animal Husbandry* **12**, 103–6.

Received 16 April 1996, accepted 11 October 1996