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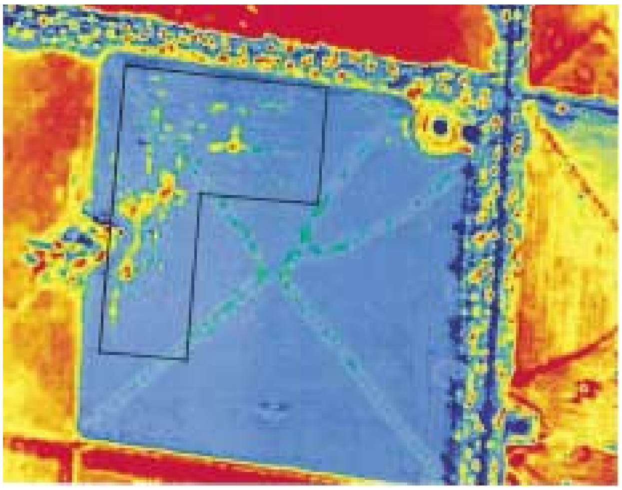

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Control of tree size and vigour in custard apple (*Annona* spp. hybrid) cv. African Pride in subtropical Australia

A. P. George[A] *and R. J. Nissen*

Maroochy Horticultural Research Station, Queensland Department of Primary Industries,
PO Box 5083, Sunshine Coast Mail Centre, Nambour, Qld 4560, Australia.
[A]Author for correspondence; e-mail: georgea@dpi.qld.gov.au

Abstract. Five methods of controlling tree size, viz. growth retardant (foliar-sprayed and trunk-injected paclobutrazol), root-restriction bags, cherimoya rootstock and sugar apple (*Annona squamosa*) interstock, were evaluated for their effects on growth, yield and fruit quality of custard apple (*Annona* spp. hybrid cv. African Pride) in subtropical Australia. Compared with trees on their own roots, sugar apple interstock was highly effective in dwarfing 'African Pride' trees, reducing tree canopy volume by 72–90%. Root-restriction bags (woven fibreglass) proved to be only partially effective in controlling tree size due to growth of major roots through the seams. Compared with trees on their own roots, cherimoya rootstock alone, and sugar apple interstock increased fruit weight per unit canopy volume by a maximum of 3- and 5-fold, respectively. Sugar apple interstock reduced the severity of fruit disorders 'woodiness' and 'brown pulp' by about 75 and 50%, respectively.

Additional keywords: tree growth, cherimoya, interstock, paclobutrazol, root restriction.

Introduction

Custard apple (*Annona* spp. hybrid) is a semi-deciduous fruit tree primarily grown in the subtropics (George and Nissen 1994). Under subtropical conditions, custard apple trees exhibit high vegetative growth rates and mature tree size is large (>5 m high). Strong vegetative flushing in the summer is associated with poor flowering, fruit set and yield (George and Nissen 1988, 1994). Excessive vegetative growth may also increase the severity of 'woodiness' in the pulp and the percentage of misshapen fruit (George *et al.* 2000).

Attempts to control tree size and vigour of custard apple by standard management practices such as pruning and close-planting have not been successful due to strong compensatory regrowth and increased shading of the lower canopy which both contribute to reduce flowering (George *et al.* 2000). Consequently, orchards must be planted with <400 trees/ha. Because of increasing labour costs for thinning, pruning and harvesting, other options are needed.

Methods for controlling tree size and vigour in temperate and other subtropical fruit crops include pruning (Leuty and Pree 1980; Young and Crocker 1982), regulated deficit irrigation (Chalmers *et al.* 1981, 1984, 1985), girdling (Noel 1979; Dann *et al.* 1984), size-control rootstocks (Tukey 1964), and chemical growth retardants (Erez 1984; Williams 1984; Martin *et al.* 1987; Allan *et al.* 1993). Most of these techniques have been only partially successful in controlling tree growth and each has drawbacks. Summer pruning may produce strong vegetative regrowth, which may delay floral initiation, floral bud development, flowering, and fruit set (Evans 1977; Stiles 1984). Regulated deficit irrigation can only be used effectively in areas of low summer rainfall. Girdling increases fruit size and advances maturity in early season peaches, but the severity and time of girdling is critical (Fernandez-Escobar *et al.* 1987; De Villiers *et al.* 1990). In custard apple, sugar apple (*Annona squamosa*) has been used as a dwarfing rootstock but this rootstock is susceptible to bacterial wilt (*Pseudomonas* spp.) (George and Nissen 1986). Soil applications of paclobutrazol (PBZ) did not control tree growth of mature custard apple trees, even when applied at high rates (12 g a.i. per tree) (A. P. George and R. J. Nissen unpublished data).

This paper evaluates the effects of paclobutrazol (foliar-sprayed or trunk-injected), root restriction and sugar apple interstocks on growth, starch concentration, yield and quality of the custard apple cv. 'African Pride' in subtropical Australia. The objective was to develop strategies to control tree size and to determine whether these lead to higher yield and quality.

Materials and methods

Sites and weather

Two experiments were conducted at the Maroochy Research Station, Nambour, Queensland (latitude 26°S). Weather conditions during the experimental period are presented in Figure 1.

Interstock, root restriction and November-applied paclobutrazol (experiment 1)

Treatments applied to 4-year-old trees of the custard apple (*Annona* spp. hybrid) cv. African Pride were the following: (i) trees propagated

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as cuttings; (ii) trees grafted onto cherimoya (*Annona cherimola*) rootstock; (iii) trees grafted onto cherimoya with a sugar apple (*Annona squamosa*) interstock; (iv) trees propagated as cuttings but field-planted in 120-L woven fibreglass growbags; (v) trees propagated as cuttings and trunk-injected with paclobutrazol (Cultar) at a.i. concentration of 1.2 g/m^2 of projected canopy area on 15 November 1991 (a.i. concentration range 6.2–8.1 g/tree) and 20 November 1992 (11.5–13.6 g/tree), and (vi) trees propagated as cuttings and foliar-sprayed with paclobutrazol at 10 g/L on 15 November 1991 and 20 November 1992.

Treatment description (experiment 1)

Hardwood cuttings were taken in late September just before budbreak, treated with 0.1% indole-3-butyric acid (IBA), and struck in sand beds under mist. Scion and interstock budwood was taken from mature trees about 8-years-old and grafted onto 1-year-old cherimoya seedlings with the scion and/or interstock grafts made at the same time. Both the grafted trees and cuttings were grown in 10 L bags and were about 2 years old at the time of planting and of similar height (80 ± 5 cm). The woven fibreglass root-restriction bags were placed 0.75 m in the planting hole and back-filled with soil from similar layers in the undisturbed row. Trees were trunk-injected with growth retardant using five 60 mL veterinarian syringes per tree, equally spaced around the trunk to obtain good radial distribution and uptake of the chemical. The tips of the syringes were implanted to a depth of 1.5 cm through the bark and into the xylem and allowed to drain over 6 h.

Trees were planted at twice the standard commercial density, 3 m within rows and 4 m between rows, equivalent to 833 trees/ha, on a sandy loam overlying a clay. Treatments were replicated in 4 randomised blocks with 3-tree plots guarded externally within the row using single trees at both ends of the plot and these trees were treated similarly to the adjacent treatment.

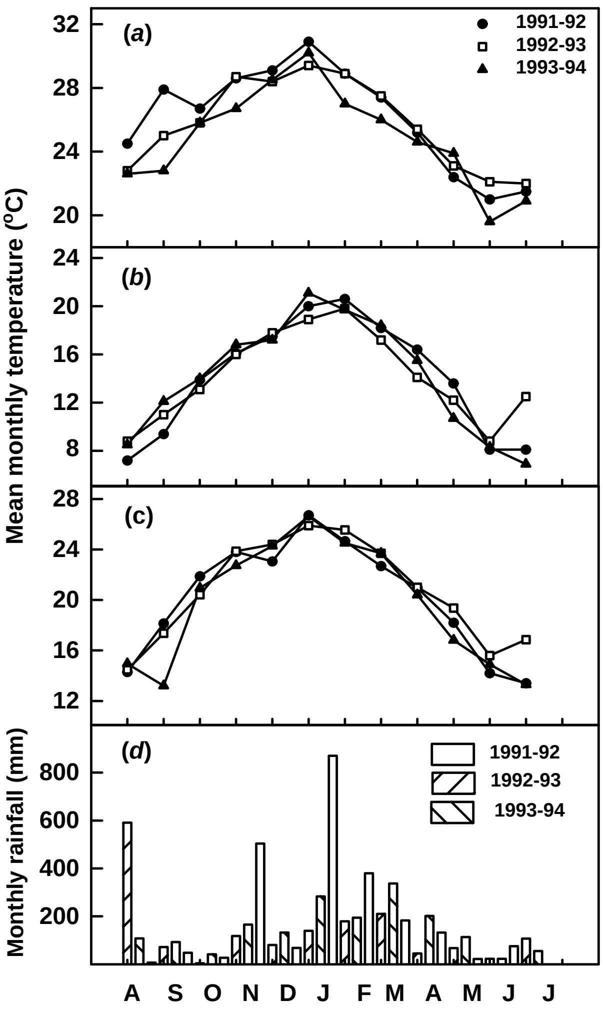

Figure 1. Mean monthly (*a*) maximum and (*b*) minimum temperatures, (*c*) average soil temperature (15 cm) and (*d*) monthly rainfall.

March-applied paclobutrazol (experiment 2)

Five-year-old trees of the custard apple cv. African Pride were selected. Trees were spaced 6 m within rows and 8 m between rows equivalent to 208 trees/ha on a sandy loam overlying a clay. Trees propagated from cuttings were grown with and without paclobutrazol trunk-injected at 1.2 g/m^2 (a.i.) of projected canopy area (range of a.i. concentration 15.5–18.6 g/tree) on 15 March 1993. These were compared with trees grafted onto cherimoya with a sugar apple (*Annona squamosa*) interstock. Propagation and trunk-injection procedures were as described in experiment 1.

Treatments were replicated in 8 randomised blocks with 3-tree plots guarded externally within the row using single trees at both ends of the plot and these trees were treated similarly to the adjacent treatment.

Cultural practices

Trees were irrigated using under-tree mini-sprinklers delivering 30 L/h to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. In experiment 1, trees were fertilised with 120 g nitrogen (N), 40 g phosphorus (P) and 100 g potassium (K) in October and with 150 g potassium in February. Due to lower planting density, fertiliser rates were 3 times higher in experiment 2 but timings were similar. Trees were trained to an open goblet system for the first 3 years after planting, and were moderately pruned each year in July, just before entering dormancy. The level of pruning (20–30% removal of the last season's shoot extension growth) was kept the same for each treatment irrespective of tree vigour.

Measurements

Tree growth and development. Each July, tree height, spread (N–S, E–W), and girth (30 cm above ground level) were measured. Tree-canopy volume was calculated from the formula for determining the volume of a semiellipsoid ($V = 2/3\ \pi r^2 h$; V = tree volume, r = tree radius, h = tree height). At weekly intervals during leaf abscission, the percentage of leaf cover in the canopy and the proportion of vegetative buds emerging were estimated visually by 2 observers working independently. After the completion of budbreak, the number of flowers at anthesis in a 1 m^3 quadrat in the middle of each of the N, S, E and W sectors for each tree was also counted every fortnight. Shoot extension was also recorded every fortnight, on 4 laterals (pruned to 30 cm) on each tree.

In experiment 2, the number of nodes, leaves, floral buds, average shoot length, leaf area and number of floral buds per centimetre of shoot length were recorded on 6 shoots per tree.

In experiment 1, incident light was measured with 1 m line Quantum sensors (LI-COR LI–191SA, USA) for 7 consecutive days in April, at the completion of vegetative flushing and when trees had reached full canopy cover. Sensors were placed horizontally at a tangent to the tree radius within the fruiting zone, in the N, S, E and W sectors at the top, middle and bottom thirds of each tree. Full sunlight above the canopy was measured with a Quantum spot sensor (LI-COR, LI-190SA, USA).

Fruit quality

Trees were harvested at the normal commercial stage of fruit maturity (change in interstice colour from green to cream) at intervals of 7 days for yield and fruit-quality assessment. Fruit-quality assessments were made 4–7 days after harvest, once fruit had softened, on 20 fruits randomly sampled from each tree at peak harvest in the final year of harvest for both experiments. In experiment 2, Brix was determined on expressed juice using an Abbe refractometer (American Optical model 10460, USA); fruit symmetry was rated on a scale from 1, poorly symmetrical, to 5, highly symmetrical; fruit smoothness was rated from 1, lumpy, to 5, smooth; severity of the internal 'woodiness' disorder was determined by weighing the hard lumps in the flesh and determining their fresh weight, and the internal 'brown pulp' disorder was rated as the proportion of a vertical cross-section of fruit that was discoloured.

Leaf nutrient concentrations

The first fully mature leaf on a terminal shoot was sampled from 10 non-fruiting shoots in March and analysed for N, P, K, calcium (Ca), magnesium (Mg), iron (Fe), boron (B), copper (Cu), zinc (Zn) and manganese (Mn) on a dry weight basis. George *et al.* (1989) has previously described analytical techniques.

Dry matter and starch reserves

In experiment 1, 4 trees per treatment were removed from the field at 0900 hours, at the completion of harvest (15 June), and divided into leaves, new season's laterals, 1-year-old laterals 2–8 mm in diameter, branches 8–16 mm in diameter, limbs >16 mm in diameter, trunk and major roots >2 mm in diameter, then dried at 60°C and weighed. Cross-sectional samples were taken at 0900 hours of branches, limbs, trunk and roots, including bark, and analysed with the leaves for starch (Rasmussen and Henry 1990). Harvest index was calculated as the proportion of total tree dry matter (including fruit) allocated to fruit.

Statistical analysis

Data were analysed using 1-way ANOVA and significant differences between the means tested at the $P = 0.05$ level. Linear and non-linear regression analysis was carried out to define the relationships between flowering and shoot production, starch concentrations and shoot growth, and internal disorders and shoot growth.

Results

Vegetative growth

Sugar apple interstocks dwarfed 'African Pride' trees, reducing canopy volume in experiments 1 and 2 by 72 and 90%, respectively, compared with trees on their own roots (Figs 2 and 3). There were also reductions in shoot extension growth (Figs 2 and 3), leaf area per shoot and average leaf area (Table 1).

The lack of increase in the canopy volume of trees with interstock between 1993 and 1994 was also due to winter (dormant) pruning that partially removed the previous season's shoot extension growth. Canopy volume of mature 5-year-old trees on their own roots, planted at the higher density in experiment 1 (1992), was about half of that for similar-age trees planted at low density in experiment 2, indicating that the trees rapidly filled the allotted space and experienced higher interplant competition. In experiment 1, cherimoya rootstock also reduced canopy volume by 60% compared with trees on their own roots (Fig. 2).

In experiment 1, November injections of paclobutrazol did not affect tree growth (Fig. 2), whereas in experiment 2, a March treatment reduced growth by >30% in the following season (Table 1, Fig. 3).

The March injection (experiment 2) did not significantly affect tree growth in the year of application, presumably because vegetative growth was nearing completion by the date of trunk injection. In experiment 1, foliar paclobutrazol reduced growth by 36% in the second season (Fig. 2). Root bags did not significantly reduce growth (Fig. 2). On tree removal, at the completion of the experiment, major roots were observed to have penetrated the seams of the bags. Trees on sugar apple interstocks had greater light transmission than those on their own roots at all heights (Fig. 4). There was also a difference between the cherimoya and own roots at the top and bottom, but no effect of root bags or paclobutrazol. Light transmission in the lower section of tree canopies was extremely low even for trees with sugar apple interstock (<8% full sun).

Leaf abscission, flowering and fruit maturity

All trees exhibited biphasic defoliation. The reasons for this are not evident. Trees with sugar apple interstock

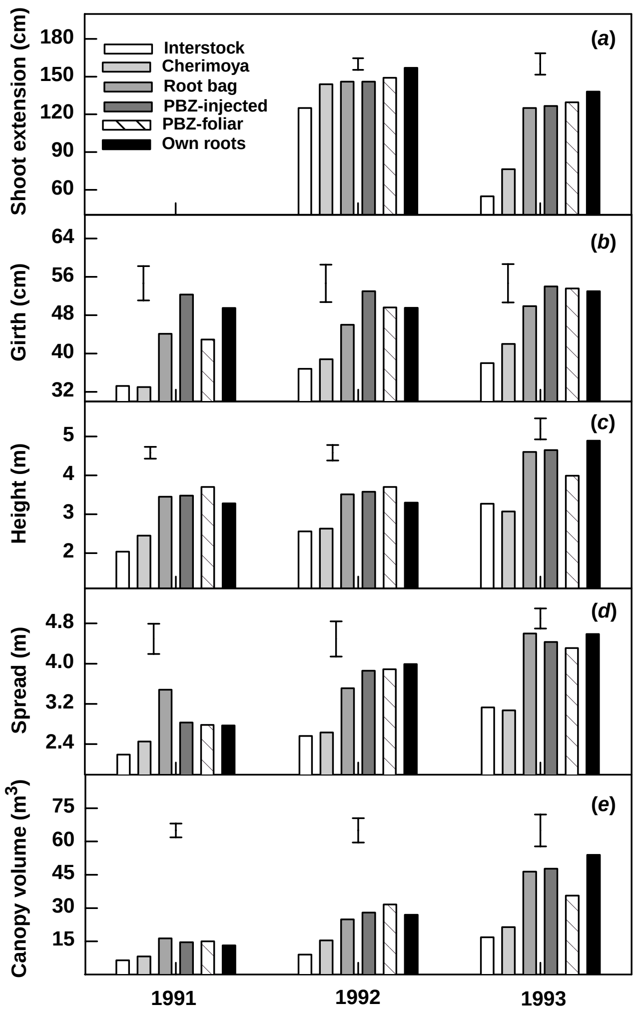

Figure 2. Experiment 1. Effects of interstock, root bag and paclobutrazol (PBZ) on (*a*) shoot extension, (*b*) girth, (*c*) height, (*d*) spread and (*e*) canopy volume growth of the custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees per treatment. Vertical bars represent l.s.d. ($P = 0.05$).

defoliated and broke dormancy slightly earlier than those on their own roots (Fig. 5). Percentage leaf cover per tree was positively (r^2 = 0.76, P<0.05) correlated with shoot extension growth (data not presented).

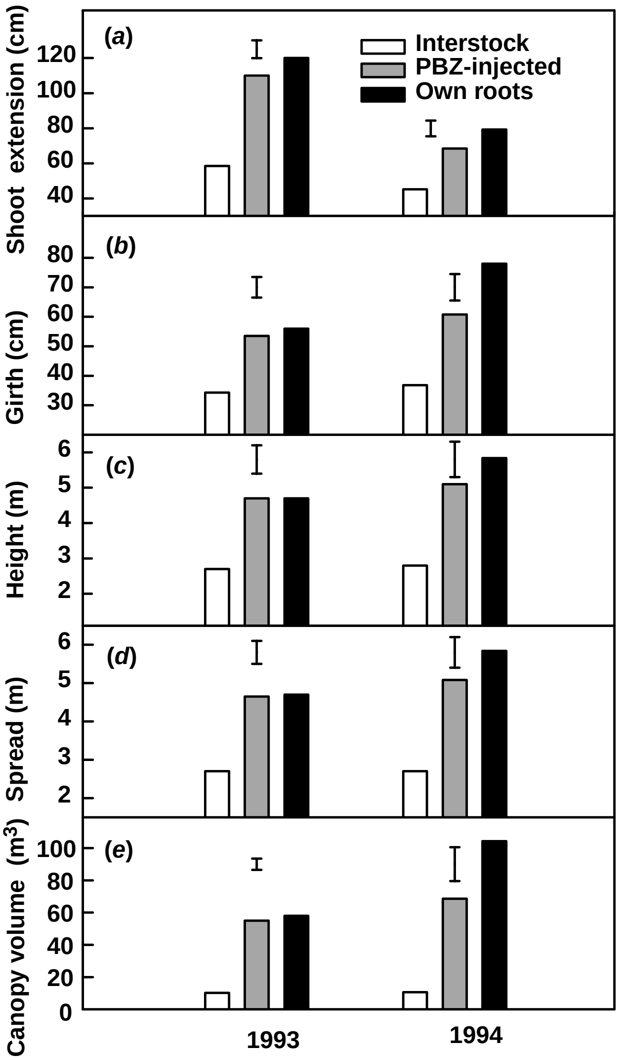

Figure 3. Experiment 2. Effects of interstock and trunk-injected paclobutrazol (PBZ) on (*a*) shoot extension, (*b*) girth, (*c*) height, (*d*) spread and (*e*) canopy volume growth of the custard apple cv. African Pride in subtropical Australia. Data are the means of 8 trees per treatment. Vertical bars represent l.s.d. (P = 0.05).

Flowering patterns were similar, with the exception of the cherimoya rootstock, which flowered about 10 days earlier than the other trees (Fig. 6). Flower number per cubic metre was greater for grafted trees and trees with root bags.

In experiment 2, trunk-injected paclobutrazol and sugar apple interstocks increased the number of laterals per shoot and the number of floral buds per shoot by 50 and 80%, respectively, and the number of floral buds per centimetre of lateral by 2.6- and 3-fold, respectively, compared with trees on their own roots (Table 1). Flowering was strongly (r^2 = 0.79, P<0.05) correlated with shoot production.

Yield

Over 2 seasons, sugar apple interstocks reduced, and cherimoya rootstocks increased, yield per tree by about 30% compared with trees on their own roots (Tables 2 and 3). Both treatments increased yield per canopy volume by about 3–4-fold, but cherimoya had a greater effect when yield

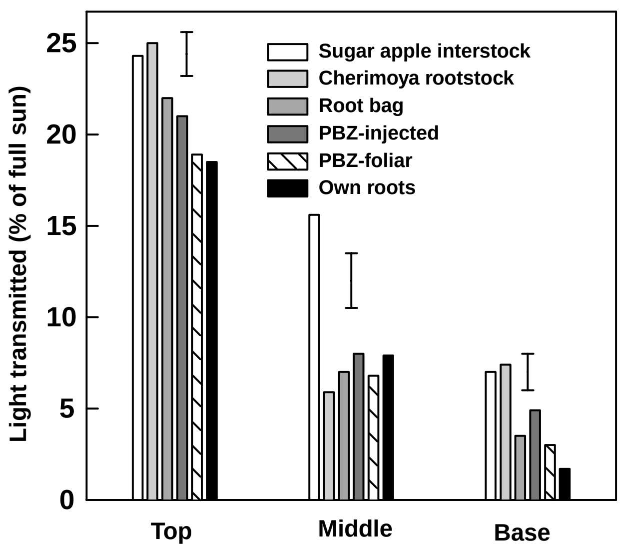

Figure 4. Experiment 1. Effects of interstock, root bag and paclobutrazol (PBZ) on light transmission with canopy position in custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees. Vertical bars represent l.s.d. (P = 0.05).

Table 1. Experiment 2. Effects of paclobutrazol and sugar apple interstock on current-season shoot growth and flowering of the custard apple cv. African Pride in subtropical Australia

Paclobutrazol was injected in March in the previous season (1993); data are the means of eight trees in 1994

Treatment	Shoot length at peak flowering (cm)	Shoot length after harvest (cm)	No. of laterals per shoot	Average length of laterals (cm)	No. of leaves per shoot	Leaf area per shoot	No. of floral buds per shoot	No. of floral buds per 100 cm of lateral
Own roots	57	79	10.4	28.1	34	3462	7.9	2.7
Own roots + paclobutrazol	39	69	15.6	8.5	37	2440	12.0	9.1
Sugar apple interstock	17	45	16.8	7.9	37	1859	14.2	10.7
l.s.d. (P = 0.05)	15	n.s.	2.1	5.3	n.s.	1071	3.5	2.5

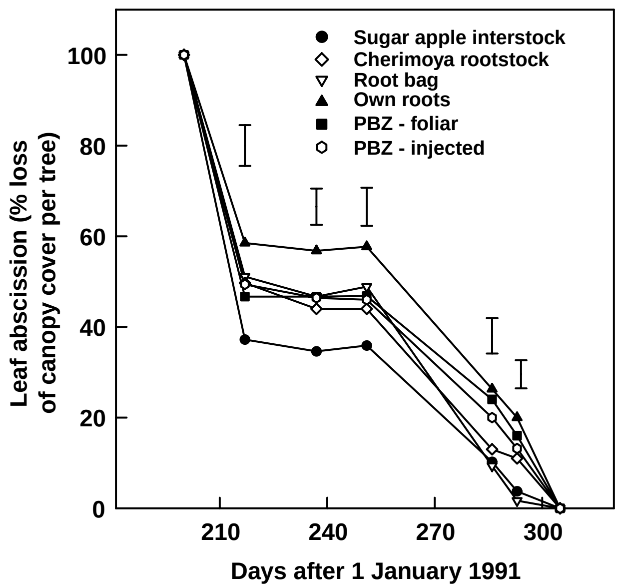

Figure 5. Experiment 1. Effects of interstock, root bags and paclobutrazol (PBZ) on leaf abscission in custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees per treatment. Vertical bars represent l.s.d. ($P = 0.05$).

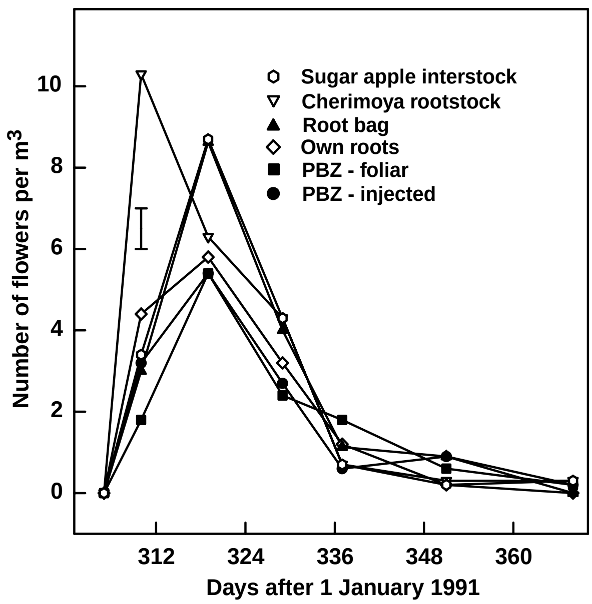

Figure 6. Experiment 1. Effects of interstock, root bag and paclobutrazol (PBZ) on flowering in the custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees. Vertical bars represent l.s.d. ($P = 0.05$).

efficiency was expressed on a butt cross-sectional area basis (Tables 2 and 3). For experiment 1, paclobutrazol and root restriction also recorded slightly higher yields and efficiencies than controls, particularly in the following year. Across treatments, yield per tree was about 2–3 times greater in the low-density planting (experiment 2) than in the high-density planting (experiment 1), but when yields were compared on a per hectare basis the reverse was the case but only by about 1–2 times (Tables 2 and 3). Overall, yields were higher in the 833 trees/ha planting because more light was intercepted on an orchard canopy surface-area basis than in the 204 trees/ha planting. In experiment 2, yield per canopy volume of the trees with sugar apple interstock increased by about 80% between 1993 and 1994, presumably due to a marked increase in the density of fruiting laterals relative to only a small increase in canopy volume (Tables 1 and 3; Fig. 2).

Harvest index was 4 times higher with cherimoya rootstock than with controls, and about double of that in other treatments (Table 2). Harvest index was positively ($r^2 = 0.64$, $P<0.05$) correlated with yield per canopy volume but not ($P>0.05$) with yield per tree.

Fruit quality

Most fruit-quality variables (average fruit weight, Brix, symmetry, seediness, pulp recovery) were not affected by the treatments (data not presented). Fruit from sugar apple interstocks were 20% smoother than those from other treatments (score 2.6 *v.* 2.1). Compared with controls, sugar apple interstock reduced the severity of 'woodiness' by about

Table 2. Experiment 1. Effects of paclobutrazol (PBZ), root restriction and sugar apple interstock on yield of the custard apple cv. African Pride in subtropical Australia

Paclobutrazol was injected in November at the commencement of the current season's growth; harvest index is the proportion of total tree dry weight allocated to fruit; data are the means of four trees

Treatment	Rootstock	Yield (kg/tree)		Yield (t/ha)		No. of fruit per tree		Fruit weight per butt cross-sectional area (g/cm^2)		Yield per canopy volume (kg/m^3)		Harvest index (%)
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1993
Sugar apple interstock	Cherimoya	15.3	14.6	12.7	12.2	34	30	174	127	1.7	1.2	11.2
No interstock	Cherimoya	25.9	33.2	21.6	27.7	61	68	216	236	1.7	1.6	22.5
Root restriction	Own roots	25.5	36.9	21.2	30.7	54	79	135	159	0.9	0.8	12.6
Trunk-injected PBZ	Own roots	17.8	34.2	14.8	28.4	32	69	89	154	0.7	0.7	12.6
Foliarly applied PBZ	Own roots	19.7	48.6	16.4	40.4	34	103	100	213	0.6	1.4	13.4
Control	Own roots	19.4	22.0	16.2	18.3	40	46	99	98	0.7	0.4	5.9
l.s.d. ($P = 0.05$)		3.5	4.2	3.4	3.9	9.4	10.5	39	45	0.4	0.4	2.5

Table 3. Experiment 2. Effects of paclobutrazol (PBZ) and sugar apple interstock on yield of the custard apple cv. African Pride in subtropical Australia

Paclobutrazol was injected in March in the previous season; data are the means of eight trees in 1994

Treatment	Yield (kg/tree)		Yield (t/ha)		No. of fruit per tree		Yield per canopy volume (kg/m^3)		Fruit weight per butt cross-sectional area (g/cm^2)	
	1993	1994	1993	1994	1993	1994	1993	1994	1993	1994
Own roots	45.6	57.2	9.5	11.9	128	156.4	0.78	0.55	183	118
Own roots + PBZ	39.7	76.4	8.3	15.9	115	214.1	0.72	1.11	175	259
Sugar apple interstock	15.6	27.2	3.2	5.7	46	68.5	1.53	2.54	167	253
l.s.d. (P = 0.05)	5.6	15.8	2.1	3.4	15.7	37.8	0.25	0.35	n.s.	54

75% and 'brown pulp' by about 50% (Table 4). Trunk-injected paclobutrazol also reduced the severity of 'woodiness' in experiment 2 (Table 4). 'Woodiness' and 'brown pulp' tended to occur together (r^2 = 0.65, P<0.05). Fresh weight of 'woodiness' increased (r^2 = 0.49, P<0.05) with shoot length at harvest.

Dry matter production

Cherimoya rootstock and sugar apple interstock reduced dry weight for most tree organs and total tree dry weight by about 60% (Fig. 7). Trunk-injected paclobutrazol also reduced limb dry weight by about 50% and root dry weight by 20%. Sugar apple interstock altered distribution in favour of leaf, 1 year-old laterals, trunk and root, but decreased the allocation to older branches (Fig. 7).

Starch concentration and reserves

Starch concentrations in increasing order were the following: leaves<new season's laterals<1-year-old laterals<branches = limbs = trunk<major roots (Fig. 8). Irrespective of the plant part sampled, starch concentrations were higher in trees on sugar apple interstocks or cherimoya rootstock than in trees on their own roots.

Sugar apple interstock increased starch concentration in most plant organs but because of reduced plant dry weight, starch reserves were generally lower than in controls (Fig. 8). The only exception was in new wood where starch reserves were higher in trees on interstock or rootstock. With other treatments the starch concentrations in different plant organs generally increased relative to the controls but the weight of starch reserves in the different organs was more variable. There was also a negative correlation between leaf and new wood starch and shoot dry weight across all treatments (Fig. 9).

Leaf nutrient concentrations

Trunk-injected (1.66 ± 0.06%) and foliarly applied paclobutrazol (1.59 ± 0.04%) and sugar apple interstocks (1.72 ± 0.07%) significantly (P<0.05) increased leaf Ca concentrations compared with controls (1.45 ± 0.04%) but treatments had no significant effect on the concentrations of other nutrients (data not presented).

Discussion

Tree growth

Sugar apple interstock reduced vegetative growth and consequently tree size of custard apple cv. African Pride. As a rootstock, sugar apple is susceptible to *Pseudomonas* spp. (George and Nissen 1986), but when used as an interstock, trees remained healthy because the susceptible tissues were not in direct contact with pathogenic organisms in the soil. Untreated trees on their own roots reached near-maximum size within 5 years after planting. Root-restriction bags proved to be ineffective due to growth of major roots through

Table 4. Effects of paclobutrazol (PBZ), root restriction and sugar apple interstock on internal fruit quality of the custard apple cv. African Pride in subtropical Australia

Paclobutrazol was applied in November at the commencement of the current season's growth in experiment 1 and injected in March in the previous season in experiment 2; data are the means of 4–8 trees

Treatment	Rootstock	Fresh weight of 'woodiness' per fruit (g)		'Brown pulp'(%)	
		Experiment 1	Experiment 2	Experiment 1	Experiment 2
Control	Own roots	11.8	13.8	7.4	10.6
Sugar apple interstock	Cherimoya	2.9	4.8	3.3	5.8
No interstock	Cherimoya	13.5	—	20.2	—
Root restriction	Own roots	11.1	—	12.2	—
Trunk-injected PBZ	Own roots	14.6	3.6	23.2	3.8
Foliarly applied PBZ	Own roots	15.1	—	25.1	—
l.s.d. (P = 0.05)		8.5	8.5	2.6	2.6

the seams. Planting densities for experiment 1 were about double the current industry standard, and light penetration to the middle and lower sections of the canopy was inadequate. However, despite light being limiting in the lower sections of the canopy, much higher yields were recorded where trees were planted at a higher density, presumably because more light was intercepted across the whole orchard because of a higher total canopy surface area.

The response to paclobutrazol trunk-injected in March, nearing completion of the second vegetative flush, was rapid, with visual changes (shorter internodes and reduced leaf size) evident within 4–6 weeks. In contrast, injections in November, at the commencement of vegetative flushing, gave a much slower and weaker response, presumably due to poor translocation to growing points. Localised necrosis was also observed with earlier injection, indicating a pooling of the chemical at the injection site. Studies on the trunk-injection of phosphonate to control *Phytophthora cinnamomi* have also shown that translocation to the roots occurs after hardening of the spring flush (Whiley *et al.* 1995).

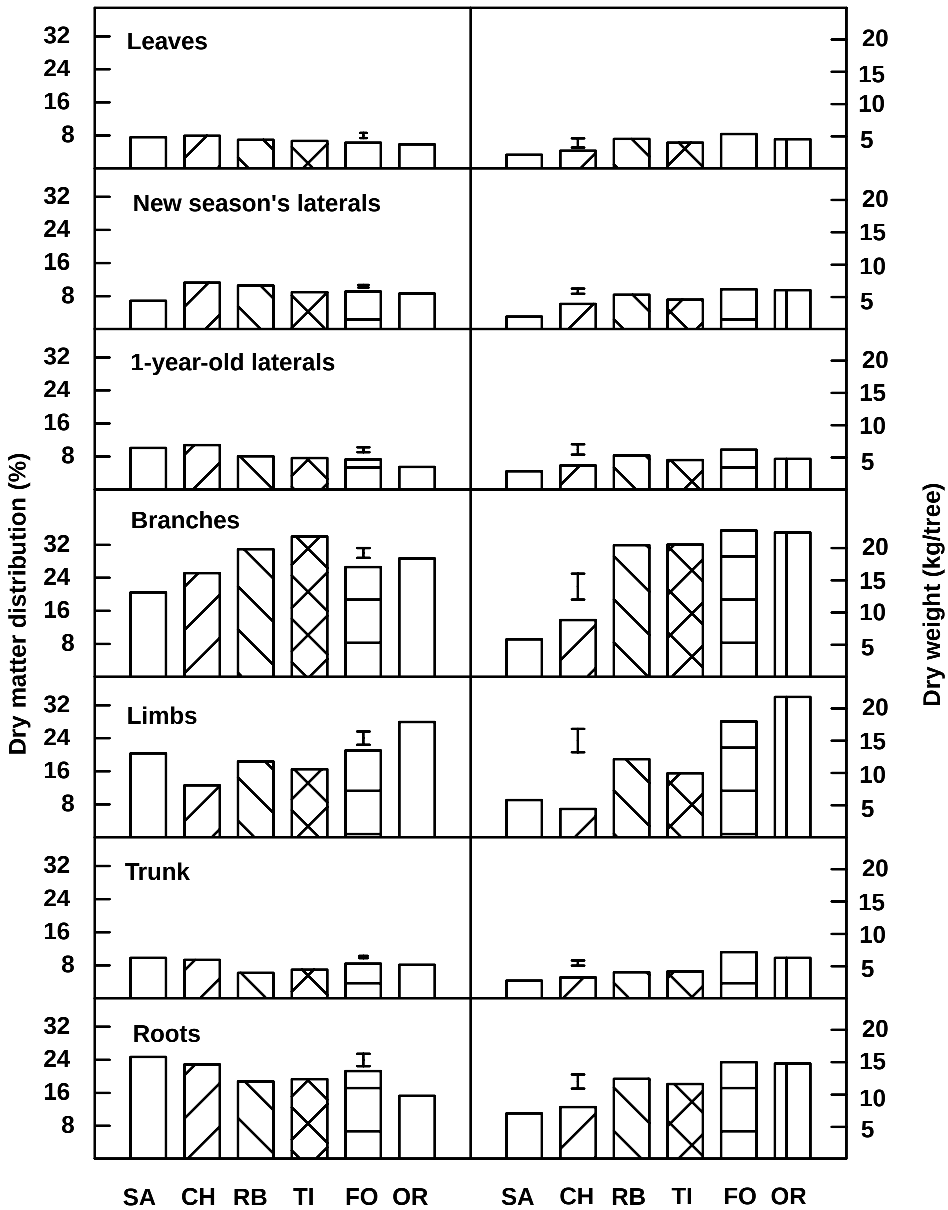

Figure 7. Experiment 1. Effects of interstock, root bag and paclobutrazol on dry weight and distribution in custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees. Vertical bars represent l.s.d. (P = 0.05). SA, sugar apple interstock; CH, cherimoya rootstock; RB, root bag; TI, paclobutrazol trunk-injected; FO, paclobutrazol foliarly applied; OR, own roots.

Because of high growth rates in the subtropics, custard apple may need to be trunk-injected with paclobutrazol within 2 years of planting to prevent excessive growth and canopy shading. Although rates of trunk-injection were 10 times higher than those used for other tree crops such as stonefruit (1.0 g a.i./tree), lower rates could be used before the trees develop an extensive root system. There was no loss of fruiting laterals due to paclobutrazol. Numerous studies

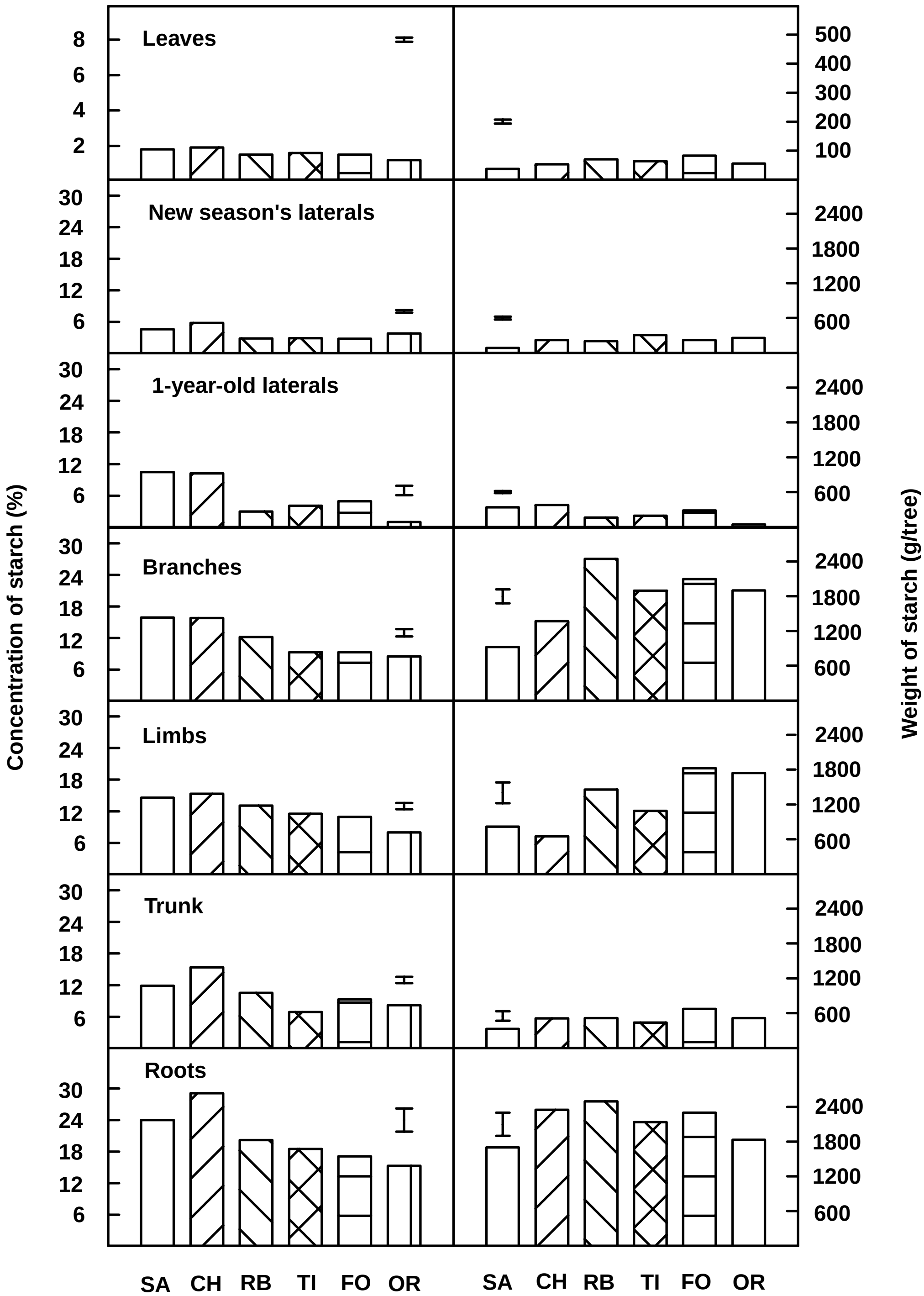

Figure 8. Experiment 1. Effects of interstock, root bag and paclobutrazol on concentration of starch in different plant organs in custard apple cv. African Pride in subtropical Australia. Data are the means of 4 trees. Vertical bars respresent l.s.d. (P = 0.05). SA, sugar apple interstock; CH, cherimoya rootstock; RB, root bag; TI, trunk injected paclobutrazol; FO, paclobutrazol-foliarly applied; OR, own roots.

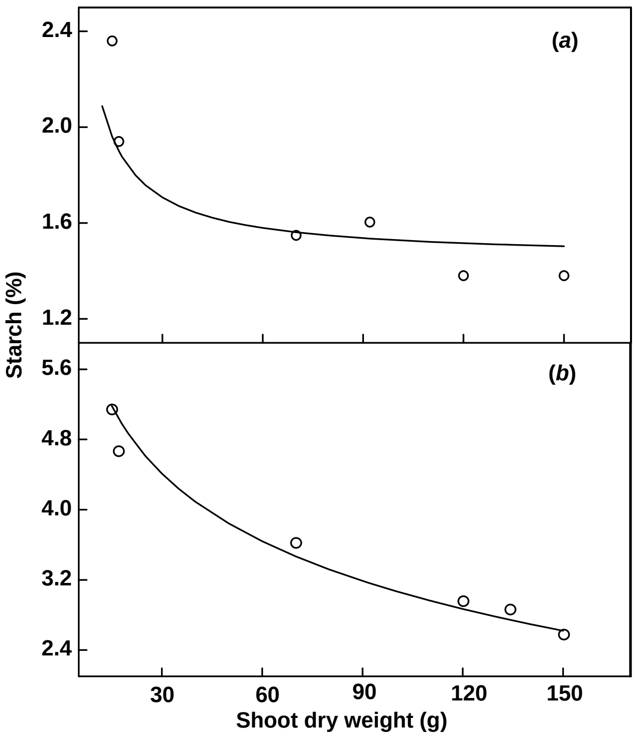

Figure 9. Experiment 1. The relationship between starch in the (*a*) leaf and (*b*) new-wood lateral and shoot dry weight in the custard apple cv. African Pride in subtropical Australia (n = 6). Equations of the lines are:

(*a*) $y = 1.453 + 7.556/x$ ($r^2 = 0.82$, $P<0.05$);
(*b*) $y = 8.19 + 1.111\log_e x$ ($r^2 = 0.97$, $P<0.05$).

have shown the beneficial effects of foliar applications in reducing tree growth (Quinlan 1980; Erez 1984; Martin *et al.* 1987). Foliar applications of paclobutrazol controlled growth only partially. More-recent studies have shown the growth retardant uniconazole to be more efficacious (A. P. George unpublished data).

Flowering

Sugar apple interstocks and trunk-injected paclobutrazol reduced apical dominance, and increased the number of weaker laterals and hence the number of flowers per shoot. The increase in fruit number per tree for sugar apple interstock and trunk-injected paclobutrazol treatments appears to be entirely due to the increased flowering, resulting in increased fruit set, and not due to increased average fruit weight which was not affected. Higher shoot starch concentrations associated with reduced shoot growth and vegetative flushing may also have contributed in improving floral initiation and flowering, as has been shown to be the case with many other tropical and subtropical fruits (Bower *et al.* 1990). Unexpectedly, paclobutrazol alone did not lead to earlier harvest (George and Nissen 1987*a*, 1987*b*; Martin *et al.* 1987).

Fruit quality

Fruit from the sugar apple interstocks and the paclobutrazol trunk-injected trees had smoother skin and also lower levels of ‘woodiness’ and ‘brown pulp’ than those in other treatments. The reduction in fruit disorders for these treatments may also have been associated with reduced fruit Ca concentrations (not measured), since leaf Ca concentrations were reduced. The reduction in the severity of ‘woodiness’ and ‘brown pulp’ is in agreement with previous studies (George *et al.* 2000), which have shown that excessive shoot extension growth and low fruit Ca concentrations are major contributing factors to increasing the severity of this disorder.

Yield and efficiency

Both interstock and paclobutrazol increased yield efficiency on a tree volume basis. In this experiment, the maximum harvest index was recorded for trees on cherimoya rootstock. These results indicate that further progress in yield efficiency may be achieved through a reduction in the structural components, which presumably have high respiration rates.

Conclusions

Sugar apple interstock, and to a lesser extent trunk-injected paclobutrazol, reduced tree growth in custard apple cv. African Pride. The interstock decreased yield per tree and per hectare whereas paclobutrazol slightly increased both. The canopy of interstock trees had not yet reached their maximum space allotted at the conclusion of either experiment; thus, it is highly possible that yield per hectare may have continued to increase. However, other factors besides yield need to be evaluated in selecting orchard management practices. The smaller tree size of trees with interstock would significantly reduce the time and therefore costs associated with pruning and harvesting. There are also benefits in using paclobutrazol and interstock in terms of internal and external fruit quality. However, because of the very high rates of paclobutrazol that need to be applied, and the associated cost, it is unlikely that this method of tree-size control will be used commercially. Root-restriction bags need to be re-evaluated using bags of different composition and stronger seams. Use of sugar apple interstock combined with higher planting densities (>800 trees/ha) than currently recommended (300 trees/ha) could be used with an improvement in fruit quality.

References

Allan P, George, AP, Nissen RJ, Rasmussen T, Morley-Bunker MJ (1993) Effects of paclobutrazol on phenological cycling of low-chill ‘Flordaprince’ in subtropical Australia. *Scientia Horticulturae* **53**, 73–84.

Bower JP, Lovatt CJ, Cutting JGM, Blanke MM (1990) Interaction of plant growth regulator and carbohydrate in flowering and fruit set. *Acta Horticulturae* **275**, 425–434.

Chalmers DJ, Mitchell PD, Van Heek L (1981) Control of peach growth and productivity by regulated water supply, tree density and summer pruning. *Journal of the American Society for Horticultural Science* **106**, 307–312.

Chalmers DJ, Mitchell PD, Jerie PH (1984) The physiology of growth of peach and pear trees using reduced irrigation. *Acta Horticulturae* **146**, 143–149.

Chalmers DJ, Mitchell PD, Jerie PH (1985) The relation between irrigation, growth and productivity of peach trees. *Acta Horticulturae* **173**, 283–288.

Dann IR, Wildes RA, Chalmers DJ (1984) Effects of limb girdling on growth and development of competing fruit and vegetative tissues of peach trees. *Australian Journal of Plant Physiology* **11**, 49–58.

DeVilliers H, Cutting JG, Jacobs G, Strydom DKL (1990) The effect of girdling on fruit growth and internal quality of 'Culemborg' peach. *Journal of Horticultural Science* **65**, 151–155.

Erez A (1984) Effect of soil-applied paclobutrazol in drip irrigated peach orchards. *Acta Horticulturae* **179**, 513–520.

Evans EP (1977) 'Pruning and crop control of peach trees.' Technical publication, Department of Agricultural Services, Pretoria, South Africa. B.I.

Fernandez-escobar R, Martin R, Lopez-rivares P, Paz suarez M (1987) Girdling as a means of increasing fruit size and earliness in peach and nectarine cultivars. *Journal of Horticultural Science* **62**, 463–467.

George AP, Nissen RJ (1986) Growth, yield and scion/rootstock interaction effects of the custard apple (*Annona atemoya* Hort.) in south-east Queensland. *Queensland Journal of Agricultural and Animal Science* **43**, 73–81.

George AP, Nissen RJ (1987*a*) Growth control of low chill stonefruit using retardants and other management techniques. In 'Proceedings of the first national low chill stonefruit conference'. (Ed. I Skinner) pp. 132–143. (Exotic Fruit Growers Association: Lismore, NSW)

George AP, Nissen RJ (1987*b*) Effects of paclobutrazol on vegetative and floral development of Fla 6-3 and Sunred nectarines. *Acta Horticulturae* **199**, 173–179.

George AP, Nissen RJ (1988) The effects of temperature, vapour pressure deficit and soil moisture stress on growth, flowering and fruit set of custard apples (*Annona cherimola* × *Annona squamosa*) 'African Pride'. *Scientia Horticulturae* **34**, 183–191.

George AP, Nissen RJ (1994) Ecophysiology of *Annona*. In 'Handbook of environmental physiology of fruit crops'. (Eds B Schaffer, PC Andersen) pp. 200–206. (CRC Press Inc.: Boca Raton, FL)

George AP, Nissen RJ, Carseldine ML (1989) Effect of season (vegetative flushing) and leaf position on the leaf nutrient composition of *Annona* spp. hybrids, cv. Pinks Mammoth in South-east Queensland. *Australian Journal of Experimental Agriculture* **29**, 587–595.

George AP, Broadley RH, Nissen RJ, Smith L (2002) Effects of calcium, boron and dwarfing inter-stock on fruit quality of custard apple (*Annona* spp. hybrid) cv. African Pride. *Acta Horticulturae* **575** (in press).

Leuty SJ, Pree DJ (1980) The influence of tree population and summer pruning on productivity, growth and quality of peaches. *Journal of the American Society for Horticultural Science* **105**, 702–705.

Martin GC, Yoshikawa F, Larue JH (1987) Effect of soil applications of paclobutrazol on vegetative growth, pruning time, flowering, yield, and quality of 'Flavorcrest' peach. *Journal of the American Society for Horticultural Science* **112**, 915–921.

Noel ARA (1979) The girdled tree. *Botancial Review* **36**, 162–195.

Quinlan JD (1980) Recent developments in the chemical control of tree growth. *Acta Horticulturae* **114**, 144–151.

Rasmussen TS, Henry RJ (1990) Starch determination in horticultural plant material by enzymic-colorimetric procedure. *Journal of Food and Agricultural Science* **52**, 159–170.

Stiles WC (1984) Effects of pruning on growth and size of trees. *Acta Horticulturae* **146**, 225–229.

Tukey LD (1964) 'Dwarfed fruit trees.' (Macmillan: New York)

Whiley AW, Hargreaves PA, Pegg KG, Doogan VJ, Ruddle LJ, Saranah JB, Langdon PW (1995) Changing sink strengths influence translocation of phosphonate in avocado (*Persea americana* Mill.) tree. *Australian Journal of Agricultural Research* **46**, 1079–1090.

Williams MW (1984) Use of bioregulators to control vegetative growth of fruit trees and improve cropping efficiency. *Acta Horticulturae* **146**, 97–104.

Young MJ, Crocker TE (1982) Severe post-harvest topping of high density peaches and nectarines. *HortScience* **17**, 220–222.

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