REMOVING PRE- AND POST-HARVEST CONSTRAINTS TO CUSTARD APPLE MARKETING

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Report compiled by Roger Broadley

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This report summarises the results of four & half years research, development and extension conducted on behalf of the custard apple industry.

Project jointly funded by HRDC (FR425) and RIRDC (DAQ- 167A), and Australian custard apple growers

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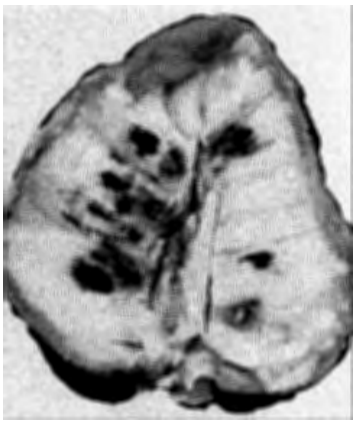
Pre-harvest research

Annona spp. hybrids have the potential to become major exotic fruits on both domestic and export markets provided problems associated with poor fruit quality and low productivity can be solved. These studies, and those previously reported by George *et al.* (1988), have shown that, although *Annona* spp. hybrids are widely adapted to the subtropics, maximum yield, productivity and fruit quality are produced only under specific environmental conditions. However, through varietal selection, which is currently in progress (George *et al.* 1997), and implementation of desirable management strategies, productivity can be significantly improved. The development of pheno/physiological models has been the basis for developing management strategies for a range of subtropical fruit crops. This approach has been used with my studies on *Annona* spp. Hybrids, as it provides an organised way of determining 'gaps' in the current knowledge on how to improve productivity and also allows for adoption of management practises used with other tree crops with similar physiology and phenology.

Annona spp. hybrids, in their phenological models, are intermediate to temperate and evergreen tree fruits, producing two growth flushes per season, one major and one minor. In this aspect it is very similar to low-chill stonefruit (Allan *et al.* 1993). The flowering pattern is strongly associated with vegetative flushing and flowering intensity is highly dependant on the number of new season, small laterals, similar to the tropical tree fruit guava (*Psidium* spp.). However, unlike most other tree fruits, *Annona* spp. hybrids flower over a 2-3 month period, with 2 and sometimes 3 flowering flushes. Strongly growing, vegetative shoots, during the first major vegetative growth flush, exert a relatively stronger sink strength compared with developing fruitlets, and this competition appears to be the primary cause of internal fruit quality problems such as 'woodiness' and 'brown pulp'.

Control of this shoot growth flush either through using growth retardants or summer tip pruning has been shown to improve fruit growth and fruit quality. Seasonal shoot extension growth should be restricted to less than 60 cm to keep 'woodiness' to an acceptable level of <10g per fruit. Foliar and soil applied calcium (Ca) were also found to be beneficial in reducing internal fruit defects, but the responses were variable. It seems that responses to Ca are more likely when whole tree and individual shoot vigour are controlled. Fruit Ca concentrations need to be maintained at >0.15% and leaf Ca >1.6%. **The current leaf nutrients standards for *Annona* spp. hybrids appear to be set too low.**



It appears that while the control of individual shoot vigour is important, this is unlikely to be achieved unless overall tree vigour is controlled. In this study, two methods; viz. trunk-injection of the growth retardant paclobutrazol, and the use of sugar apple inter-stock, were highly effective in controlling tree size and vigour and improving yield efficiency. The very high rates of trunk-injected paclobutrazol necessary to obtain adequate growth control indicate that earlier treatment after planting is warranted or alternative methods, such as bark painting, should be used. Also, because of the current small size of the *Annona* spp. hybrid industry, it is highly unlikely that the manufacturers of paclobutrazol will be interested in registering this product for use on this species; however an 'off' label registration may be

applied for. In contrast, the use of dwarfing sugar apple inter-stock provides a relatively cheap method of dwarfing tree size and reducing overall shoot vigour.

Overall tree vigour may also be controlled through use of water stress and nitrogen (N) restriction, this latter method is currently being investigated. Mild water stress was highly beneficial in improving floral initiation and flowering, however, these benefits were associated with a slight reduction in fruit size in the field. Because of this adverse response, water stress is a less effective technique to control growth than either paclobutrazol or an appropriate inter-stock. The adverse effect of water stress on fruit size is probably due to the effects on reducing cell division. There was no threshold value of soil moisture potential below which a response occurred. The slight osmotic adjustment of *Annona* spp. hybrid leaves in the field may account for the slightly higher stress values that field-grown trees can endure without loss of turgor (George and Nissen, 1992). Based on current findings, further studies are needed to elucidate on the benefits of water stress as a means of controlling tree vigour and improving yield in commercial orchards.

With tree fruits, of major concern, is the harvest increment ie. the allocation of resources to fruit and not vegetative components of the tree. Trees with dwarfing sugar apple inter-stocks had harvest increments that were more than double that of trees on their own roots and yield efficiency was more than 40% higher. **Even so, the harvest increments for trees on dwarfing inter-stock were low compared with those obtained with modern apple cultivars on dwarfing rootstocks.** It is anticipated that for trees on dwarfing inter-stocks that training them onto a palmette or Tatura trellis system may improve light penetration and yield and fruit quality. These experiments, which are currently in progress, are already showing the comparative advantages in using Tatura trellising to improve yield and fruit size.

In terms of assimilation physiology, *Annona* spp. hybrids have similar rates of A to temperate fruits which have typical rates of A of between 14-18 μmol CO_2 m^{-2} s^{-1} (Flore, 1994). Interestedly, trees compensated for increasing crop loads by increasing A by about 30%. Similar responses have been observed in stonefruit and these were shown to be due to increased g_s and not due to 'feedback inhibition' caused by leaf starch accumulation (Flore, 1994). The high correlation between A and root flushing indicates that the roots have a sink activity. Similar findings have been found with non-astringent persimmon (George *et al.*, 1997).

A and g_s of *Annona* spp. hybrids were highly positively related to increasing relative humidity of the atmosphere and to a much lesser extent on other plant and environmental variables. Similar findings were found for *Annona* spp. hybrids in a previous study by George *et al.*(1990) and for a wide range of other plants (Cowan, 1977; Losch and Tenhunen, 1981). Besides affecting A, relative humidity appears to the key environmental variable affecting the productivity of *Annona* spp. hybrids with high relative humidity (70-90%) improving fruit set and aiding movement of insect pollinators (George *et al.* 1989).

Methods of improving fruit size and yield in the field would involve raising relative humidity using overhead intermittent misting and windbreaks and adjusting crop load to maximise A but without reduction in fruit size. Alternatively, selection of cultivars which are environmentally less sensitive may prove a more fruitful approach to improving the productivity of *Annona* spp. hybrids. This, coupled with further selection of dwarfing rootstocks, offers the most exciting possibilities for improving productivity of *Annona* spp. hybrids in the future.

Post-harvest research

Low oxygen atmospheres for export shipments

Using low oxygen atmospheres (controlled atmosphere [CA] or modified atmosphere [MA]) to increase post-harvest life was extensively researched but found to be severely limited, by either disease in CA, or in MA, from a previously unreported physiological disorder, hardcore. Extensive research couldn't find a successful way of either reducing disease severity or of overcoming hardcore. Investigations examined both 13°C (simulated container shipments) and 30°C (simulating Singapore ambient) with similar results. Concomitantly, a major Singapore importer indicated serious concern about the deleterious effects on current good prices if test shipments of 20 foot container loads of fruit were out-turned on the Singaporean market.

Further work on low oxygen storage was abandoned for the above reasons, and efforts were directed towards improving post-harvest quality by other means.

Best Packaging

Suitable test equipment and procedures for packaging trials were successfully developed. The new equipment allowed a wide range of different packaging combinations to be quickly and accurately compared, by ensuring each carton received an equal (simulated road) test treatment. Of more than 12 combinations tested in triplicate, Styrofoam socks with a carton liner of 10mm bubble wrap gave outstanding protection. The beneficial effect on export grade fruit is quite dramatic compared to the standard tissues.

However, if fruit at packing show more than about 10% skin blackness (common on the domestic market), the effective visual improvement is masked. Two trial demonstration consignments into Singapore were attempted but thwarted by factors beyond control. Two domestic trial consignments to Sydney with African Pride and Pinks Mammoth were successful and confirmed the laboratory conclusions.

Post-harvest skin blackening

Low post-harvest humidity (60% RH), common in air-conditioned retail shops, was found *not* to increase skin blackening in Pinks Mammoth fruits. African Pride fruit were not tested but may be sensitive to low humidities. Fruit immaturity in Pinks Mammoth was found to result in increased blackening, but immaturity in Pinks mammoth is not an important commercial problem.

Optimal post-harvest temperatures

A post-harvest storage temperature of 7°C was shown to result in variable and often unacceptable skin blackening in African Prides after only 2-3 days constant, whereas 10°C was acceptable for 5 days constant.

So our current recommendation for cool storage and transport of custard apple remains unchanged at 10°C.

Retail studies

Introductory trials on examining limitations to retail sales in Brisbane were made. (1) Increased skin blackening did not result from handling by consumers. (2) previously unexplained increases in skin blackening were shown to be most likely attributable to rain during harvest.

Accelerated cooling

Cooling using crushed ice was found to result in substantial increased abrasion (apparently from the edges of the ice), and also gave no important increase in post-harvest life compared to fruit held at 10°C.

Pruning affects fruit quality

A pruning regime aimed at minimising internal woodiness was found to increase sweetness and extend post-harvest life by 10 %.

Gibberellic acid ineffective

Gibberellic Acid (GA) was found to have no beneficial effect on extending fruit post-harvest life. On persimmons GA is reported to substantially extend post-harvest life.

Post-harvest quality variable

Fruit examined in post-harvest experiments continue to show unacceptable variation in quality, either in woodiness or eating quality. The cause of the variation is the subject of extensive research in the current HRDC funded custard apple project.

Extension of Results

All the results of our research development and extension work over the past four and a half years has been compiled in a format suitable for easy use by custard apple growers in Australia. This will be known as the Agrilink Custard Apple Information Kit, and be published by the Second Australian Custard Apple Conference in July 1999. Appropriate acknowledgment of inputs by funding bodies will be made.

It will contain the following sections:

- A checklist of things growers need to know before you start growing the crop.
- The twenty or so most commonly asked questions about the crop
- Information on growing the crop
- More detailed information on the key issues and important decisions affecting the crop
- A picture series of the common problems, and their practical solutions
- A list of industry organisations, product suppliers, information sources and further reading
- An A to Z index to help you find information quickly
- A place to store further information that has been collected

A breakdown of the information is attached on the following page. In addition a list of the key issues is also attached. Examples of three key issues are given in full in the section titled Full Technical Papers (see page 101)

Technical summary

1.0 Pre-harvest research

1.1 PHENOLOGICAL CYCLING OF *ANNONA* SPP. HYBRIDS IN SUBTROPICAL AUSTRALIA

A.P.GEORGE[1] and T.S.RASMUSSEN[2]

The phenological cycles of *Annona* spp. hybrids were established over a 2-3 year period in subtropical Australia. Seasonal changes in growth of fruits, shoots and roots and starch and nutrients concentrations were monitored fortnightly. At Nambour (Lat. 26°), termination of endo-dormancy occurred about 40 days in advance of vegetative budbreak. Trees exhibited a major growth flush in early summer and either one or two, smaller flushes in the early autumn, and three root flushes; late spring, late summer and early winter. Fruit exhibited a normal sigmoidal growth pattern.

At Nambour and Palmwoods the mean fruit development periods (FDP) for cv. Hillary White and African Pride were 21 and 26 weeks, respectively. For cooler and warmer growing regions, the mean FDP was increased or shortened by 2 and 4 weeks, respectively. FDP was highly negatively correlated (r^2=0.98, P<0.05) with increasing mean monthly minimum temperature. Starch reserves were greatest in the roots followed by the trunk and shoots. Starch concentrations fell to their lowest levels during budbreak and reached their peak about one month prior to the commencement of leaf abscission. Leaf analysis showed that N, P and K concentrations decreased throughout the season, while Ca and Mg increased. These studies provide a basis for the correct timing of key management practises such as fertilising, thinning and irrigation.

1.2 EFFECTS OF ENVIRONMENTAL VARIABLES, SEASON AND CROP LOAD ON NET CO_2 ASSIMILATION, LEAF CONDUCTANCE AND PLANT WATER STATUS OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

A.P. GEORGE

Diurnal and seasonal changes in net CO_2 assimilation (A), leaf conductance (g_s) and leaf water potential (Ψ_L) were investigated for *Annona* spp. hybrid (*Annona cherimola* X *Annona squamosa*) trees cv. African Pride in subtropical Australia. Most of the diurnal variation in A and g_s could be attributed to changes in RH (r^2>0.65, P<0.05). The addition of other variables besides RH into multiple linear regressions analysis added little to explaining the variation in A or g_s. Leaf water potential (Ψ_L) was highly responsive to air temperature (AT) (r^2=0.56, P<0.05). The marked sensitivity of *Annona* spp. hybrid stomata to low RH may be one of the reasons for poor fruit set and size of *Annona* spp. hybrid under subtropical conditions due to carbohydrate source limitations. Studies on seasonal changes in A over 2 seasons showed 4 major peaks in A which coincided with periods of root growth. A increased with crop load with a rapid, non-linear (r^2=0.98, P<0.05) increase with fruit number per tree and a linear (r^2=0.89, P<0.05) increase with fruit number per unit canopy volume.

1.3 EFFECTS OF PRUNING, CINCTURING AND PACLOBUTRAZOL ON SHOOT GROWTH, YIELD AND FRUIT QUALITY OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

A.P.GEORGE[1] and T.S. RASMUSSEN[2]

Three experiments were conducted to evaluate the effects of different methods of reducing shoot growth on flowering, fruit set, fruit growth and fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. The methods evaluated were: dormant cane vs. spur pruning, early summer shoot tipping, shoot cincturing and foliarly-applied paclobutrazol. Both shoot tipping and foliar application of paclobutrazol in mid-November, at the commencement of the first, major vegetative growth flush, suppressed vegetative growth by about 70% and increased fruit weight by 16% and 26%, respectively. Foliar application of paclobutrazol reduced the severity of 'woodiness' disorder by 29% but shoot tipping had no significant (P>0.05) effect. In a comparative study of cane vs. spur, dormant pruning systems, spur pruning increased the severity of 'woodiness' and 'brown pulp' disorders 10-fold due to excessive, compensatory regrowth. Cane-pruned trees carried three

times the number of fruit and about double the weight of fruit per tree compared with spur-pruned trees.

1.4 EFFECTS OF CALCIUM, BORON AND TREE VIGOUR ON FRUIT QUALITY OF THE *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

A.P. GEORGE

Two experiments were conducted to evaluate the interactive effects of soil and foliar applied Ca and B and tree and shoot vigour on fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Fruit, and to a lesser extent leaf Ca and B concentrations, were more influenced by tree vigour, and not by soil or foliar applications of Ca or B. At harvest, dwarfing sugar apple (*Annona squamosa*) inter-stock increased fruit Ca concentration by about double and total Ca content per fruit by 80%. Over 2 seasons, sugar apple inter-stock reduced the severity of two internal disorders 'woodiness' and 'brown pulp' by 30-70%.

The severity of 'brown pulp' disorder was six times greater with early-season fruit compared with the late-season fruit due to the strong competition between the developing fruitlet and the first major vegetative growth flush. Fresh weight of 'woodiness' per fruit increased with shoot extension (r^2=0.62, P<0.05) and decreased with fruit Ca concentration in January, three months prior to harvest (r^2=0.57, P<0.05). Soil applied B reduced 'brown pulp', but its effects were less than for Ca. Two sequentially applied, foliar sprays of calcium nitrate (2 g l^{-1}) at fruit set and 4 weeks later reduced fresh weight of 'woodiness' per fruit and % 'brown pulp' by 31 and 51%, respectively, but foliarly-applied B had no significant effect. Paclobutrazol significantly increased fruit fresh weight by 24 % and pulp recovery by 10.8%.

1.5 SEASONAL LEAF NUTRIENT PATTERNS AND LEAF NUTRIENT STANDARDS FOR *ANNONA* SPP. HYBRIDS IN SUBTROPICAL AUSTRALIA

A.P. GEORGE[1] and G.F. HAYDON[2]

Several studies were conducted to determine the influence of variety and rootstock on seasonal leaf nutrient patterns and to set new leaf nutrient standards and sampling times for *Annona* spp. hybrids in subtropical Australia. Seasonal leaf nutrient patterns were established for the two, main commercial *Annona* spp. hybrids cvs. African Pride and Hillary White. Overall, seasonal leaf nutrient patterns for both cultivars and rootstocks were similar to one another and to those previously established for *Annona* spp. hybrids. The current leaf sampling time, about 1 month prior to harvest, was found to be appropriate. In addition, a leaf nutrient survey was also conducted over three years for twelve, high-yielding orchards, representative of the range of soil types in Queensland and northern NSW, the major *Annona* spp. hybrid producing regions of Australia. Based on this survey, new, leaf nutrient standards have been set which will replace existing standards. Leaf nutrient standards for B have doubled and those for Ca increased by 58% compared with those previously set. Leaf Ca concentrations were negatively correlated with shoot growth (r^2=-0.64, P<0.05) which, in turn, was positively correlated with leaf N (r^2=0.73, P<0.05).

1.6 EFFECTS OF WATER STRESS ON FRUIT SET, YIELD AND FRUIT QUALITY OF CONTAINER-GROWN *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE

By A.P.GEORGE[1] and T.S.RASMUSSEN[2]

Two glasshouse experiments were conducted to evaluate the effects of drought on container-grown *Annona* spp. hybrid cv. African Pride, the main cultivar currently grown in Australia. The first experiment primarily evaluated the effects of water stress applied during flowering on subsequent flowering intensity and fruit set; the second experiment evaluated the effects of water stress applied during the fruit development period on subsequent fruit growth, yield and fruit quality. For both Experiments, trees were either watered daily to field capacity (about 20% v/v, 0 day drying cycle) or allowed to dry out to one of three levels of available soil moisture contents (before rewatering to field capacity. At the completion of the stress period for both Experiments, severe soil water stress (about 20% of available water) had reduced shoot growth by about 30%. In Experiment 1, mild soil water stress only (14.8% v/v) during flowering almost doubled the number of flowers per tree compared with well-watered trees. This response appears to be due to a reduction in apical dominance and increased floral initiation. Other stress treatments did not significantly affect flowering intensity.

Project jointly funded by HRDC (FR425) and RIRDC (DAQ- 167A), and Australian custard apple growers

Water stress increased fruit set with the severely-stressed trees setting 27% more fruit than well-watered controls. Due to both increased flowering and fruit set, mildly-stressed trees produced the greatest total weight of fruit per tree, more than double that of severely-stressed trees, and 25% more than well-watered controls. Severe water stress either during flowering or fruit development reduced average fruit weight by 81 and 50%, respectively. The reduction in fruit weight appears to be due to stomatal closure with increasing leaf (Ψ_L) and soil water potential (Ψ_S) with stomatal conductance (g_s) and net CO_2 assimilation (A) declining rapidly with the onset of stress. There appeared to be no threshold stress value, above which there was no response of A to stress. In conclusion, mild to moderate water stress during the flowering period appears to be beneficial to increasing flowering and fruit set, but fruit size was adversely affected irrespective of the level of stress applied.

1.7 FIELD RESPONSE OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE TO WATER STRESS

A.P.GEORGE[1] and T.S.RASMUSSEN[2]

A field study was conducted to evaluate the effects of water stress applied during the flowering and early fruit set period on subsequent fruit set, yield and fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Treatments were: wet plots irrigated weekly to replace E_t to bring the profile close to field capacity (16%, v/v) and a dry treatment which was allowed to dry out slowly during the 10 weeks flowering period (11%, v/v), before trees were rewatered. Water was mainly extracted from the top 20-40 cm of the soil profile and to a much lesser extent from deeper levels, indicating that the majority of roots are located in the surface zone.

The effects of soil moisture stress on leaf water potential (Ψ_L) did not become apparent until about 3 weeks after withholding irrigation. At the completion of the stress period, the differences in Ψ_Ls between the wet and dry treatments was about 0.7 MPa. Stressed trees produced 35% more flowers than with well-watered trees as a consequence of reduced apical dominance, a doubling of small lateral shoots per branch and increased floral initiation. Although fruit set patterns were different for the wet and dry treatments there was no significant difference in overall percentage fruit set (av.55%). Water stress increased tree fruit weight and numbers by about 26 and 47%, respectively. Yield efficiency as measured on a butt cross-sectional and canopy volume basis was increased by 17 and 37%, respectively, but stress reduced average fruit weight by 11%. In conclusion, moderate water stress during the flowering period appears beneficial to increasing flowering and subsequent yield but this yield increase may be partially negated by reduced fruit size.

2.0 Post-harvest research

2.1 PRODUCTION AREA AFFECTS POST-HARVEST QUALITY

L.G. Smith, G.F. Meiburg, and J.A. Barker

Mature African Pride custard apples were harvested from 2 farms in each of 4 production areas Central Queensland (CQ), North Queensland (NQ), southeast Queensland (SEQ), and Northern New South Wales (NSW). Fruit were fungicide dipped (hot Benlate®) and ripened at 22°C. Fruit quality parameters of weight, carpel pointedness, days to eating soft, degree of fruit splitting, flesh translucency, woodiness (an internal disorder), seeds per 100 grams and eating quality were recorded.

Table *Production area effects on quality of mature ripe African Pride custard apples.*

District	NQ	CQ	SEQ	NSW
Weight (grams)	451 a	423 a	425 a	451 a
Days to eating soft	7.2 b	5.8 a	5.1 ac	4.5 c
Carpel pointedness (1-3)	1.5 a	1.4 ab	1.2 bc	1.0 c
Splitting (0-3)	0.6 b	1.4 a	0.2 bc	0.1 c
Translucency (0-3)	1.4 a	1.0 a	0.6 a	1.1 a
Woodiness (0-5)	1.6 bc	3.1 a	2.1 b	1.5 c
Seeds per 100 grams	10.4 a	-	10.0 a	10.1 a
Eating quality (1-9)	5.6 a	-	6.6 b	6.1 ab

Production area significantly affected days to eating soft, carpel pointedness, splitting, and woodiness, with SEQ and NSW fruit generally being less pointy and less woody than NQ and CQ fruit. Internal translucency was highly variable within all localities, and not related to district or farm. Importantly, internal woodiness differed between individual farms, indicating a farm management (fertiliser practice) effect on the severity of the disorder.

2.2. COMPARING CUSTARD APPLE PACKAGING MATERIALS

L.G. Smith, G.F. Meiburg, J.A. Barker, and J.A. Campbell[1]

Packaging materials were evaluated for their effects on the incidence of skin blackening caused by abrasion and impact during marketing of custard apples in laboratory simulations (using a vibrating table and impact tests) and semi-commercial trials (Sydney and Singapore).

Packaging materials included a single layer tissue wrap (the currently industry standard), polythene bubble wrap (4, 10 and 20 mm bubbles), polythene socks (ezi-sleeves, polysox), PVC foam (11 mm medium density) and cotton wool (as a reference). Bubble wraps were also assessed as top and bottom carton liners.

While polysox and 10 mm bubble wrap gave the best protection, tightness of the pack, both vertical and horizontal, was critical. Loosely packed fruit suffered more abrasion damage in all treatments. Double socks gave better protection to the pointier African Pride fruit.

Carton liners substantially reduced top/bottom damage, but where fruit could move vertically, impact damage still occurred. Foam and cotton wool provided excellent protection. However, they increased fruit temperature by thermal insulation and were rejected, as was 20 mm bubble wrap due to frequent bubble breakages.

The best combinations were able to reduce damage levels on fruit by more than 85%. Some Sydney agents reported that Pinks Mammoth in single socks plus 10mm bubble wrap at the top and bottom of the carton were worth $6-8 per carton more than cartons packed with tissue paper alone.

2.3 EFFECT OF TREE WATER STRESS ON POST-HARVEST FRUIT QUALITY

L.G. Smith, G.F. Meiburg, J.A. Barker, and A.P. George[1]

Samples of 12 fruit from stressed (-1.6 MPa leaf water potential) and non-stressed (-1.0 MPa) trees were weighed, ripened at 22°C, and assessed for post-harvest quality. No significant differences in average weight, days to eating soft, eating quality of ripe fruit, external appearance or internal appearance (including woodiness) were recorded.

2.4 BRISBANE RETAIL MARKETING SURVEY

G.F. Meiburg, and J.A. Barker

A cross section of retailers, from large supermarkets to small fruit shops in Brisbane, was surveyed during the 1996 season to assess the display quality and retailers' opinions and practices.

Severe skin blackening, reported in a previous survey in 1991, was not evident. Minor to moderate skin blemish currently observed appears to be due to natural senescence and deficiencies in packaging. An apparent correlation between rainy conditions during harvesting and subsequent increased chilling injury susceptibility was reported by some retailers, and needs further investigation. Asian customers are major buyers while many Australians seem unfamiliar with the fruit. Retailers frequently preferred medium sized Pinks Mammoth fruit, African Pride often being regarded as inferior tasting and excessively seedy.

2.5 CUSTOMER HANDLING AND SKIN BLACKENING

L.G. Smith, G.F. Meiburg, and J.A. Barker

The effect of customer handling on the development of skin blackening in custard apples had been reported as an important damaging factor in Singapore and Australia. Cartons of Pinks Mammoth and African Pride custard apples were monitored regularly during a 7 day retailing period in each of 2 suburban shops. Control cartons nearby were kept untouched for comparison. All fruit sold within 5-7 days.

No differences in skin blackening were determined between the handled and the control fruit.

2.6 EFFECTS OF NITROGEN PULSING ON STORAGE QUALITY

L.G. Smith, G.F. Meiburg, and J.A. Barker

Samples of 8 African Pride custard apples were stored under 99.5% nitrogen gas for 0, 2, 4, 6, 8, or 10 days at 13°C, to look for increased post-harvest life. After pulsing, fruit were held in air at 22°C until soft ripe and assessed for quality. Pulsing for 2 days had no adverse effect on ripe fruit quality, but did not increase shelf life. Fruit pulsed for >2 days ripened unacceptably with mild to severe external brown blotches, off-flavours and internal infections.

Nitrogen pulsing is not recommended to extend shelf life.

2.7 EFFECT OF HARVEST DATE ON CHILLING INJURY

L.G. Smith, J.A. Barker, and G.F. Meiburg

African Pride custard apples were harvested at weekly intervals from the same farm block in south-east Queensland from April to June, 1996. Fruit were rated for initial skin blackness (%) and stored at 0, 4, 7, 10 or 22 degrees (°C) for 0.6, 1, 2, or 3 days. After storage, fruit were held at 22°C until soft ripe when they were again assessed for skin blackening, and the increase in blackening due to chilling injury (CI) was calculated.

Skin blackening increased as the season progressed, even in the fruit samples held at constant 22°C. Fruits from the first harvest (mid-April) were not injured by any treatment. Generally, no chilling injury occurred at 10°C, while fruit stored at 0 and 4°C were nearly always showed chilling injury.

The data clearly showed that chilling injury susceptibility varies over the season, changing with either internal factors related to development/maturity, or external factors such as weather. Further research is examining the effect of pre-harvest weather on chilling susceptibility.

2.8 EFFECT OF VAPOUR HEAT ON FRUIT QUALITY

G.F. Meiburg

Vapour heat (VH), an approved disinfestation treatment for some fruits, often produces an additional benefit of reducing post-harvest disease levels. This is important for custard apples where the only registered effective treatment, hot Benlate dipping, is being phased out.

Freshly harvested Pinks Mammoth and African Pride fruit were held overnight at 13°C, then heated under 50% or 95% relative humidity (RH) to a 45°C core temperature held for 15 minutes. Fruit were water cooled and stored at 22°C until soft ripe. Control fruit were held at 22°C throughout.

All fruits from both treatments and both varieties developed unacceptable skin browning, flavour loss and watery flesh, although Pinks Mammoth had a better external appearance than African Pride. Fruit treated at 95% relative humidity developed uneven internal ripening, while fruit treated at 50% relative humidity exhibited 2-3 days less shelf-life than controls.

Recent findings in Israel indicate that skin injury can be reduced in hot water dips by increasing osmotic strength of the dip solution eg by adding salt. This should be followed up with further investigations.

2.9 CONTROLLED AND MODIFIED ATMOSPHERE STORAGE OF CUSTARD APPLES

L.G. Smith, and J.A. Barker

The effect of district and season on fruit response to controlled atmosphere (CA) and modified atmosphere packaging (MAP) was examined for cv. African Pride and Pinks Mammoth custard apples.

Fruit were obtained at 2-3 harvest dates from 2-4 farms in each of 4 regions (north, central and south Queensland, and northern New South Wales). All fruit were dipped in Benlate (1g/L at 48±1°C for 2 min) prior to storage for 5, 10, 15 and 20 days at 13°C.

A CA of 2% oxygen and 5% carbon dioxide flowing at 200 mL/min was used. The MAP treatments used 25 and 32 μm polythene bags with 0-4 micro-perforations, 2 Bloomfield purafil sachets and a 150 gram lime sachet insert.

CA stored fruits generally out-turned hard green and subsequently ripened after 2-4 days at 22°C. Quality was unpredictable, often adversely affected by unacceptable skin rotting and breakdown. Some stem end splitting occurred during CA storage, particularly with the early harvests.

MAP stored fruit self-equilibrated to similar CO_2 and O_2 levels as the CA system after 2-3 days. Fruit out-turned hard green, but only the outer 3-5 mm of the fruit subsequently softened, with an inner core remaining hard and poor quality. We have termed this disorder 'hardcore'. Hardcore was not related to district, farm or harvest date, and was not affected by purafil or charcoal inserts within the MAP bag.

Three semi-commercial pilot scale CA container experiments using African Pride were commenced during 1995-96. Out-turn quality was limited by a high disease incidence and shortened green-life from late harvests.

In summary, no modified atmosphere or controlled atmaosphere storage methodology was shown to be commercially acceptable.

2.10 CAUSES OF VARIABLE CHILLING INJURY SUSCEPTIBILITY

L.G. Smith, G.F. Meiburg, and J.A. Barker

Previous research shows that chilling injury susceptibility of African Pride custard apples varies greatly between harvests from individual farms. To determine possible maturity and weather effects, fruit were harvested at 8 weekly intervals from a south east Queensland farm and corresponding weather data recorded.

At each harvest, fruit were held at 0, 4, 7, or 10°C for 15, 24, 48 or 72 hours prior to ripening at 22°C. Control samples were ripened immediately at 22°C. Chilling injury was determined as the increase in % skin blackening (% black) since harvest. Shelf life was determined as the days to eating soft after removal from storage. Four harvests were preceded by rain in the 48 hours before picking.

Shelf life did not show a consistent trend with harvest date (maturity) or weather conditions. In general, % black increased with storage treatment severity and was 2 to 6 times higher in fruit stored at 0 and 4°C compared to other temperature treatments. Chilling susceptibility was affected by weather conditions before harvest, including rainfall and relative humidity (%relative humidity). Effects were consistent in fruit stored at 0, 4 and 7°C for 2 or 3 days, but not in those stored for shorter times, at 10°C, or controls.

Table *Effects of harvest and weather on chilling injury (% black) in fruit stored for 3 days at 7°C.*

Harvest	Rainfall (mm) in 48 hours before harvest	Relative humidity (%) in field at harvest	Black (%)
1	0	40	8.5
2	29	93	31.0
3	4	89	36.8
4	28	96	45.8
5	0	83	25.3
6	0	62	15.8
7	0	84	30.3
8	25	85	17.8

After storage at 0, 4 and 7°C for 3 days, fruit from all except one harvest showed increasing % black from consecutive harvests if rain occurred in the last 48 hours, and a reduction if the weather improved. Changes in relative humidity also affected external blemish levels. This might explain harvest 7 where, although weather remained fine, average relative humidity was higher, compared to harvest 6. This suggests that increased chilling susceptibility is cumulative and fruit need continuing dry conditions to return to base levels.

To fully determine weather effects, further trials should be conducted under controlled environment conditions using fruit tagged early in the season to remove other sources of variability such as flowering date.

2.11 CUSTARD APPLE QUALITY AFTER STORAGE AT 7°C AND 10°C

L.G. Smith, G.F. Meiburg, and J.A. Barker

The recommended storage temperature for custard apples is 10°C. Previous results have shown that fruit can be stored successfully at lower temperatures but resultant chilling incidence is variable. Representative fruit from the major growing regions were tested to determine if a lower storage temperature could be recommended.

African Pride (AP) custard apples were harvested over 4 months from 4 districts. Fruit were stored at 7 or 10°C for 3 to 6 days before being placed at 22°C to ripen. Pinks Mammoth (PM) fruit were similarly harvested from 2 sites and held at 7 or 10°C for 4 to 7 days before ripening. Control fruit were placed directly at 22°C. Some harvests were during or directly after rain. Where possible, fruit were harvested a few weeks later from the same district after dry weather.

During ripening, fruit were rated daily for % skin blackening; shelf life was calculated as the days to eating soft after being placed at 22°C. At some harvests, fruit developed a temporary chilling injury as a light bronze-grey skin colour shortly after removal from storage. By eating soft, the colour had darkened to the typical black skin colour. Chilling injury was therefore rated as % bronze (expressed on the same intensity basis as black skin) and finally as an increase in black since harvest (% black).

Rainfall prior to harvest affected chilling susceptibility. Bronze skin occurred on African Pride and Pinks Mammoth at some wet harvests but not in any of the dry harvests, inferring a rainfall or weather related effect. In comparative wet and dry harvests from 2 districts, fruit from 1 site showed higher increases in % black under wetter conditions while the other did not, indicating a regional or climatic variability.

African Pride fruit from wet harvests generally ripened with higher levels of % black after storage at 7°C compared to 10°C. Pinks Mammoth chilling susceptibility was less affected by rainfall at harvest than African Pride , and Pinks Mammoth performed better under those conditions. At dry harvests, differences between cultivars, sites and temperatures were minimal, but African Pride did have less % black at eating soft.

Of the 24 storage temperature comparisons, one quarter produced significant differences between 7°C and 10°C stored fruit. Shelf life of both African Pride and Pinks Mammoth fruit was not improved by storage at 7°C compared to 10°C and, in fact, was reduced by up to 4 days in wet harvested African Pride fruit from one site.

Due to inconsistencies in fruit chilling injury after storage at 7°C, on current information, we recommend 10°C be the storage temperature for custard apples.

One or two degrees lower may be investigated in the future, to order to try to further increase post-harvest life.

2.12 EFFECTS OF PRUNING ON FRUIT QUALITY

G.F. Meiburg, J.A. Barker, and A.P. George

Pruning of custard apple trees is routinely recommended to growers but, although effects on tree yield have been investigated, little is known about the effect on post-harvest fruit performance.

At normal pruning time, 3 similar trees had their branches pruned back 20-30 cm (spur pruned) while another 3 were tip pruned. In June, 15 fruit from each treatment were harvested, weighed, and ripened 22°C. Shelf life was measured as the days to eating soft, at which time fruit quality parameters of % black skin, fruit carpel pointedness (0-6), incidence of *Pseudocercospora* (0-5), internal woodiness (0-5) and sweetness (TSS: total soluble solids) were assessed.

Fruit from the spur pruned trees were almost double the weight, twice as pointy, and had about 1 day's greater shelf life, twice the % black and incidence of *Pseudocercospora* than tip pruned fruit. The more pointy appearance and longer shelf life indicate that these fruit were more immature than tip prune fruit, yet they had an average 3% higher TSS, indicating better eating quality. One of the trees produced pointier, more woody fruit with a greater % black than the others, verifying previous work indicating variable tree performance.

Heavy pruning produced both positive and negative effects on fruit quality. This was due not only to opening the canopy and allowing greater light interception, but also to exposing fruit to increased external damage from other factors, *eg* rainfall.

More research is needed to determine the optimum pruning regime producing the best quality custard apples.

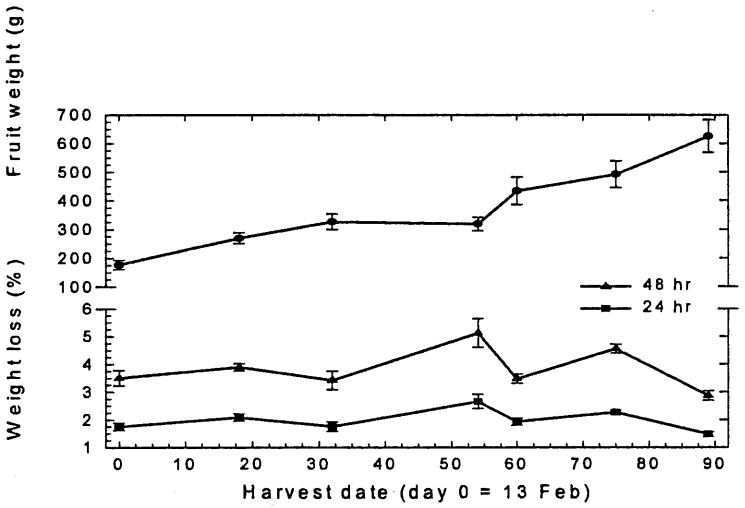
2.13 MOISTURE LOSS AS AN INDICATOR OF MATURITY

L.G. Smith, G.F. Meiburg, and J.A. Barker

Optimum maturity in African Pride custard apples is more difficult to identify than in other varieties, resulting in inferior quality fruit being marketed. Immature fruit fail to soften before turning black and mummifying. This preliminary trial investigated whether changes in the rate of fruit moisture loss over time were linked to changes in fruit maturity.

Small samples of fruit tagged at golf ball size were harvested from 2 trees at 7 fortnightly harvests from February (immature) to May.(mature). Fruit were weighed at harvest and again after 24 and 48 hours at 22°C. Days to eating soft at 22°C was determined and fruit were rated for % black skin.

Figure. ***Changes in fruit weight and weight loss of African Pride custard apples with harvest date.***



Fruit weight differed significantly between trees but generally increased linearly with harvest date. Weight loss after 24 and 48 hr was fairly constant but decreased slightly with harvest date. Deviations from these patterns occurred at harvest 4 when fruit reached a maturity adequate for normal softening and, to a lesser extent, at harvest 6, when fruit first lost their excessive seediness, a major constraint to attaining good eating quality. At these harvests, average fruit weight dropped below the regression line, while weight loss measurements, most noticeably after 48 hr at 22°C, rose above the line. It can be assumed that these deviations are due to internal physiological changes in the fruit.

Larger sample sizes will be required to verify links between maturity milestones and weight change parameters. Further studies on maturity of African Pride custard apples should include these parameters.

However the results clearly indicate that rate of fruit weight loss after harvest cannot be used as a maturity index.

2.14 GIBBERELLIC ACID ON CUSTARD APPLES

G.F. Meiburg, J.A. Barker, and A.P. George

Gibberellic acid (GA) has increased the post-harvest life of some fruits *eg* persimmons. To determine whether custard apple fruit quality was similarly affected, a foliar spray of 100 ppm GA3 was applied to some branches of African Pride trees 3 weeks prior to harvest. At harvest, 15 fruit were taken from treated and untreated branches. Fruit were weighed and ripened at 22°C. Post-harvest life was measured as the days to eating soft, at which time fruit quality parameters of % black skin, fruit carpel

pointedness (0-6), incidence of *Pseudocercospora* (0-5), internal woodiness (0-5) and sweetness (TSS: total soluble solids) were assessed.

GA produced no significant differences between treated and untreated fruit for any of the parameters measured.

It can therefore be concluded that custard apple fruit quality is not affected by GA3 applied three weeks prior to harvest.

In any further investigations, the method of application and/or GA type would need to be altered.

2.15 REMOVING FIELD HEAT AT HARVEST WITH ICE SLUSH

L.G. Smith, and G.F. Meiburg

Custard apples harvested in high temperatures must have the field heat removed rapidly to prevent premature ripening. Harvesting fruit into ice slush may be an effective method. African Pride custard apples were harvested at two central Queensland farms but weather prior to, and at harvest, was rainy, overcast and less extreme than is often experienced. Que sera sera!!!!!!!!!!!!

However, fruit core temperature at harvest was over 30°C and took about 50 minutes of immersion in ice slush to reach 10°C.

Blemish-free fruit of similar size and appearance were harvested and treated on-site. Half were placed in ice slush until fruit core temperature reached 10°C and then refrigerated at 7°C, while matching controls were placed directly under refrigeration at 7°C. Fruit were stored for either 3 or 4 days before being transferred to 20°C to ripen. Shelf life was measured as the days taken to reach eating soft after removal to 20°C; chilling injury was measured as the change in black skin colour from harvest to eating soft (% black) and % bronze skin colour.

Two types of pre-packed ice were used: crushed ice and ice frozen in small disks of about 2 cm diameter. **Using crushed ice resulted in 3 times more abrasion damage than the other type. However, both treatments resulted in about 65% of fruit exhibiting bronzing at eating soft compared to 14% in controls.**

Results varied between sites by an average 1 day shelf life and 18% black skin. This was probably due to both normal fruit variability and the differing ice abrasion damage levels impacting on final fruit injury levels. Fruit stored for 4 days at 7°C showed about double the injury and 0.5 day more shelf life than fruit stored for 3 days.

The ice slush treatment resulted in one grower's fruit having an average 0.4 days less shelf life than controls, while the others had 1.3 days more. Fruit treated in ice slush and subsequently stored for 3 days had 21% more black skin.

Given the mixed results and detrimental effects on external fruit quality resulting from immersion in ice slush, this method of rapid cooling is not recommended in its present form for African Pride custard apples.

2.16. PACKAGING TRIAL. SOCKS AND TISSUES COMPARED: A BIGGER PICTURE IS INVOLVED.

L.G. Smith, G.F. Meiburg, Roger Broadley and Patti Stacey

The usefulness of styrofoam socks as carton packaging was compared to paper tissues as protection in fruit sent to Sydney June 1997, using both African Pride and Pinks Mammoth fruit. The following results were obtained.

- In terms of absolute % black, the difference between using socks or tissues was not great, about 1-2 % decrease results from using socks. In relative terms, for high quality near-unblemished fruit, the 2% black increase represents nearly a 100% increase in blemish which down grades the carton.

The actual $ effect is complex and needs to be calculated of one or more seasons. The results are in contrast to earlier laboratory work where much more marked differences were shown, and the consequences are being considered within a much broader perspective. This is because the results are only a small part of the marketing scene (see 2. below) where a whole range of factors interacts and impinge on each other. A collation of results is shown in Table 1.

- A whole raft of impinging issues are now seen to be involved, organisational as well as packaging and economics, and these issues cannot be resolved in a simple fashion. It's little use spending time and effort assessing individual factors as there are many involved and all inter-relate. The whole marketing system needs to be analysed and assessed as an interactive whole, rather than just a sum of individual components. As a direct consequence, a program of domestic market research has been developed and will commence in late 1998 involving wholesalers, retailers and consumers.

- It should be noted that, to properly compare different packaging procedures and materials, large numbers of fruit need to be examined over several trials, to enable an adequate comparison of all the many factors involved. These factors include the variability of initial blemish within the cartons, as well as the effect of different fruit sizes, and the fruit from different growers, and production areas and market destinations. Such an exercise would be highly labour intensive, costly, and exhausting for the staff involved as several hundreds of fruit would need to be individually closely assessed for damage, and repacked, all without too much disruption to the normal marketing process and price structuring. That exercise was beyond our resources so we chose a smaller trial involving three farms, each with quite different procedures and fruit quality, and using two varieties from two of the farms. From each farm we had three cartons of each styro-socks and tissue paper, and each carton with a different count size. Fruits of comparable blemish were packed in each treatment.

Full technical papers

3.1 Pre-harvest research

PHENOLOGICAL CYCLING OF *ANNONA* SPP. HYBRID IN SUBTROPICAL AUSTRALIA

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Summary

The phenological cycles of *Annona* spp. hybrids were established over a 2-3 year period in subtropical Australia. Seasonal changes in growth of fruits, shoots and roots and starch and nutrients concentrations were monitored fortnightly. At Nambour (Lat. 26°), termination of endo-dormancy occurred about 40 days in advance of vegetative budbreak. Trees exhibited a major growth flush in early summer and either one or two, smaller flushes in the early autumn, and three root flushes; late spring, late summer and early winter. Fruit exhibited a normal sigmoidal growth pattern. At Nambour and Palmwoods the mean fruit development period (FDP) for cv. Hillary White and African Pride was 21 and 26 weeks, respectively. For cooler and warmer growing regions, the mean FDP was increased or shortened by 2 and 4 weeks, respectively. FDP was highly negatively correlated (r^2=0.98, P<0.05) with increasing mean monthly minimum temperature. Starch reserves were greatest in the roots followed by the trunk and shoots. Starch concentrations fell to their lowest levels during budbreak and reached their peak about one month prior to the commencement of leaf abscission. Leaf analysis showed that N, P and K concentrations decreased throughout the season, while Ca and Mg increased. These studies provide a basis for the correct timing of key management practises such as fertilising, thinning and irrigation.

Introduction

The growth of tree fruit species, whether they be evergreen or deciduous, follows a cyclic seasonal pattern which is repeated each year, though not necessarily on the same time scale or with the same intensity of growth for each stage (Cull, 1986; Whiley *et al* ., 1988). Three separate growth organs can be easily distinguished: root, shoot and reproductive. While they are dependent on each other, they do compete for limited tree nutrients and carbohydrates and, if the vegetative:reproductive balance is not maintained, fruit yield is ultimately reduced. By recognising the stages of growth and understanding their requirements and interactions within the tree, management practises can be modified and programmed to develop strategies which lead to productivity gains (Whiley *et al*., 1988). The phenological cycle for *Annona* spp. hybrids has only been partially described (George and Nissen, 1987a,b; 1988a,b,c), with most studies evaluating only one aspect of the cycle, usually in isolation to the rest.

Several studies were conducted to develop phenological cycle models for *Annona* spp. hybrids in subtropical Australia. Effects of cultivar, rootstock and regional climatic differences on tree growth stages were evaluated. The aims of this research were to provide a greater understanding of the vegetative:reproductive balance and a basis for the timing of key management practises such as fertilising, thinning and irrigation in both commercial and experimental situations.

Materials and methods

Sites and climate (Experiments 1 and 2)

Experiment 1 was conducted at the Maroochy Horticultural Research Station, Nambour, Queensland and Experiment 2 at a commercial orchard at Palmwoods, Queensland, both at Latitude 26S. Sites were within 15 km of each other. Due to the similar climatic conditions during the experimental period, climatic data for the Nambour site only is presented (Figure 1).

Project jointly funded by HRDC (FR425) and RIRDC(DAQ-167A), and Australian custard apple growers

Experiment 1

Treatments

Two groups, each of 10 uniformly-sized, 5 year old trees, of the *Annona* spp. hybrid cv. African Pride were selected for monitoring. One group was propagated as cuttings and grown on their own roots; the other, grafted onto cherimoya (*Annona cherimola*) rootstock with a sugar apple (*Annona squamosa*) inter-stock. Seasonal changes in growth of fruits, shoots and roots, and starch and nutrient concentrations were monitored over a two year period (1991-92; 1992-93). Trees were spaced 3 m in rows and 4 m between rows (833 trees ha^{-1}) on a sandy loam overlying a clay substratum. The rows were mounded to a depth of 50 cm to improve drainage.

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year trees were fertilised in September and November with a complete fertiliser supplying 150 g N, 50 g P, 125 g K and in February with 120 g K (as K_2SO_4) per tree. Trees were trained to an open goblet system and were winter-pruned in July.

Experiment 2

Treatments

Ten, 8 year old, uniformly-sized trees of the *Annona* spp. hybrid cv. African Pride and Hillary White, both on cherimoya (*Annona cherimola*) rootstock, were selected for monitoring. Seasonal changes in growth of fruits, shoots and roots, and variations in starch and nutrient concentrations were evaluated over a two year period (1992-93; 1993-94). Trees were spaced 7 m in rows and 7 m between rows (204 trees ha^{-1}) on a sandy loam overlying a clay substratum.

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees were fertilised in August with a complete fertiliser supplying 300 g N, 60 g P, 250 g K and in February, with 200 g K (as K_2SO_4) per tree. Trees were trained to an open goblet system and were spring-pruned in October of each year.

Measurements (Experiments 1 and 2)

Tree yield and growth

Trees were harvested at the normal commercially acceptable stage of fruit development and fruit numbers and fruit weights recorded. Growth measurements were made on each datum tree over a two year period. Tree height, spread (N-S, E-W), and girth (30 cm above ground level) were measured in July, when trees were dormant. Tree canopy volume was calculated from the formula for determining the volume of a semi-ellipsoid ($V = 2/3\ pr^2\ h$; V = tree volume, r = tree radius, h = tree height). In 1990 and 1991, two observers working independently visually estimated the percentage of the vegetative buds breaking dormancy weekly. Flowering intensity and pattern was determined by counting, at about fortnightly intervals, the number of flowers at anthesis in a m^3 quadrat placed at a median tree height in the N and S sectors of each tree. Shoot extension was recorded at about fortnightly intervals in both growing seasons on 4 uniform laterals (dormant-pruned to 30 cm) on each datum tree.

Root growth was also measured in both growing seasons. A 250 cm^2 area of top-soil was scraped away to a depth of 5 cm revealing dormant roots, which were then covered with 5 layers of newspaper, a layer of shade cloth, and then mulch. By lifting the shade cloth and mulch, the newspaper could be lifted off to study the development of new white roots on the surface soil. The development of new white roots was rated fortnightly on a scale from 1-5 (1 = no new roots, 5 = new roots covering the whole area).

Fruit growth

Six fruit, one per lateral (similar size as those used for shoot extension measurements) were selected and fruit length and diameter (2 directions at equator) was measured at about fortnightly intervals. For 'African Pride' only, the relationship between fruit fresh weight and fruit breadth, fruit length, fruit volume and fruit dry weight

was also established (Figure 2). Approaching rest, the percentage defoliation of each tree was estimated visually by two observers working independently.

Starch sampling and analyses

At about 6 weekly intervals, leaf, shoot, trunk and roots were sampled from each of four datum trees for starch analyses using the enzymic-colorimetric procedure (Rasmussen and Henry, 1990). Shoot samples were taken from the middle third section of six fruiting lateral shoots per tree. The leaves from these laterals were also pooled for analyses. Core samples (6 cm^3) were taken from the trunks about 30 cm above ground for starch determination. Root samples were taken from major roots about 1 cm in diameter.

Leaf nutrient sampling and analyses

At both sites only, all datum trees were sampled at about fortnightly intervals from budbreak to the commencement of leaf senescence for 1992-93, only. Leaves (the first fully mature leaf sampled from 15 non-fruiting shoots on each tree) were pooled for each datum tree and analysed for N, P, K, Ca, Mg, Fe, B, Cu, Zn and Mn.

Regional differences in tree phenology

A survey of high-yielding `African Pride' orchards was conducted in each of five climatically different regions of Queensland and Northern NSW to determine the influence of macroclimatic variables on tree phenology. Regions chosen were: Alstonville (Lat. 28°), Nambour (Lat. 26°), Bundaberg (Lat. 25°), Yeppoon (Lat. 23°), and Atherton Tableland (Lat. 17°). Data was collected over a two year period from 8-15 mature yielding orchards selected in each region. Some tree phenological stages (eg. budbreak, date of first flowering) were estimated visually by growers whilst others, such as date of first harvest, were based on actual harvest records.

Results and discussion

Relationship between date of leaf abscission and budbreak, flowering and fruit maturity

Annona spp. hybrid trees are semi-deciduous. Leaf abscission commences from the periphery of the tree and moves inwards and occurs over a period of about three months (Figure 2). Provided soil temperatures are high enough, vegetative budbreak occurs simultaneously with leaf abscission as the leaf shedding process exposes sub-petiolar buds. The timing of leaf abscission is important, whether occurring naturally or artificially induced through the use of chemical defoliants, as it influences the time of budbreak (Figure 3), and subsequently time of flowering and fruit maturity (Figure 4). Dormant-pruning, which is often carried out at the same time as chemical defoliation, also influences budbreak with early pruning advancing budbreak (Figure 3).

Artificial defoliation

At Yeppoon, all orchards are artificially defoliated, compared with <30% of orchards at Nambour, Bundaberg and Atherton Tablelands and none at Alstonville. For Yeppoon growers, artificial defoliation produces a higher percentage of fruit for the high-priced early market. In contrast, at Alstonville, many growers prune their trees in late spring and do not artificially defoliate so as to obtain late-maturing fruit, which also receives high prices.

However, there are limitations to artificially defoliating trees too early (Figure 3) with little response when soil and air temperatures are below 12-15°C (George and Nissen, 1988b). At Nambour, optimum root temperatures (15 cm depth) at the time of rest termination in mid-October are between 19 -22°C (Figure 1).

Effects of tree vigour on leaf abscission

Tree vigour also influences time of budbreak (Figure 2). At Nambour, `African Pride' trees grafted onto sugar apple inter-stock defoliated slightly earlier than trees on their own roots. The date of 50% defoliation was negatively correlated ($r=0.85$, $P<0.05$) with shoot length. In contrast, the defoliation period was later and more protracted at Palmwoods compared with the Nambour (Figure 2). The reasons for the differences between sites is not clear but may be due to the higher vigour and leaf N status at Palmwoods, although these variables were not measured at this site.

Flowering pattern

At Nambour and Palmwoods, flowering occurred over a 2 month period, concomitant with the first vegetative growth flush (Figures 5 and 6). Previous studies by George and Nissen (1987b) have shown that most flowers are produced on the basal nodes of newly emerging vegetative lateral shoots. At Nambour, the intensity and pattern of flowering for the 'African Pride', either on its own roots or on dwarfing inter-stock, were similar. Although the flowering patterns of both cultivars were similar, at Palmwoods, Hillary White produced less flowers than 'African Pride' due to the lower percentage budbreak of Hillary White compared with African Pride. In this study we showed only one major peak in flowering compared with 2-3 weeks in younger, more vigorous trees with the later flowering flushes much smaller than the first (George and Nissen, 1988b). Additional flowering flushes can be obtained through late summer pruning and leaf stripping (George and Nissen, 1988b). In previous studies (George and Nissen, 1988a), we have also shown that peak fruit set occurs after the completion of the exponential growth stage of the first major vegetative flush. We have also shown that the flowering period can be advanced by artificial defoliation in the late winter/spring and extended by summer pruning or shoot tipping in the late summer or autumn (George and Nissen, 1988b)

Flowering period

Compared with Nambour, under warmer (Yeppoon; Lat. 27°S) or cooler (northern NSW; Lat 28° S) subtropical conditions, budbreak and flowering can be advanced or delayed by as much as 2-3 months, respectively (Table II). In New Zealand, under much cooler growing con dition, budbreak of the closely related species, *Annona cherimola*, does not occur until late December. The timing of early flowering was highly correlated with date of budbreak (Figure 4).

Pattern of fruit growth

Fruit exhibited the normal sigmoidal growth pattern (Figures 5 and 6). At Nambour, irrespective of rootstock, fruit growth of 'African Pride' was very rapid during Stage I of growth which lasted for about 60 days after fruit set. Stage II was more protracted, lasting about 70 days, and Stage III was relatively shorter, lasting only 50 days (Figures 5 and 6). At Nambour, the total fruit development period (FDP) was about 180 days (26 weeks). Fruit fresh weight was highly correlated with fruit breadth, length, volume and dry weight (r^2 >0.85, P<0.05) (Figure 7).

Effects of variety and rootstock on fruit growth

Fruit growth rates on dwarfing inter-stock were slightly greater than those on their own roots but these effects were not significant (Figure 5). At Palmwoods, Hillary White exhibited a shorter FDP (21 weeks), maturing about 30-40 days before 'African Pride' (Figure 6). Commercial growers in the Nambour region have recorded slightly shorter (19 weeks) FDP for early-set Hillary White fruit (Thompsen, pers comm., 1994).

Effects of temperature on FDP

For warmer growing regions of Australia eg. Yeppoon, the range in FDP of 'African Pride' appears to be considerably narrower (4-6 weeks), compared with that for the cooler growing regions eg. Northern NSW (6-10 weeks) (Table II). The FDP was highly negatively correlated with mean monthly minimum temperature (r^2 =0.98, P<0.05) (Figure 8).

Shoot and root growth

At Nambour, shoots exhibited a major vegetative flush which occurred between 30 and 50 days after budbreak and sometimes one or two subsequent, smaller flushes (Figures 5 and 6). Surface roots exhibited 3-4 flushes. A small root flush preceded vegetative budbreak, however, the major root flush occurred about 30 days after the first, major vegetative flush (Figure 5 and 6). The timing of the first root flush appears to be influenced by soil temperature and date of defoliation. Root flushes were cyclical but out of phase with vegetative flushes. For vigorous trees the shoot and root growth phases are clearly separated, but for trees artificially defoliated considerable overlap of stages will occur. It appears that to ensure rapid and uniform budbreak, fertiliser and irrigation should be applied well in advance of the first appearance of budbreak. Surprisingly there was a strong root flush in mid-winter, after the completion of harvest. The time of root flushing has important implications

for timing of fertiliser application, with the ideal times to apply fertiliser just prior to peak root growth periods (A.P. George, 1994, unpublished data).

Seasonal starch patterns

At Nambour and Palmwoods, there were marked seasonal variations in average starch concentrations in the shoots (Figures 9 and 10). A peak in starch concentration for all tree organs was recorded at early leaf senescence and lows at about 50 days after budbreak and again during the first major root flush (Figures 9 and 10). Starch levels remained relatively constant throughout the rest of the growing season before increasing again in the late winter-early spring period. Starch concentrations were greatest in the roots, followed by the trunk, shoots and leaves (Figures 9 and 10). The overall lower starch concentrations in the 1991-92 may have been due to heavier crop loads and lower irradiance.

Seasonal leaf nutrients patterns

At Nambour, seasonal leaf nutrient patterns established for `African Pride' on their own roots and on dwarfing inter-stock were similar (Figures 10). At Palmwoods, although the leaf nutrient patterns were similar, `African Pride' exhibited higher leaf concentrations of K and lower leaf concentrations of B and Ca. Leaf nutrient patterns were also similar to those previously established for the *Annona* spp. hybrid cv. Pink's Mammoth (George *et al.* 1989a) and for temperate fruits in general (Clark and Smith, 1990). One group of nutrients showed a general decline in concentration in the leaves with time (K, 1.4-0.8%; P, 0.3-0.15) while another group showed an overall increase (Ca, 0.4-1.4%; Mg, 0.3-0.55%; B, 24-66 mg kg^{-1}). Nitrogen leaf nutrient patterns were strongly influenced by vegetative flushing with a rapid decline in N concentrations during periods of strong vegetative flushing (Figure 11). Previous studies have shown similar patterns (George and Nissen, 1988c; George *et al.*, 1989). Compared with trees on their own roots, sugar apple inter-stock had no significant effects on leaf nutrient concentrations. In contrast, George and Nissen (1988c) found that the `African Pride' trees grafted onto sugar apple rootstock, alone, exhibited reduced leaf concentrations of Ca, B, Zn, Cu, Mn and Fe compared with those grafted on cherimoya rootstock. Seasonal leaf nutrient patterns will need to be verified for other growing regions to determine the influence of tree phenology and temperature on them.

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CAPTIONS FOR FIGURES

Figure 1. Climatic changes at Nambour and Palmwoods, Queensland, Australia during the period of the experiment.

Figure 2. Leaf abscission patterns for the *Annona* spp. hybrid cvs. African Pride and Hillary White at Nambour and Palmwoods, Queensland, Australia. Data are the means of 10 trees. Vertical bars represent LSDs (*P=0.05*). *Experiment 1* Nambour, cv. African Pride on sugar apple inter-stock, 1991; , 1992; cv. African Pride on own roots, , 1991; 1992. *Experiment 2* Palmwoods, cv. African Pride, , 1992; , 1993; cv. Hillary White, , 1992; , 1993.

Figure 3 Effects of pruning and defoliation dates on date of budbreak of the *Annona* hybrid cv. African Pride in subtropical Australia. Pooled data for 8-15 orchards sampled in 5 climatically different regions of subtropical Australia.

Figure 4. Relationship between date of budbreak and flowering and date of harvest of *Annona* spp. hybrid cv. African Pride in subtropical Australia. Pooled data for between 8-15 orchards sampled in 5 climatically different regions of subtropical Australia.

Figure 5. Seasonal changes in flowering, shoot extension, fruit and root growth of the *Annona* hybrid cv. African Pride at Nambour, Queensland, Australia. Vertical bars represent LSDs (*P=0.05*). Open symbols represent cv. African Pride on sugar apple inter-stock; closed symbols, cv. African Pride on own roots.

Figure 6. Seasonal changes in flowering, shoot extension, fruit and root growth of the *Annona* spp. hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Vertical bars represent LSDs (*P=0.05*). Open symbols represent Hillary White; closed symbols, African Pride. (L), fruit length; (B) fruit breadth.

Figure 7. The relationship between fruit fresh weight of the *Annona* spp. hybrid cv. African Pride and fruit breadth, length, volume and dry weight.

Figure 8. The relationship between FDP for the *Annona* spp. hybrid cv. African Pride and mean monthly minimum temperature during fruit development. Data are the mean FDPs for between 8-15 orchards recorded in 5 climactically regions of subtropical Australia.

Figure 9. Seasonal changes in leaf, shoot, trunk and root starch concentrations of the *Annona* hybrid cv. African Pride at Nambour, Queensland, Australia. Open symbols represent cv. African Pride on own roots; closed symbols represent cv. African Pride on sugar apple inter-stock. Vertical bars represent LSDs (*P=0.05*).

Figure 10. Seasonal changes in leaf, shoot, trunk and root starch concentrations of the *Annona* hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Open symbols represent cv. African Pride; closed symbols represent cv. Hillary White. Vertical bars represent LSDs (*P=0.05*).

Figure 11. Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cv. African Pride on own roots and with sugar apple inter-stock and cherimoya rootstock at Nambour, Queensland, Australia. Open symbols represent cv. African Pride on its own roots; closed symbols represent sugar apple inter-stock/cherimoya rootstock. Vertical bars represent LSDs (*P=0.05*).

Figure 12. Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Open symbols represent cv. African Pride; closed symbols represent cv. Hillary White. Vertical bars represent LSDs (*P=0.05*).

Table. ***Tree growth and yield of the Annona spp. hybrid cvs. African Pride and Hillary White over 2 cropping seasons at Nambour and Palmwoods, Queensland, Australia. Data are the means of 6-10 trees.***

Cultivar	Rootstock	Year	Tree height (m)	Tree spread (m)	Tree girth (cm)	Tree canopy volume (m^3)	Tree yield (kg)	Yield per butt cross sectional area (kg cm^{-2})	Yield per canopy volume (kg m^{-3})
Experiment 1									
African Pride	own roots	1991	2.78	3.28	49.5	13.21	19.4	99	0.72
	inter-stock	1991	2.19	2.56	36.86	6.44	15.3	174	1.69
	LSD (*P*=0.05)		0.32	0.38	5.61	4.56	2.98	15	0.31
	own roots	1992	3.99	3.23	49.54	26.98	22.0	98	0.41
	inter-stock	1992	2.90	2.04	33.29	9.02	14.6	127	1.16
	LSD (*P*=0.05)		0.8	0.45	3.12	6.09	3.89	12	0.26
Experiment 2									
African Pride	cherimoya	1992	3.35	5.46	64.4	52.3	84	254	1.61
Hillary White	cherimoya	1992	3.46	5.69	67.5	58.8	91.5	253	1.56
	LSD (*P*=0.05)		0.10	0.15	1.8	2.3	4.5	n.s.	0.23
African Pride	cherimoya	1993	4.15	5.72	66.8	71.1	37.5	106	0.67
Hillary White	cherimoya	1993	5.05	6.18	70.8	101.0	80.0	201	0.79
	LSD (*P*=0.05)		0.45	0.32	1.8	15.4	12.9	28	0.05

Table ***Effects of location on days to various stages of phenological development. Data are the means of 8-15 orchards sampled in each region.***

Variables	Days from 1 January to stage of growth	Region/district Northern NSW	Nambour	Bundaberg	Yeppoon	Atherton Tablelands
Budbreak	**Mean**	307	262	263	226	258
	SD	27.9	14.8	27.7	12.4	28.0
	Range	289-342	228-289	263-289	213-259	228-312
First flowering	**Mean**	326	295	296	265	290
	SD.	20.7	15.3	19.3	11.1	21.7
	Range	289-350	274-320	281-320	251-289	259-305
Peak flowering	**Mean**	351	357	342	303	327
	SD	72.2	22.6	34.4	19.1	28.1
	Range	350-396	305-380	295-380	289-340	289-350
Fruit set	**Mean**	388	339	341	295	326
	SD	21.0	34.0	24.8	22.8	31.5
	Range	320-396	295-380	312-403	274-350	281-350
First harvest	**Mean**	148	86	100	57	82
	SD	21.5	13.3	24.3	12.3	24.1
	Range	106-172	67-106	61-141	46-75	60-128
Last harvest	**Mean**	270	181	182	138	165
	SD	54.9	33.0	46.7	17.7	46.7
	Range	136-389	136-228	92-259	106-167	98-197
FDP	**Mean**	209	175	152	154	161
	SD	33.2	77.8	19.8	29.8	20.6
	Range	122-278	108-204	133-197	76-182	151-207
Pruning date	**Mean**	305	238	222	201	220
	SD	79.8	20.4	22.7	20.2	28.2
	Range	305-365	197-274	202-264	167-228	182-233
Defoliation date	**Mean**	na	223	228	186	235
	SD		44.5	30.3	16.5	17.1
	Range		197-274	202-274	167-228	220-259

SD=standard deviation

Table. ***Effects of location on days to various stages of phenological development. Data are the means of 8-15 orchards sampled in each region.***

Variables	Days from 1 January to Stage of Growth				
	Northern NSW	Nambour	Bundaberg	Yeppoon	Atherton Tablelands
Budbreak	307	262	263	226	258
First flowering	326	295	296	265	290
Peak flowering	351	357	342	303	327
First harvest	148	86	86	57	82
Last harvest	270	181	175	138	165
FDP	209	175	152	154	161
Pruning date	305	238	222	201	220
Defoliation date	na	223	228	186	235

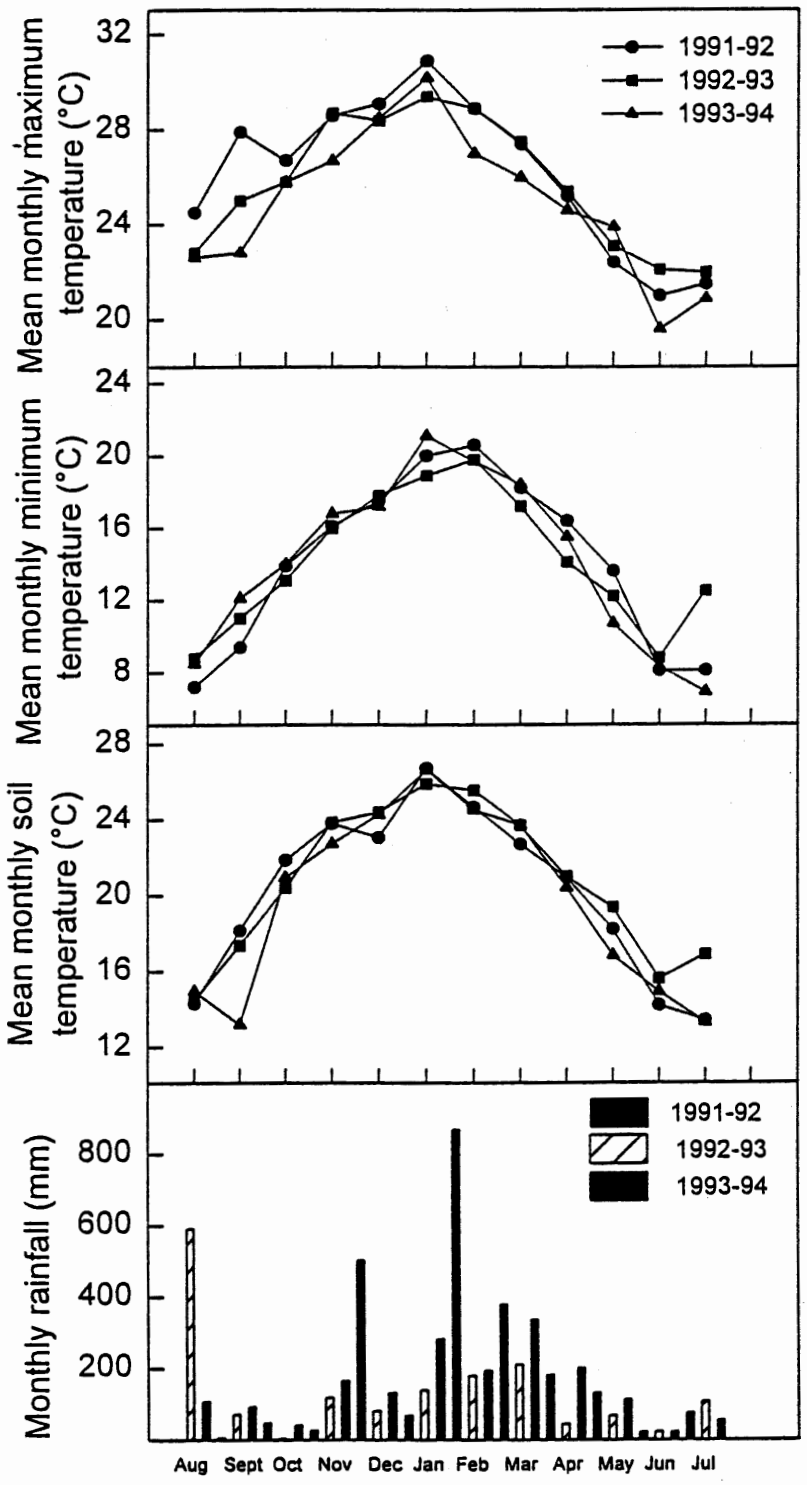

Fig. 1 Climatic changes at Nambour and Palmwoods, Queensland, Australia during the period of the Experiment.

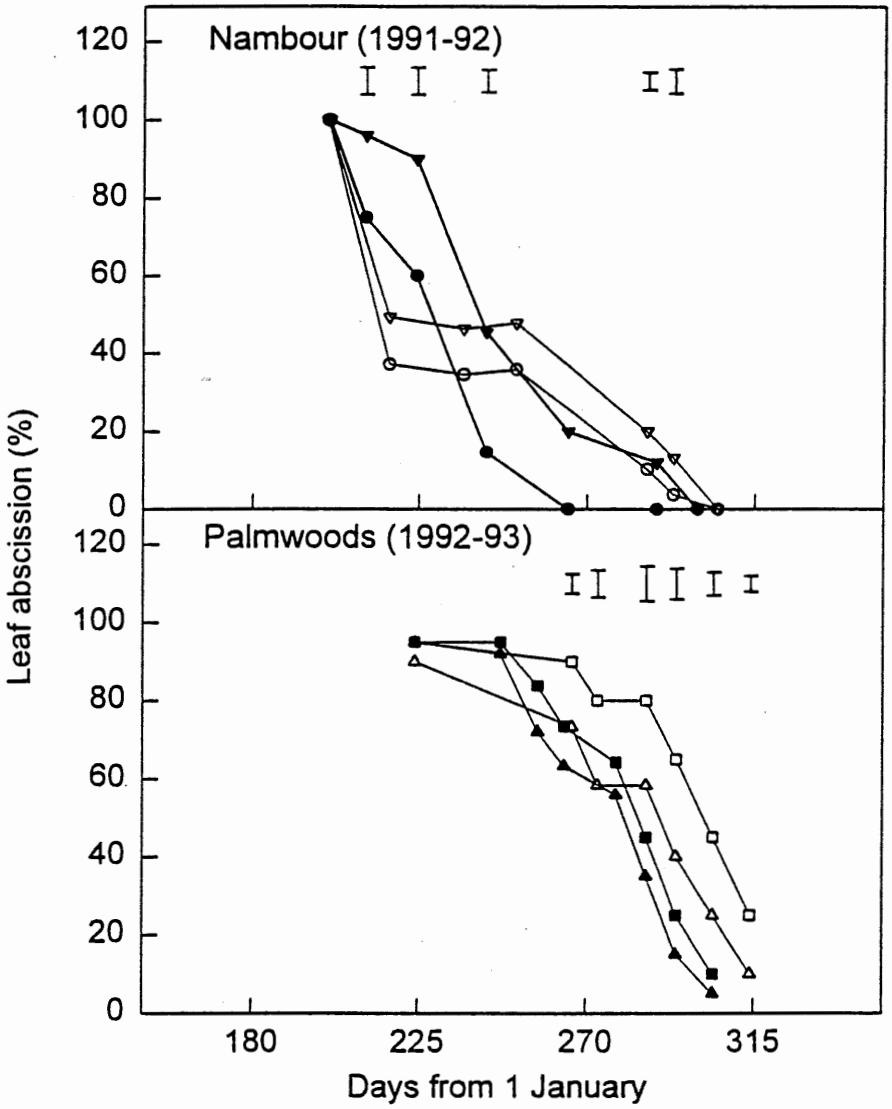

Fig. 2 Leaf abscission patterns for the *Annona* spp.hybrid cvs. African Pride and Hillary White at Nambour and Palmwoods, Queensland, Australia. Data are the means of 10 trees. Vertical bars represent LSDs (P=0.05). Experiment 1, Nambour, cv. African Pride on sugar apple interstock,▿,1991;○,1992; African Pride on own roots,▼, 1991;●, 1992. Experiment 2, Palmwoods, cv. African Pride ,□,1992,△, 1993; Hillary White,■, 1992;▲, 1993.

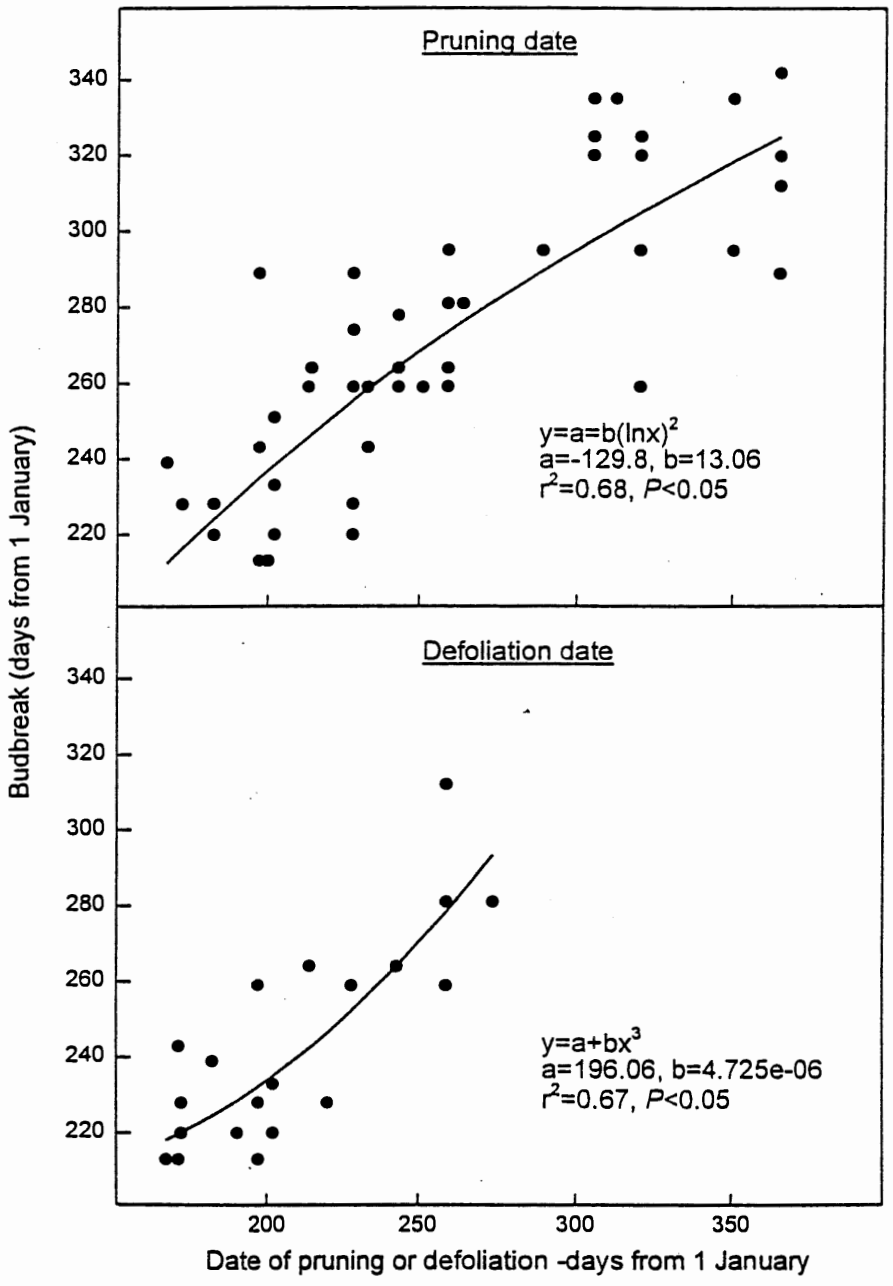

Fig. 3 Effects of pruning and defoliation date on date of budbreak of the *Annona* hybrid cultivar African Pride in subtropical Australia. Pooled data for between 8-15 orchards sampled in 5 climatically different regions of subtropical Australia.

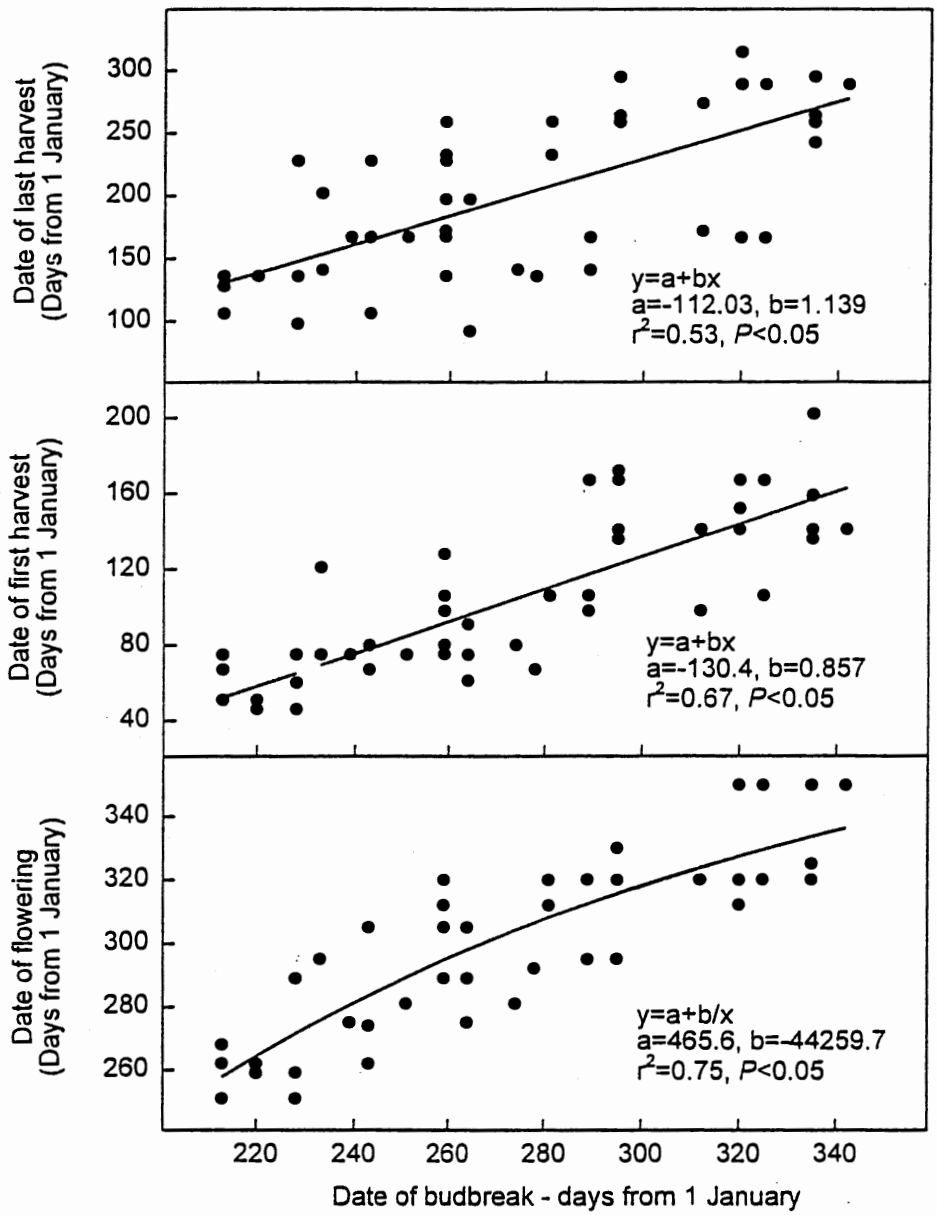

Fig. 4 Relationship between date of budbreak and flowering and date of harvest of *Annona* spp. hybrid cv. African Pride in subtropical Australia. Pooled data for 8- 15 orchards sampled in 5 climatically different regions of subtropical Australia.

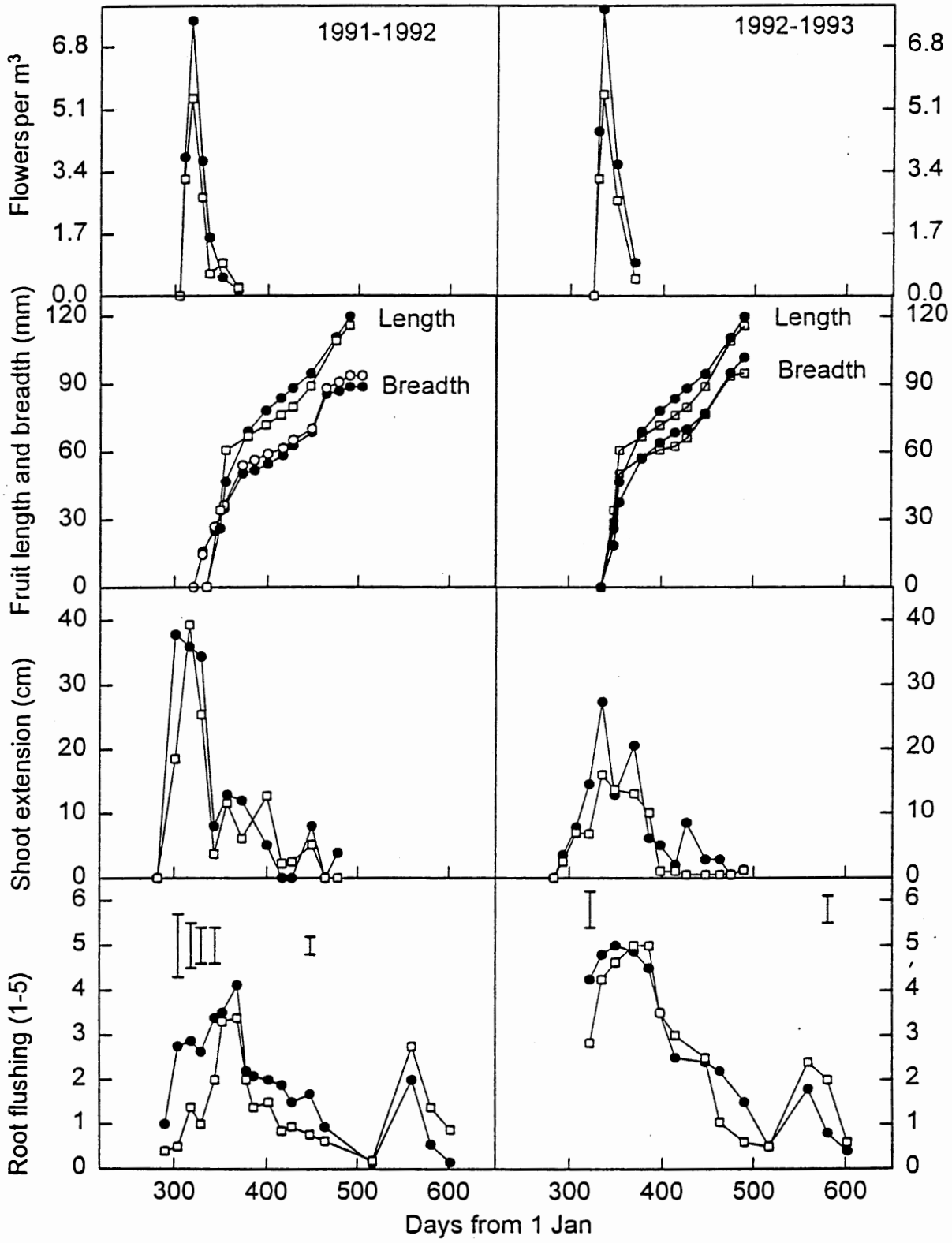

Fig. 5 Seasonal changes in flowering, shoot extension and fruit and root growth of the *Annona* spp. hybrid cv. African Pride at Nambour, Queensland, Australia. Vertical bars represent LSDs (P=0.05). Open symbols represent African Pride on sugar apple interstock; closed symbols, African Pride on own roots.

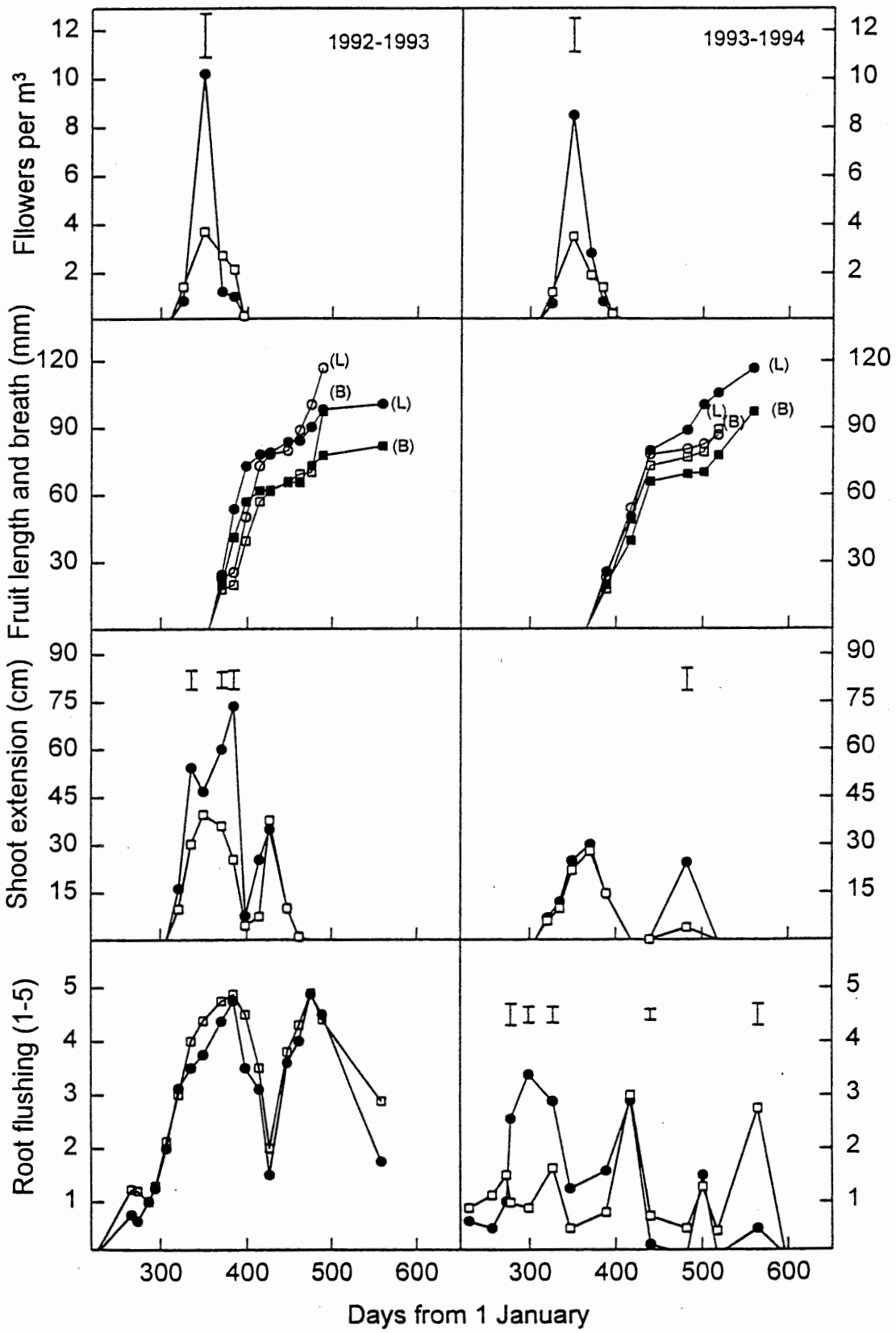

Fig. 6 Seasonal changes in flowering, fruit growth, shoot extension,root growth of the *Annona* spp. hybrid cv. African Pride and Hillary White at Palmwoods, Queensland, Australia. Vertical bars represent LSDs (P=0.05). Open symbols represent Hiliary White; closed symbols, African Pride. (L), fruit length; (B), fruit breadth

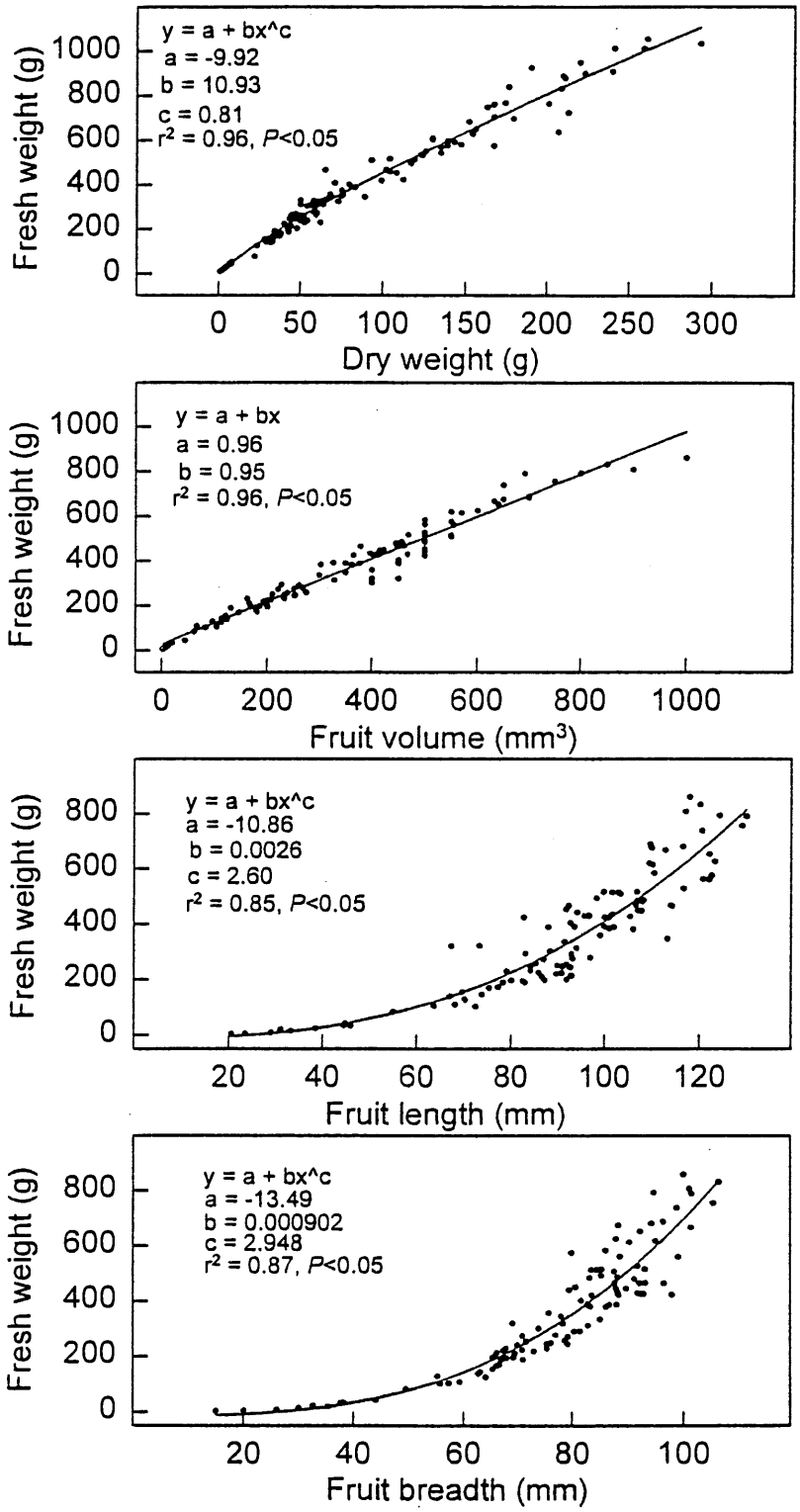

Fig. 7 The relationship between fruit fresh weight of the *Annona* spp. hybrid cv. African Pride and fruit breadth, length, volume and dry weight.

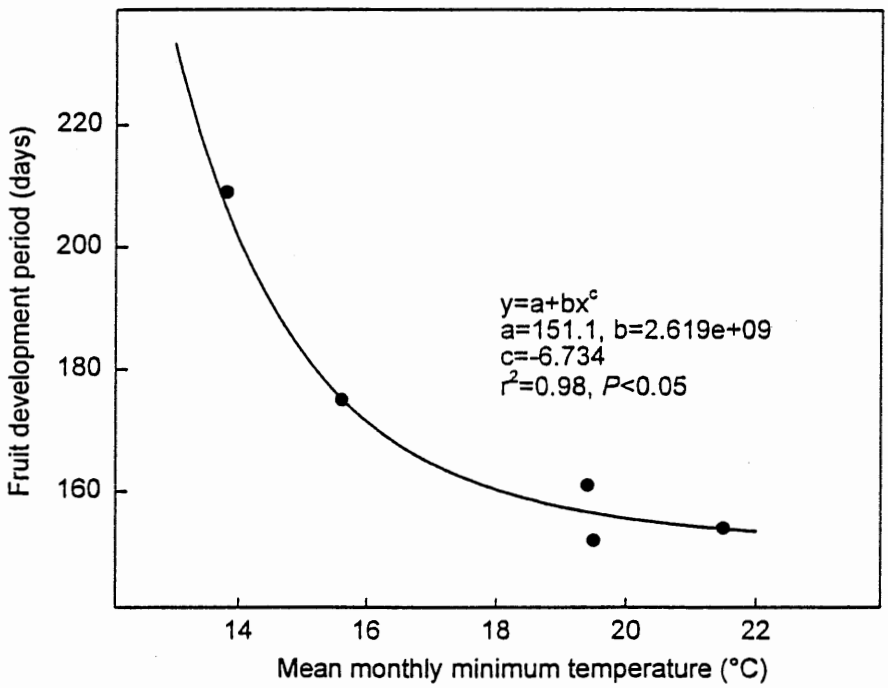

Fig. 8 The relationship between FDP for the *Annona* spp. hybrid cv.African Pride and mean monthly minimum temperature during fruit development. Data are the mean FDPs for 8-15 orchards recorded in 5 climatically different regions of subtropical Australia.

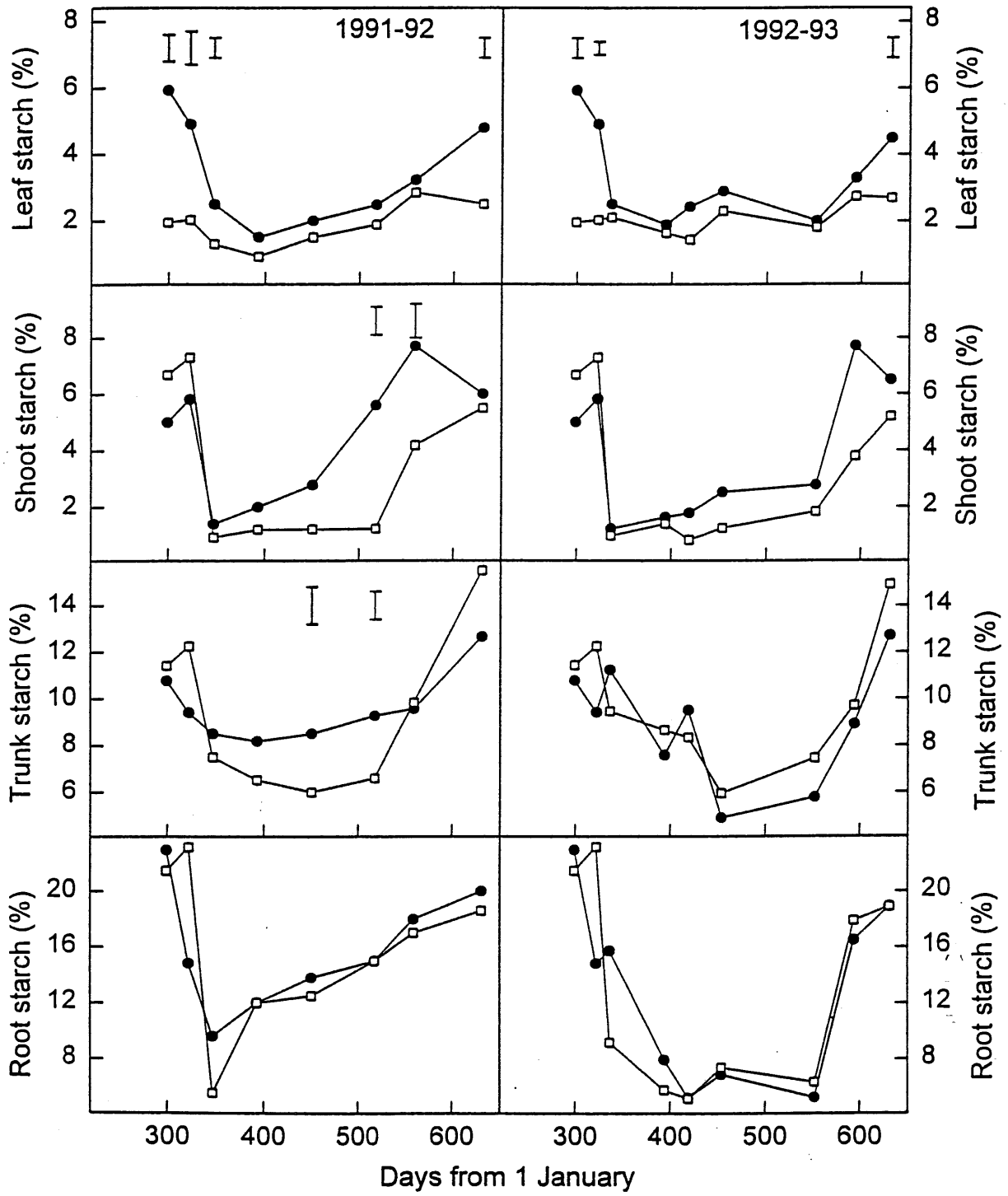

Fig. 9 Seasonal changes in leaf, shoot, trunk and root starch concentrations of the *Annona* spp. hybrid cv. African Pride at Nambour,Queensland, Australia. Open symbols represent African Pride on own roots; closed symbols represent African Pride on sugar apple interstock. Vertical bars represent LSDs (P=0.05).

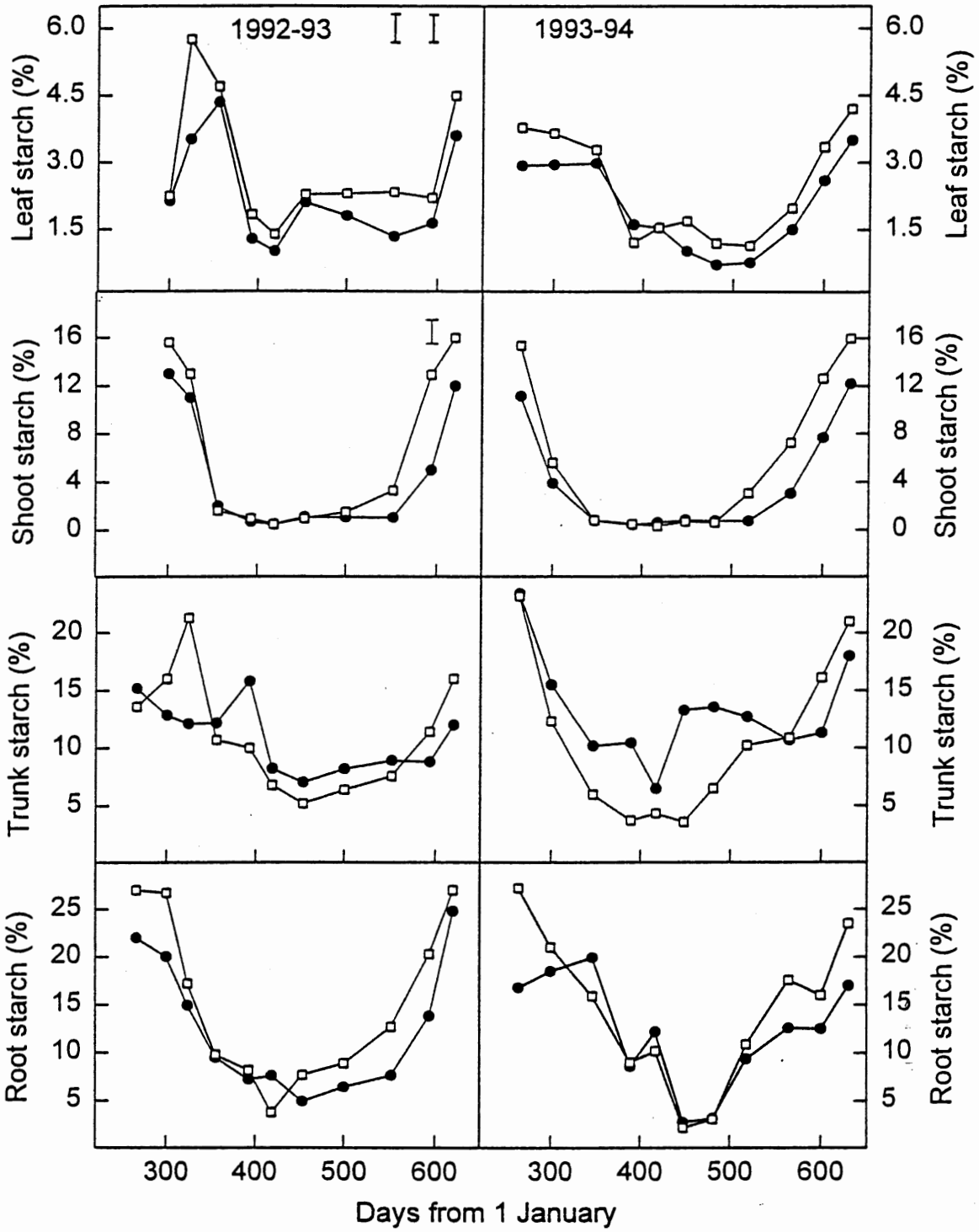

Fig.10 Seasonal changes in leaf, shoot, trunk and root starch concentrations of the *Annona* spp.hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Open symbols represent African Pride; closed symbols represent Hillary White. Vertical bars represent LSDs (P=0.05).

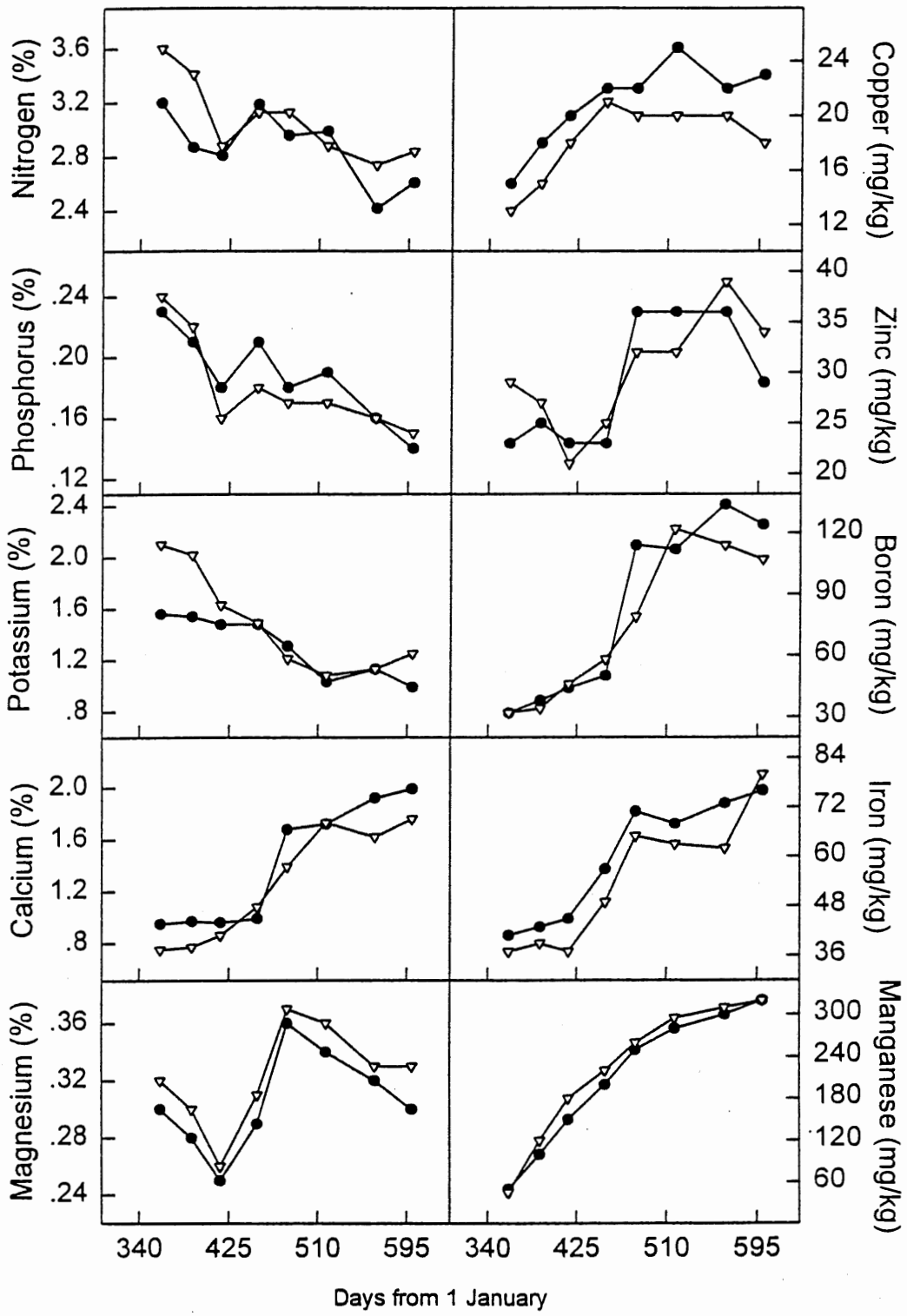

Fig. 11 Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cultivar African Pride on own roots and with sugar apple interstock and cherimoya rootstock at Nambour, Queensland, Australia. Open symbols represent African Pride on its own roots; closed symbols represent sugar apple interstock/cherimoya rootstock. Vertical bars represent LSDs (P=0.05).

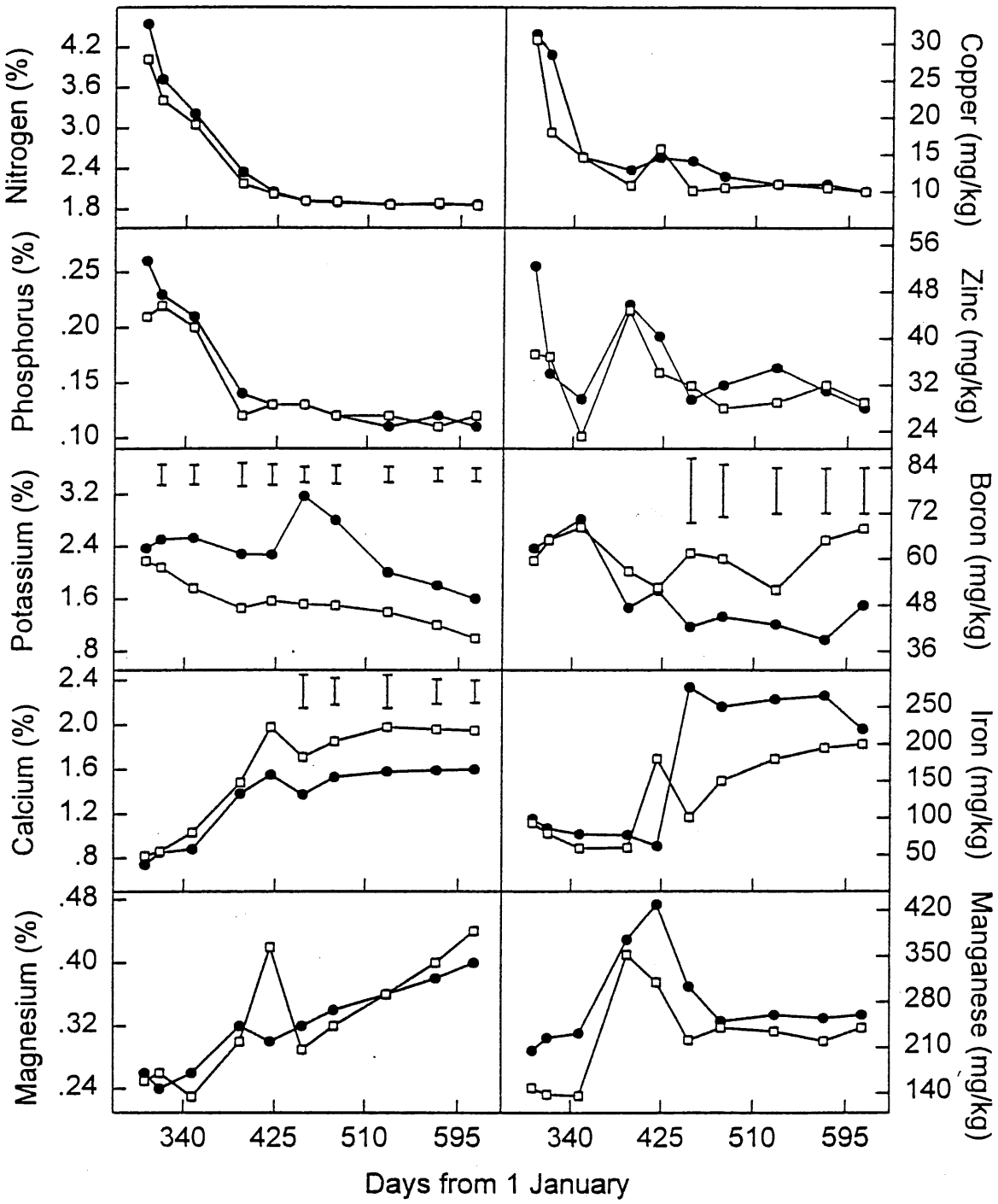

Fig.12 Seasonal changes in leaf nutrient concentrations of the *Annona* spp.hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Open symbols represent African Pride; closed symbols represent Hillary White. Vertical bars represent LSDs (P=0.05).

EFFECTS OF ENVIRONMENTAL VARIABLES, SEASON AND CROP LOAD ON NET CO_2 ASSIMILATION, LEAF CONDUCTANCE AND PLANT WATER STATUS OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

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Summary

Diurnal and seasonal changes in net CO_2 assimilation (A), leaf conductance (g_S) and leaf water potential ($_L$) were investigated for *Annona* spp. hybrid (*Annona cherimola* X *Annona squamosa*) trees cv. 'African Pride' in subtropical Australia. Most of the diurnal variation in A and g_S could be attributed to changes in RH (r^2>0.65, P<0.05). The addition of other variables besides RH into multiple linear regressions analysis added little to explaining the variation in A or g_S. Leaf water potential ($_L$) was highly responsive to air temperature (AT) (r^2=0.56, P<0.05) The marked sensitivity of *Annona* spp. hybrid stomata to low RH may be one of the reasons for poor fruit set and size of *Annona* spp. hybrid under subtropical conditions due to carbohydrate source limitations. Studies on seasonal changes in A over 2 seasons showed 4 major peaks in A which coincided with periods of root growth. A increased with crop load with a rapid, non-linear (r^2=0.98, P<0.05) increase with fruit number per tree and a linear (r^2=0.89, P<0.05) increase with fruit number per unit canopy volume.

Introduction

Small fruit size is a major problem in high-yielding *Annona* spp. hybrid orchards. Small fruit size may be attributed to excessive crop loads and environmental stresses which may affect carbohydrate availability for fruit filling. Since most *Annona* spp. hybrids orchards are planted at low density, without adequate windbreaks and irrigation is applied infrequently, high atmospheric and soil moisture stresses are common occurrence in the orchard.. Previous studies on *Annona* spp. hybrids by George *et al.* (1990) have shown stomatal closure with decreasing humidity, suggesting that net CO_2 assimilation (A) could be drastically reduced at low RH. The reduction in A during the FDP could adversely affect carbohydrate supply and consequently fruit size.

Plant water status has also been shown to be related to specific physiological processes such as stomatal closure, photosynthesis, carbohydrate translocation and expansive growth (Hsiaso, 1973). Various studies with other tree and vine crops have shown that plant water status may change with crop load, environmental variables and sampling position (Smart and Barrs, 1973; Allan *et al.*, 1982; Moreshet and Green, 1984; Menzel and Simpson, 1986).

Besides environmental factors affecting diurnal changes in A, A may also vary during the growing season due to physiological and tree growth factors. For example, with peach, A rates may vary with rate of leaf emergence in the spring and crop load (Chalmers *et al.*, 1975; Sams and Flore, 1986). For persimmon, George *et al.* (1997) found that the peaks in A appeared to coincide with the period of maximum root growth and stage II of fruit growth.

This study was conducted to evaluate the effects of environmental, seasonal tree growth and crop load variables on A, leaf conductance (g_S) and leaf water potential ($_L$) with a longer term view of modifying these variables by cultural techniques such as windbreaks, overhead misting, efficient irrigation scheduling and fruit thinning.

Materials and methods

Experiment 1. Diurnal changes in A, g_S, and $_L$.

Six, eight-year old, uniformly sized trees of the *Annona* spp. hybrid cv. African Pride (mean yield of 60 kg per tree), on their own roots, were selected for the experiment at the Maroochy Horticultural Research Station, Nambour, Queensland. (Latitude 26°S). Trees were spaced 6 m in rows and 8 m between rows (416 trees ha^{-1}) on a sandy loam overlying a clay substratum. The rows were mounded to a depth of 50 cm to improve drainage.

Project jointly funded by HRDC (FR425) and RIRDC(DAQ-167A), and Australian custard apple growers

Under tree irrigation was applied by mini-sprinkler twice weekly, based on foliage ground cover and replacement of 80% of class A pan evaporation, with rainfall less than 5 mm considered ineffective. Irrigation maintained soil moisture tension at 20 cm < 20 kPa. Trees were fertilised each year in August with a complete fertiliser supplying 300 g N, 60 g P, 250 g K, and, in February, 200 g K (as K_2SO_4) per tree. Trees were trained to an open goblet system and were dormant pruned in September of each year.

On 5 non-consecutive days during April, May and June 1996 (early-harvest period), A, g_S, leaf temperature (LT), air temperature (AT), wind speed (WS) and $_L$ were measured at approximately 2-hourly intervals from sunrise to sunset. Leaf conductance, A and LT measurements were made on 1 leaf, the first fully expanded on fruiting terminals, on each of 6 trees with a LiCor 6200 photosynthesis meter using a 1L chamber. Leaf water potential ($_L$) was measured in a pressure chamber (Scholander *et al.*, 1964) using all precautions suggested by Ritchie and Hinckley (1975). Leaves were enclosed in small plastic bags prior to excision to avoid rapid water loss and thus decreases in ($_L$) (West and Gaff, 1971; Wenkert *et al.*, 1978). Readings were taken within 30s after excision on 1 leaf on each of 6 datum tree using similar leaves as used for A measurements. All measurements were made about 1.5-2.0 m above ground level.

Wet and dry bulb (AT) temperatures (Taylor hygrometer) and wind speed (WS) (Tradewinds anemometer) were measured 2 times during each sample period at a height of about 1.5-2.0 m above the ground and 20 cm from the foliage. The difference in vapour pressure between leaf and air (VPD) is expressed by kPa. Photon flux density (PPF) was measured with the sensor head on the LiCor 6200 photosynthesis meter chamber held horizontally.

Correlation, and simple, multiple linear and non-linear regression analyses were carried out to establish if significant relationships existed between A, $_L$ and g_S and the following environmental variables: PPF, LT, AT, RH, VPD, and WS. Log transformation of some variables was carried out to improve ease of interpretation of data.

Experiment 2. Seasonal changes in A

Site, variety and tree management were the same as for Experiment 1. Ten, uniformly- sized trees of similar crop load were selected for monitoring over 2 seasons, 1995-96, 1996-97. Yields per tree in the 1996 and 1997 harvest seasons were 60 kg and 35±5 kg, respectively. A measurements were made between 08.30-09.00 h at ca. 10-14 day intervals from budbreak to the commencement of leaf senescence. Measurements were made between 8.30-0900 h on 1 leaf (the first fully mature) on each datum trees. During the measurements, PPF was above 1200 µmol m^{-2} s^{-1}, the light saturation point for *Annona* spp. hybrid cv. African Pride (Figure 1) and average VPD was 0.81±0.23 kPa. Leaf temperature varied between 15-38°C (Figure 5).

On the same dates used for A measurements, shoot extension was recorded at about on 4 uniform lateral shoots (pruned to 30 cm) on each datum tree. Six fruit, one per lateral (similar size as those used for shoot extension measurements) were selected and fruit length and diameter (2 directions) were also measured. For the 1996-97 growing season only, root growth was measured in a 250 cm^2 area of top-soil scraped away to a depth of 5 cm revealing dormant roots, which were then covered with 5 layers of newspaper, a layer of shade cloth, and then mulch. By lifting the shade cloth and mulch the newspaper could be lifted off to study the development of new white roots on the surface soil. The development of new white roots was rated fortnightly on a scale from 1 to 10 (1 = no new roots, 10 = new roots covering the whole area).

On the same dates used for tree growth and A measurements, leaf, shoot and trunk samples were taken from each datum trees for starch analyses. Twenty leaves, similar to those used for A measurements were taken for the leaf starch sample. Shoot samples were taken from the middle third section of six fruiting lateral shoots per tree. Core trunk samples (6 cm^3) were taken about 30 cm above ground. Tissues were oven-dried for 5 days at 60°C, milled at 100 mesh and analysed by a 2-stage enzymatic hydrolysis of starch to glucose, and the concentration determined colormetrically using a coupled glucose-oxidase-peroxidase-chromogen system (Rasmussen and Henry, 1990).

Experiment 3. Effects of crop load on A and g_S

Site, variety and tree management were the same as for Experiment 1. Eight uniformly-sized trees were thinned in January to between 20-300 fruit per tree. A measurements were made on 6, the first fully expanded leaves,

on each tree at peak harvest. During the measurements (08.30-09.00 h), leaf temperatures was 25±1.0 °C, VPD was 0.86±0 1 kPa and PPF was >1200 μmol m^{-2} s^{-1}.

Results

Experiment 1 Effects of environmental variables on A, g_s and $_L$

Plant and environmental variables recorded during the experiment are presented in Table I. Diurnal changes in A, $_L$ and g_s and the following environmental variables PPF, AT, RH, are presented in Figure 2. The effects of cloud cover during the middle of day 3 on reducing PPF, and consequently A, are clearly shown. RHs were highest in the early morning and late afternoon. On days 1 and 2, low As were associated with low RHs throughout the day. A was at a maximum between 08.30 and 10.00 h, after which A declined gradually throughout the rest of the day. In contrast $_L$ was at a maximum between 11.30 and 13.00 h, with these peaks coinciding with maximum ATs.

For all values, A was mildly linearly related to PPF (r^2=0.045, P<0.01) and moderately with PPF+RH (r^2=0.72, P<0.01) but not to RH alone except at values of PPF > 1 200 μmol m^{-2} s^{-1} (light saturation) (Figure 3). The addition of other variables besides RH or PPF into multiple, linear regressions analysis added little to explaining the variation in A. Stomatal conductance increased non-linearly with RH (Figure 3). As expected A increased with increasing g_s (Figure 3). Leaf water potential increased linearly with AT (r^2=0.56, P<0.05) and PPF (r^2=0.52, P<0.05). The addition of other variables besides AT or PPF into multiple linear regressions analysis also added little to explaining the variation in $_L$.

Experiment 2 Seasonal changes in A

Seasonal changes in shoot growth are presented in Figure 5. Similar patterns of A were recorded in both seasons with 4 major peaks. For the 1996-97 season, A rates prior to harvest were about half those recorded in 1995-96. Peaks in A coincide with periods of root growth (Figure 5) with the maximum rate of A (15 .0 μmol CO_2 m^{-2} s^{-1}) occurring during a period of root flushing and early harvest. The rate of A increased with the strength of the root flush (Figure 6). The maximum rate of A recorded in this Experiment was similar to that reported for deciduous fruit species such as peach (13.3±3.8 μmol CO_2 m^{-2} s^{-1}) (Flore, 1994). Seasonal changes in A were not correlated with changes in leaf or air temperatures, RH, VPDs or leaf, shoot and trunk starch concentrations.

Experiment 3 Effects of crop load on A

There was a rapid, non-linear increase in A with increasing fruit number per tree up to 150, above which A rates slowed (Figure 7). In contrast, a linear relationship was found between A and fruit number per unit canopy volume (Figure 8). A and g_s were moderately correlated (r^2 = 0.32, P<0.05).

Discussion

The relationship between A and environmental variables is often difficult to define in the field because of the confounding effects and interactions between variables (Cowan, 1977). However, we were able to clearly show that both A and g_s of *Annona* spp. hybrids are highly positively related to increasing RH of the atmosphere and to a much lesser extent on other plant and environmental variables. Similar findings were found for *Annona* spp. hybrids in a previous study by George *et al.*(1990) and for a wide range of other plants (Cowan, 1977; Losch and Tenhunen, 1981). For example, Menzel and Simpson (1986) were able to show that variation in g_s of lychee, a subtropical evergreen species, could be attributed to negative responses to VPD (r=0.90, P<0.01). A direct response of stomata to changes in RH indicates a mechanism to conserve water in a dry atmosphere at the expense of A and growth.

RH appears to the key environmental variable affecting the productivity of *Annona* spp. Hybrids. Flowers abscise and desiccate at RH<70% and fruit set is reduced severely (George and Nissen, 1988). In California, where RH during flowering of the closely related species, cherimoya, is low, it must be hand-pollinated to set satisfactory

crops (Schroeder, 1943). However in Spain, Ecuador and Peru, high natural set of cherimoya trees has been ascribed to high RH (>60%) during flowering which prevents stigma desiccation (Popenoe, 1970; Hofmann and Hofman, 1987).

Multiple regression techniques have been used to model the effects of microclimate on $_L$ of various crops (Smart and Barrs, 1973; Stanley *et al.*, 1981). In both this study and a previous study (George and Nissen, 1992), we found that $_L$ was highly responsive to LTs and ATs and to a lesser extent on PPF and VPD. The response of $_L$ to these variables is to be expected since transpiration is the key factor determining leaf water potential (Cowan, 1977) and transpiration rates are directly and indirectly affected by PPF, AT, LT and VPD (Jones *et al.* 1985). Our results are in agreement with the findings of Smart and Barrs (1973) who found that PPF and AT to be the two most important meteorological variables for predicting diurnal trends in $_L$ for a range of horticultural crops (citrus, grapes, peaches and prunes). In our study the relative contributions of other variables to the regression models were quite small.

The small fruit size of some *Annona* spp. hybrid cvs. in Queensland may be the consequence of crop load and reduced assimilation rates under low RH conditions experienced during the flowering and FDPs. Trees compensated for increasing crop loads by increasing A by about 30%. Similar responses have been observed in stonefruit and these were shown to be due to increased g_s and not due to 'feedback inhibition' caused by leaf starch accumulation (Flore, 1994). The high correlation between A and root flushing indicates that the roots have a sink activity. Similar findings have been found with persimmon (George *et al.*, 1997).

Methods of improving fruit size and yield in the field would involve raising RH using overhead intermittent misting and windbreaks and adjusting crop load to maximise A but without reduction in fruit size. As a consequence of greater A under higher RHs, irrigation scheduling may also need to be altered according to atmospheric demands. The selection of cultivars which are less sensitive to RH may in the long term prove a more fruitful approach to improving the productivity of *Annona* spp. hybrids.

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CAPTIONS FOR FIGURES

Figure. 1 Response of A of *Annona* spp. Hybrid cv. African Pride to varying PPF.

Figure.2 Diurnal changes in A, $_{L}$, g_S AT, PPF, RH of the *Annona* spp. hybrid cv. African Pride for 5 non-consecutive days during April, May and June 1996 in Experiment 1. Data are the means of 2-6 readings on 6 datum trees.

Figure 3. The relationship between A, g_s and RH of the *Annona* spp. hybrid cv. African Pride. Measurements for PPF>1200 μmol $m^{-2}s^{-1}$.

Figure. 4 The relationship between A and g_S of the *Annona* spp. hybrid cv. African Pride in Experiment 1.

Figure. 5 Seasonal changes in A, leaf temperature and root growth (rated 1-10, 1=no new roots, 10=new roots covering 250cm^2) for the 1995-96 and 1996-97 growing seasons (Exp.2). Data are the means of 10 trees. Vertical bars are representative SEs.

Figure. 6 The relationship between root growth (rated 1-10, 1=no new roots, 10=new roots covering 250cm^2) and A of the *Annona* spp. hybrid cv. African Pride for the 19996-97 growing season (Exp. 20. Data are the means of 10 trees.

Figure. 7 The relationship between fruit number per tree of the *Annona* spp. hybrid cv. African Pride and A measured at peak harvest in Experiment 3. Data are the means of 8 trees.

Figure. 8 The relationship between fruit number per m^3 of canopy volume of the *Annona* spp. hybrid cv. African Pride and A measured at peak harvest in Experiment 3. Data are the means of 8 trees.

Table. ***Range of plant and environmental variables during Experiment 1.***

Variable	Symbol	Unit	No of observations per mean	18 April		19 April		9 May		14 May		5 June	
				Max.	Min.	Max.	Min	Max.	Min.	Max.	Min.	Max.	Min.
Net CO_2 assimilation	A	µmol CO_2 $m^{-2}s^{-1}$	6	11.3	8.3	13.3	6.4	18.9	7.3	17.8	4.0	14.6	3.6
Leaf conductance	g_S	mmol H_2O m^{-2} s^{-1}	6	0.170	0.110	0.189	0.068	0.316	0.137	0.394	0.086	0.524	0.028
Air temperature	AT	°C	6	32.0	26.6	31.2	24.1	27.5	24.3	30.7	24.7	27.6	16.6
Leaf temperature	LT	°C	6	35.1	29.7	33.5	24.9	29.2	22.0	33.5	24.6	28.7	14.8
Leaf-air water vapour concentration	VPD	kPa	2	1.93	1.12	1.66	1.135	0.93	0.45	1.14	0.51	0.925	0.595
Relative humidity	RH	%	2	63	52	67	52	84	67	88	71	88	71
Photon flux density	PPF	µmol quanta m^{-2} s^{-1}	6	2048	650	2036	680	2041	185	2054	503	1806	303
Leaf water potential	L	MPa	6	16.7	8.3	17.7	8.6	14.6	10.3	14.8	8.6	13.0	5.6
Wind speed	WS	km h^{-2} 1		7.4	6.5	8.8	6.0	7.4	0.0	9.9	0.0	0.0	0.0

Table. ***Linear and multiple linear regressions between A, g_S and $_L$ and plant and environmental variables for Annona spp. hybrid cv. `African Pride' in Experiment I.***

Y variable	X			R^2	Equations
	Variable 1	Variable 2	Variable 3		
A(all values)	PPF			0.45**	A=5.775+0031PPF
	PPF	RH		0.72**	A=-0.457+0.426PPF+0.130RH
A (values >1 200 µmol quanta m$^-$ 2 $_s$-1	RH			0.72**	A=0.457+0.159RH
L	AT			0.56**	L =-0.552+0.676AT
	PPF			0.52**	L=0.707+0.418PPF
	PPF	WS	AT	0.79**	L=-0.169+0.346PPF+0.918WS+0.349AT
g_S	RH			0.52**	g_S=-0.291+0.0071RH

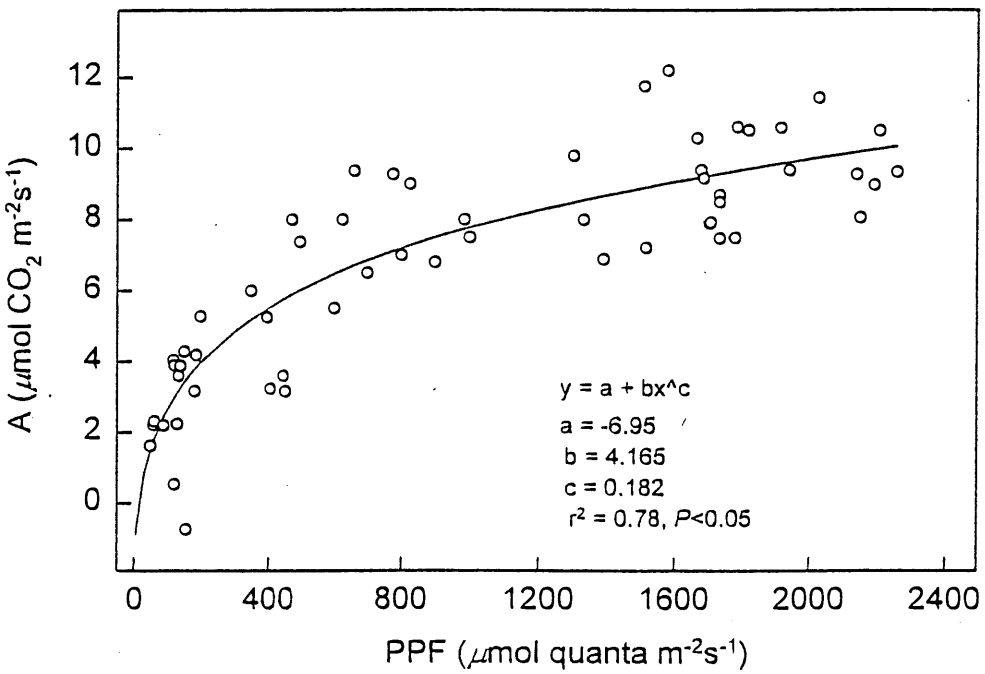

Fig. 1 Response of A of *Annona* spp. hybrid cv. African Pride to varying PPF.

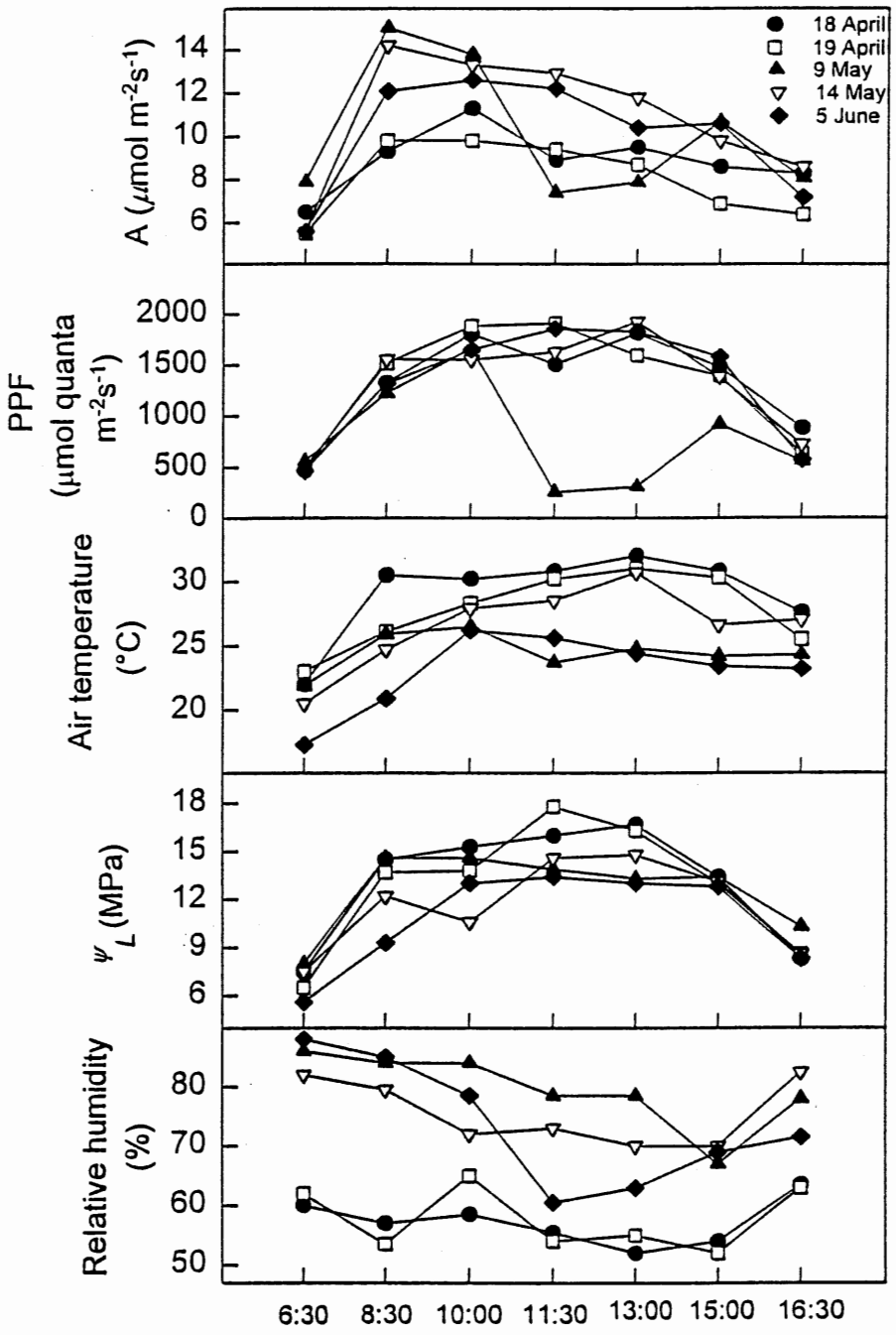

Fig 2. Diurnal changes in A, ψ_L g_s, AT, PPF, RH of *Annona* spp. hybrid cv. African Pride for 5 non-consecutive days during April, May and June1996 in Experiment 1. Data are the means of 2-6 readings on 6 datum trees.

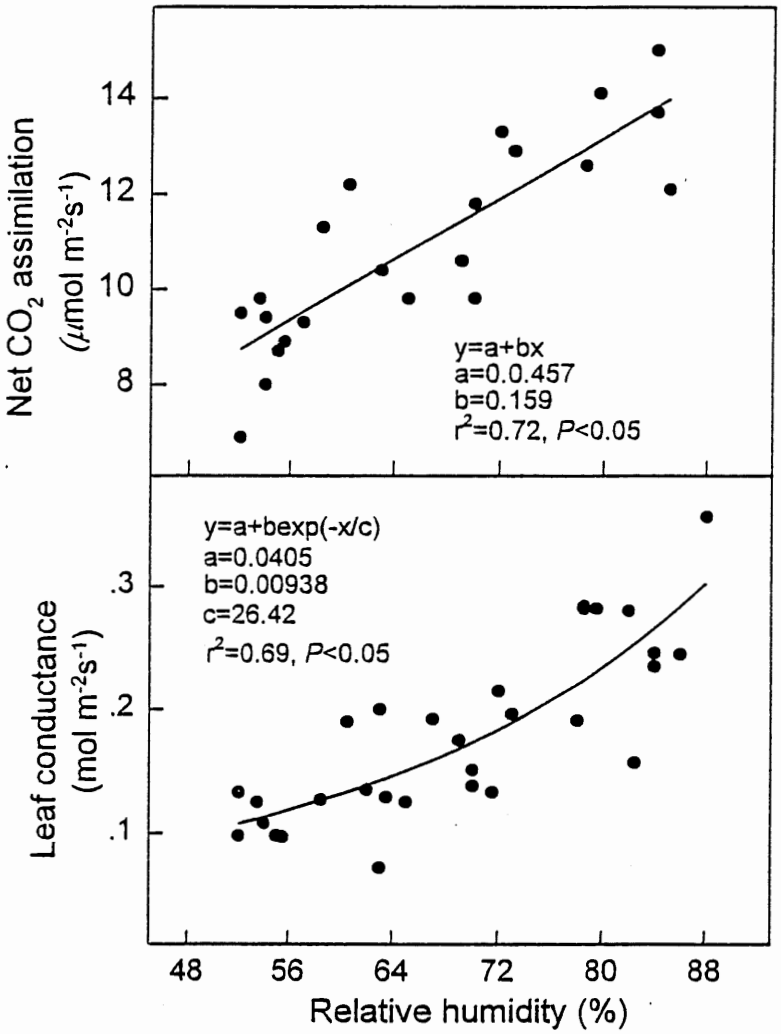

Fig.3 The relationship between A, g_s and RH of the *Annona* spp. hybrid cv. African Pride in Experiment 1. Measurements for PPF>1200 μmol $m^{-2}s^{-1}$.

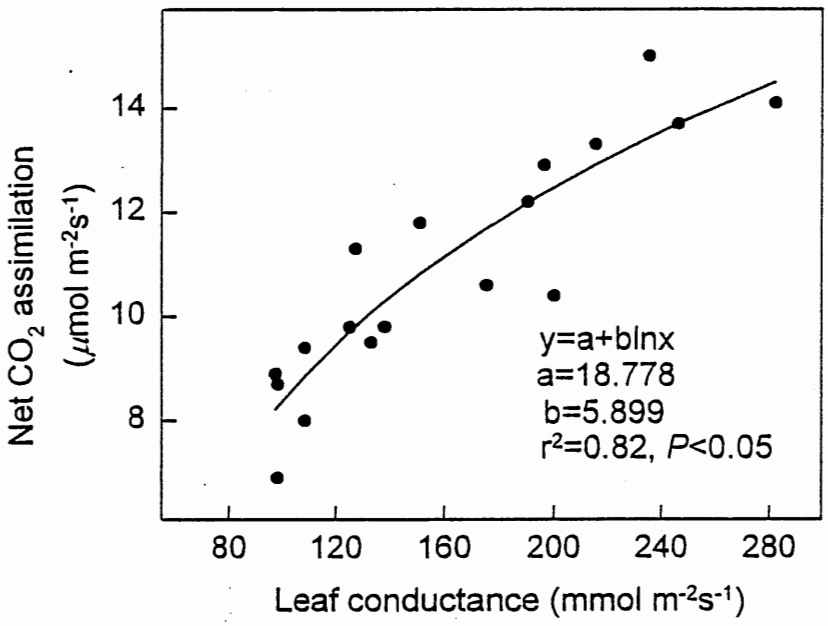

Fig 4. The relationship between A and g_s of *Annona* spp. hybrid cv. African Pride in Experiment 1.

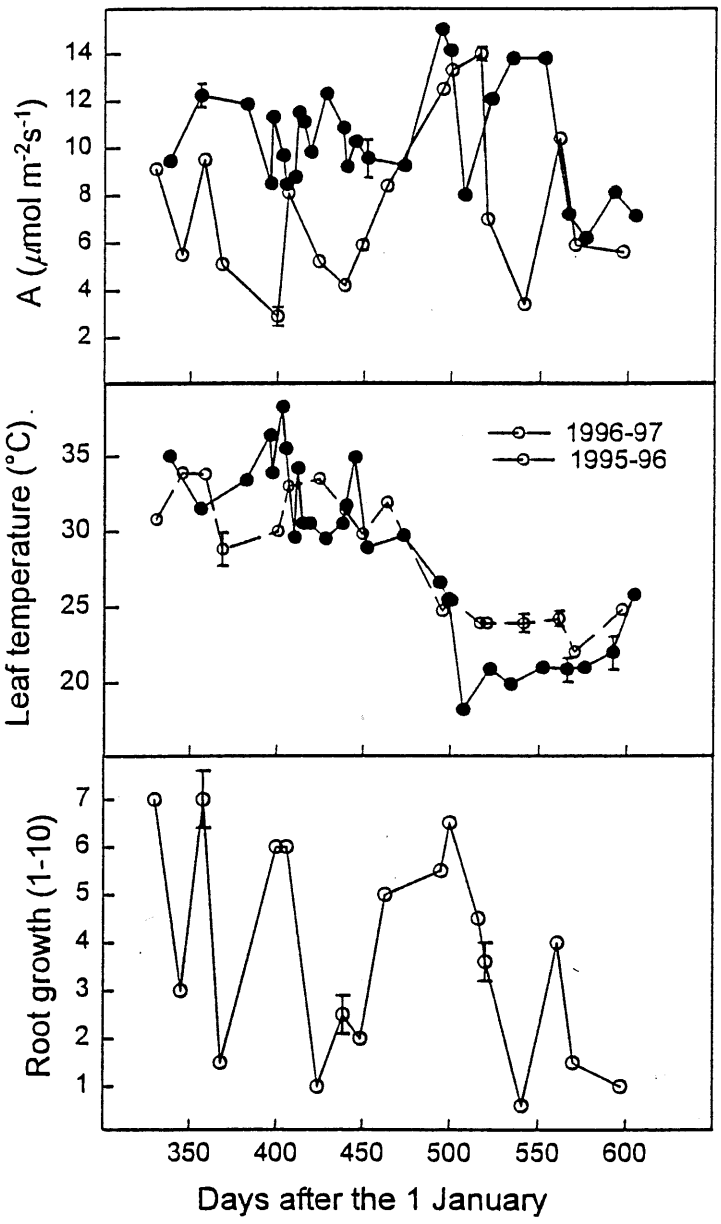

Fig. 5 Seasonal changes in A, leaf temperature and root growth (rated 1-10, 1=no new roots, 10=new roots covering 250cm^2 area) of the *Annona* spp. hybrid cv. African Pride for the 1995-96 and 1996-97 growing seasons. Data are the means of 10 trees. Vertical bars are representative SEs.

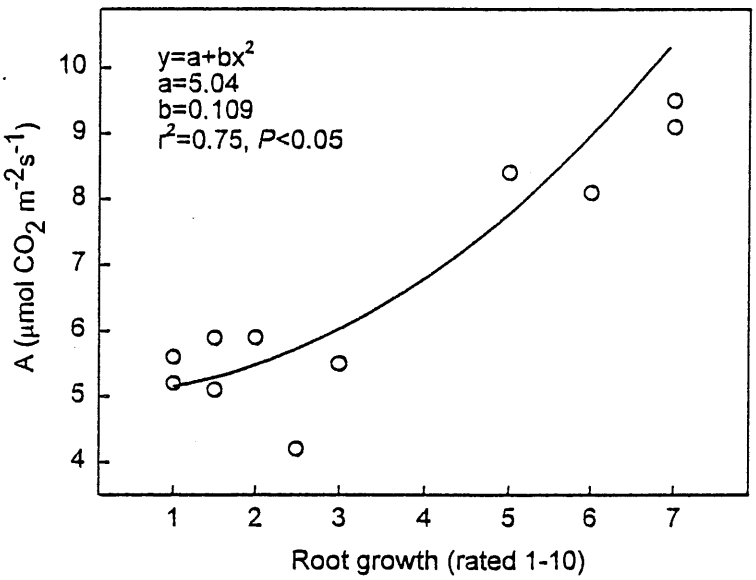

Fig.6 The relationship between root growth (rated 1-10,1=no new roots,10=new roots covering 250cm^2 area) and A of the *Annona* spp. hybrid cv. African Pride for the1996-97 growing season. Data are the means of 10 trees.

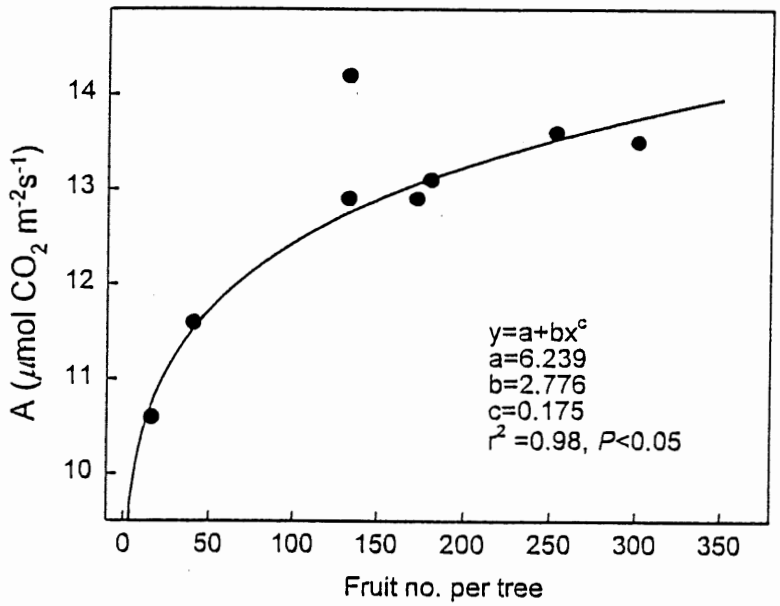

Fig.7 The relationship between fruit number per tree of the *Annona* spp. hybrid cv. African Pride and A measured at peak harvest in Experiment 3. Data are the means of 8 trees.

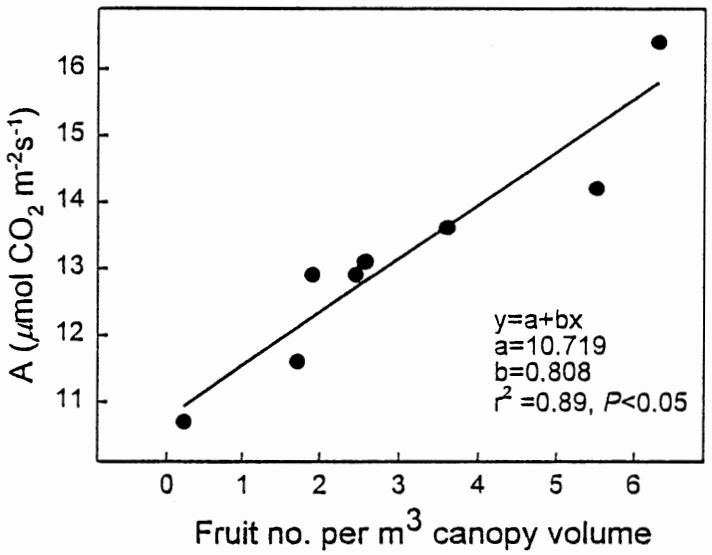

Fig.8 The relationship between fruit number per m^3 of canopy volume of the *Annona* spp. hybrid cv. African Pride and A measured at peak harvest in Experiment 3. Data are the means of 8 trees.

EFFECTS OF PRUNING, CINCTURING AND PACLOBUTRAZOL ON SHOOT GROWTH, YIELD AND FRUIT QUALITY OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

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Summary

Three experiments were conducted to evaluate the effects of different methods of reducing shoot growth on flowering, fruit set, fruit growth and fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. The methods evaluated were: dormant cane vs. spur pruning, early summer shoot tipping, shoot cincturing and foliarly-applied paclobutrazol. Both shoot tipping and foliar application of paclobutrazol in mid-November, at the commencement of the first, major vegetative growth flush, suppressed vegetative growth by about 70% and increased fruit weight by 16 and 26%, respectively. Foliar application of paclobutrazol reduced the severity of `woodiness' disorder by 29% but shoot tipping had no significant ($P$>0.05) effect. In a comparative study of cane vs. spur, dormant pruning systems, spur pruning increased the severity of `woodiness' and `brown pulp' disorders 10-fold due to excessive, compensatory regrowth. Cane-pruned trees carried three times the number of fruit and about double the weight of fruit per tree compared with spur-pruned trees.

Introduction

Young *Annona* spp. hybrid trees are excessively vigorous and exhibit poor precocity of bearing. Flowering in *Annona* spp. hybrids is strongly associated with vegetative flushing (George and Nissen, 1987) with most flowers being produced on the basal nodes of newly emerging vegetative laterals. Fruit set occurs only on small weak laterals with base circumferences between 20-40 mm (George and Nissen, 1986; George *et al.*, 1995, unpublished data). Stronger laterals and leaders fail to set. After budbreak, strong vegetative flushing may adversely affect fruit set and quality with vigorous trees producing fruit with asymmetrical shape, rough skin and severe internal disorders such as `woodiness' and `brown pulp' (George and Nissen, 1988a, 1995, unpublished data).

Annona spp. hybrid trees are normally structurally pruned in September, when dormant. The severity of this pruning varies widely amongst growers, with some growers, severely pruning their trees, cutting back shoots and laterals to less than 20 cm (spur pruning) whilst other only lightly tip their shoots (cane pruning). Studies on young, juvenile trees (George and Nissen, 1986) have shown that if dormant pruning is too severe, fruit set and yield in the first cropping season is reduced by 80%. However, the response of mature trees to spur pruning has not been evaluated. Tip pruning in the early summer may also be beneficial because strong vegetative flushing occurs concomitantly with flowering and early fruit growth. However, the timing of shoot tipping has not been evaluated. Experience with other fruit crops, deciduous, temperate and subtropical, evergreen species, have shown that the response to both dormant and summer pruning is often highly variable and few guidelines are currently available for the severity and timing of such practises (Marini, 1985; Menzel, *et al.*, 1996).

Few or no studies have been conducted to evaluate the influence of dormant pruning severity and summer tip pruning on subsequent shoot growth, flowering, fruit set, fruit growth and fruit quality of *Annona* spp. hybrids in subtropical Australia. Foliar applications of paclobutrazol and shoot cincturing were also evaluated as alternative methods to summer tip pruning to control shoot vigour.

Materials and methods

Experiment 1. Summer tip pruning
Ten, eight-year old, uniformly sized trees of the *Annona* spp. hybrid cv. African Pride, on cherimoya (*Annona cherimola*) rootstock, were selected at a commercial orchard at Palmwoods, Queensland. Trees were spaced 6 m in

rows and 8 m between rows (208 trees ha^{-1}) on a sandy loam overlying a clay substratum. The rows were mounded to a depth of 50 cm to improve drainage.

Treatments were 4 different time of lateral tipping viz, mid-November 1996, mid-December 1996, mid- January 1997, mid-February 1997. Controls were left untipped. Treatment were applied to 6 tagged laterals on each datum tree. Laterals were initially selected for uniformity of size (22±2 cm long) and position (median tree height and equally distributed around the circumference of the tree). One flower per lateral was hand-pollinated using pollen cv. African Pride on the 19 November 1996 to ensure adequate fruit set and to determine the influence of tipping in mid-November (peak flowering) on fruit set.

Shoot length and fruit diameter were measured on all treatments on each date of tipping. On 20 March, at the commencement of harvest, tagged shoots were destructively sampled into their components: fruit, leaves and shoot, before leaf area and fresh and dry weight determinations. Leaves were also analysed for complete nutrients using analytical methods described by George *et al.* (1989). Fruit symmetry was rated on a scale of 1 - 5; 1, poorly symmetrical, 5, highly symmetrical. Fruit smoothness was also rated on a scale 1 - 5; 1, lumpy, 5, smooth. The severity of the internal fruit disorder `woodiness' was determined by extracting hard lumps from the flesh and determining their fresh weight and the internal browning disorder `brown pulp' was visually rated as a percentage of the surface area of vertical cross-section of fruit which was discoloured.

Experiment 2. Pruning severity

Site and tree selection were the same as for Experiment I. Eight trees each were either spur pruned or cane pruned on the 20 September 1996. Spur pruning involved shortening of laterals by 70% to leave spurs of about 20 cm length. Some thinning out of branches of the centres of trees was also carried out. For cane-pruned trees laterals were shortened by 20% to leave canes 80-100 cm in length and there was no thinning out of leaders or branches in the centre of trees. Both groups of trees were skirted as a means of controlling ant and consequently mealy bug populations. For effects on fruit set, 10 flowers on each datum tree were hand-pollinated by brush at early (17 November 1996), mid (15 December 1996) and late (21 January 1997) flowering, using pollen cv. African Pride.

The total number of one-year-old shoots on each tree was counted by two observers working independently. The total number of laterals per shoot, and the floral bud number per laterals were recorded on 10 representative shoots on each tree. The total number of laterals and flowers per tree were estimated by multiplying the total number of shoots per tree by the average number of flowers per individual shoot.

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 on 20 fruit randomly sampled from each tree at peak harvest. Apart from Brix, fruit quality measurements were the same as for Experiment 1. Brix was determined on expressed juice for each fruit sampled using an Abbe refractometer (American Optical model 10460). On 20 March, about 1 month prior to harvest, leaves, the first fully mature, were sampled from each datum tree and analysed for complete nutrients using analytical methods previously described by George *et al.* (1989). Twenty fruit, randomly sampled from each datum tree were also sampled for nutrient analyses.

Experiment 3

Orchard site and cultivar used were the same as for Experiments 1 and 2 except that trees were 4-year-old. The experimental design was a randomised block with 8 treatments, applied in a factorial arrangement, to 4 uniform laterals (about 30 cm in length) on 10 single-tree plots. Treatments were: ±cincturing, ±GA_3, ±paclobutrazol. One flower on each lateral was hand-pollinated (pollen cv. African Pride) on the 30 November 1997 to ensure adequate fruit set and fruitlets were thinned to leave only one fruit per lateral. After hand-pollination, a single application of gibberellic acid (GA_3) at 20 g l^{-1} was applied to the open flower only on the selected shoots. The aim of this application was to increase the sink strength of the developing fruitlet. Laterals were cinctured by removing a strip of bark 2 mm thick from the base of each lateral. Paclobutrazol (Cultar®, 10.0 g a.i. l^{-1}) was applied on the same date as hand-pollination to the terminal 4-5 nodes of new shoots which were about 30 cm long. Fruit quality measurements were the same as for Experiment I except harvested fruit were also assessed for pulp recovery (pulp recovery =total fruit weight-(seed + skin weight)).

Cultural practices

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees in all Experiments were fertilised in November with a complete fertiliser supplying 300 g N, 86 g P, 226 g K, and again in February with 130 g N, 383 g K per tree. With the exception of Experiment 2, trees were trained to an open vase system and were dormant spur pruned in early Spring (15 September).

Results

Fruit set

For Experiment 1, fruit set of hand-pollinated flowers was very high (>70%) irrespective of treatment. However, compared with controls, tipping in mid-November gave a slight but significant ($P<0.05$) increase in fruit set (79.8 vs. 87.8%). For Experiment 2, although initial fruit set was slightly higher on the spur pruned trees (50 vs. 34%), later fruit set on cane pruned trees was significantly higher (5 vs. 25%). No fruit set was recorded for either treatment for flowers hand-pollinated on the 21 January 1997.

Shoot growth

In Experiment 1, shoot tipping in mid-November was highly effective in controlling shoot growth reducing final shoot length (20 cm) by more than 3-fold (Figure 1). Tipping after December did not significantly reduce shoot growth compared with controls, because the first major vegetative flush was completed by end of January and further growth after that was minimal. Irrespective of the date of tipping, no regrowth was observed on tipped shoots. For Experiment 2, spur- pruned trees at the commencement of flowering had more than double the lateral extension growth of cane-pruned trees and at harvest this had increased to more than 10 fold (Figure 2). In Experiment 3, foliar application of paclobutrazol stopped shoot growth within 2 weeks after application. Final shoot lengths were: paclobutrazol-treated 35 cm, control, 1.2 m; other treatments had no significant effects on shoot growth.

Tree flowering and shoot morphology

In Experiment 1, shoot tip pruning in November severely reduced shoot fresh and dry weights, leaf area per shoot, and increased the % of total shoot weight allocated to fruit by 48% and fruit weight per unit leaf area 9 fold (Table I). In Experiment 2, compared with cane-pruned trees, spur-pruned trees had 26% fewer shoots and 62% fewer laterals per tree (Table II). Cane-pruned trees produced a third more flowers per lateral and about three times more flowers per shoot and per tree (Table II).

Fruit weight and yield

Compared with controls, shoot tipping in mid-November increased average fruit weight by 16% (Table I). Cane-pruned trees carried about three times the fruit number and double the fruit weight per tree compared with spur-pruned trees (Table III). Consequently, due to the heavier crop loads, average fruit weight of cane- pruned trees was 27% lower than that of spur-pruned trees. Foliarly-applied paclobutrazol increased fruit weight by 26% (Table IV). Cincturing and GA_3 treatments did not affect fruit weight.

Fruit quality

Tip pruning in mid-November and cane pruning both improved fruit smoothness by 27 and 40%, respectively (Tables I and III). Fruit symmetry was not affected by either tip pruning or whole tree cane or spur pruning. Tip pruning did not affect the severity of internal disorders 'woodiness' and 'brown pulp'. In contrast, spur pruning increased the severity of internal disorders ten-fold compared with cane pruning (Table III). For Experiment 3, severity of 'woodiness' was reduced by about 30 and 57%, respectively, when paclobutrazol and cincturing were combined but GA_3 had no affect on internal fruit disorders (Table IV). Paclobutrazol when combined with cincturing improved flesh recovery by about 8%. Cane pruning improved fruit Brix concentration by 20% (Table III).

Leaf and fruit nutrient concentration

Reduced shoot growth associated with the earlier tip pruning dates increased leaf Ca, K and Zn concentrations, but reduced N and Mg relative to later tipping dates (Figure 3). Cane pruning increased leaf and fruit Ca, K, B and Zn concentrations but decreased leaf N concentrations.

Discussion

Both fruit set and fruit size was significantly increased by controlling vegetative shoot growth during the early stages of the first major growth flush due to reduced competition between developing fruitlets and shoots for nutrients. Both shoot tipping and foliarly-applied paclobutrazol were both highly effective in controlling this early-seasons growth. Tipping improved shoot efficiency by increasing dry weight allocation to fruit.

The effects of controlling individual shoot growth on internal fruit disorders was variable with paclobutrazol giving a positive response but not shoot tipping. A different response may have been obtained if all the shoots on the tree had been tipped since internal disorders increase with low fruit Ca concentrations, the movement of which is related to evapo-transpiration. Tissues with greater evapo-transpiration such as strongly growing new season shoots will generally accumulate more Ca than weak sinks such as the developing fruitlet (Bangerth, 1979; Witney *et al.,* 1990). Competition between sinks is also intensified when Ca is in short supply. In contrast to tip pruning, spur pruning on a whole tree basis promoted strong compensatory regrowth and increased internal fruit disorders presumably because the evapo-transpiration of newly growing shoots was increased relative to the fruit. This was also reflected in higher fruit Ca concentrations for cane pruned trees.'

Spur pruning promoted strong compensatory regrowth and strong apically dominant shoots with fewer weak laterals and consequently poorer flower production. Whilst spur pruning offers a quick means of thinning African Pride trees which often set an excessive number of fruit, this advantage is outweighed by the reduction in yield and fruit quality. A more effective means of controlling shoot vigour is to reduce whole tree vigour and size with dwarfing inter-stocks or rootstocks. Use of mild water stress during the flowering period although beneficial in increasing flower number was also detrimental to fruit size presumably due to reduction in cell numbers during the critical fruit growth stage (George *et al.*, 1998, unpublished data). Nitrogen restriction during the flowering period is also currently being investigated as a means of controlling tree vigour. In this study cincturing individual shoots was ineffective in controlling growth or improving fruit weight or quality. Similar responses have been obtained with whole tree cincturing (George and Nissen, 1998b).

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CAPTIONS TO FIGURES

Figure 1. Effects of tip pruning date on shoot growth of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 10 trees. Vertical bars represent LSDs (P=0.05).

Figure 2. Effects of cane and spur pruning on lateral and fruit growth of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 8 trees. Vertical bars represent LSDs (P=0.05).

Figure 3. The relationship between leaf nutrient concentrations for different tipping treatments and shoot growth measured in March, 1 month prior to harvest. Data are the means of 10 trees.

Table. ***Effects of shoot tip pruning on fruit size, fruit quality and partitioning on a whole shoot basis of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 10 trees in Experiment 1.***

Date of tip pruning	Fruit weight (g)	Skin type[1]	Shoot fresh weight (g)	Shoot leaf area (cm^2)	Fruit:total shoot dry weight (including fruit) (%)	Wt of fruit per unit leaf area per shoot ($g\ cm^{-2}$)
November	398	2.8	6.8	562	97.1	0.591
December	372	2.9	25.0	1542	81.9	0.213
January	320	2.3	27.8	2188	68.5	0.105
February	303	2.2	33.1	2220	70.7	0.095
Control	285	2.2	47.0	3525	65.4	0.065
LSD (*P*=0.05)	25	0.4	5.6	425	4.2	0.016

[1] 1=lumpy, 5=smooth

Table. ***Effects of spur and cane pruning on flowering and shoot growth variables of the Annona spp. hybrid cv African Pride in subtropical Australia. Data are the means of 8 trees in Experiment 2.***

Treatment	Shoot no. per tree	Lateral no per shoot	Total lateral no per tree	Floral bud no per lateral	Floral bud no per shoot	Total floral bud no per tree
Spur- pruned	187.5	5.1	956	1.8	9.3	1751
Cane- pruned	253.5	10.0	2535	2.5	25.8	6540
LSD (*P*=0.05)	21.6	1.3	126	0.4	4.5	218

Table.***Effects of spur and cane pruning on yield and fruit quality of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 8 tree in Experiment 2.***

Treatment	Fruit no. per tree	Total fruit weight per tree (kg)	Average fruit weight (g)	Skin type[1]	Brix (°)	Fresh wt. of 'woodiness' per fruit (g)	Brown pulp' (%)
Spur- pruned	126	72	571	2.0	16.9	13.1	14.4
Cane- pruned	368	153	416	2.8	20.3	1.2	1.1
LSD (*P*=0.05)	35	12.5	26	0.2	1.8	1.6	1.9

[1] 1=lumpy, 5=smooth

Table. ***Effects of pruning severity on the nutrient composition of fruit and leaves of the Annona spp. hybrid cv. African Pride. Fruit nutrient concentrations are the means of 10 fruit and leaf nutrient concentrations are the means of 20 leaves sampled from each of 8 datum trees in Experiment 2.***

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Cu (mg g^{-1})	Zn (mg g^{-1})	B (mg g^{-1})	Fe (mg g^{-1})	Mn (mg g^{-1})
Spur-pruned	1.54	0.24	1.79	0.16	0.22	0.16	16	19	10	38	68
Cane-pruned	1.65	0.25	2.13	0.27	0.23	0.17	16	29	13	54	77
LSD (P=0.05)	n.s.	n.s.	0.14.	0.15	n.s.	n.s.	n.s.	3.1	1.04	n.s.	n.s.
Leaf											
Spur-pruned	2.58	0.17	1.35	1.08	0.31	0.26	23	15	47	47	410
Cane-pruned	2.05	0.13	1.12	1.61	0.34	0.28	23	31	77	41	630
LSD (P=0.05)	0.21	n.s.	0.12	0.01	n.s.	n.s.	n.s.	4.5	6.8.	n.s.	56.

Table ***Effects of foliar applied paclobutrazol and GA_3 and cincturing on fruit quality variables of the Annona spp. hybrid cv. `African Pride' in subtropical Australia Data are the means for 10 trees per treatment in Experiment 3.***

		Fruit quality parameter			
Treatment	Level	Average fruit weight (g)	Pulp recovery (%)	Fresh weight of woodiness per fruit (g)	Brown pulp' (%)
Paclobutrazol	+	535.5	66.9	3.8	7.4
	-	423.6	62.4	5.4	17.1
Cincturing	+	475.5	66.2	4.1	13.3
	-	483.6	63.3	5.1	11.2
GA_3	+	440.2	63.5	4.6	12.3
	-	518.8	65.9	4.5	12.3
LSD (P =0.05)					
Paclobutrazol		109.6	1.3	1.2	8.2
Cincturing		n.s.	n.s.	n.s.	n.s.
GA_3		n.s.	n.s.	n.s.	n.s.
Paclobutrazol X cincturing		n.s.	1.8	1.6	11.7
Paclobutrazol X GA_3		n.s.	n.s.	n.s.	n.s.
Cincturing X GA_3		n.s.	n.s.	n.s.	n.s.

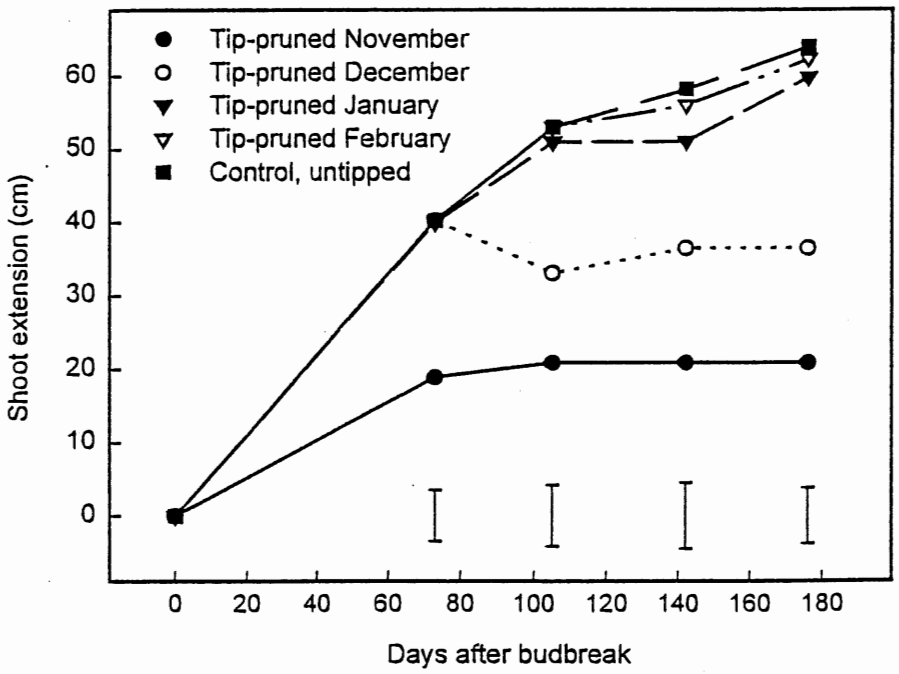

Fig. 1 Effects of tip pruning date on shoot growth of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 10 trees. Vertical bars represent LSDs (P=0.05).

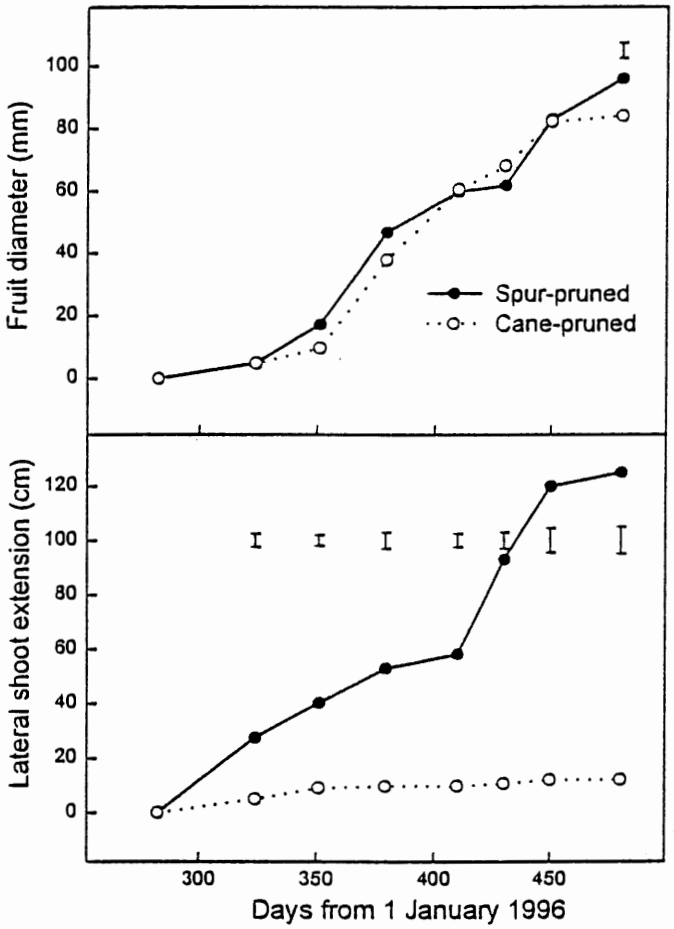

Fig. 2 Effects of cane and spur pruning on lateral shoot and fruit growth of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Data are the means of 8 trees. Vertical bars represent LSDs (P=0.05).

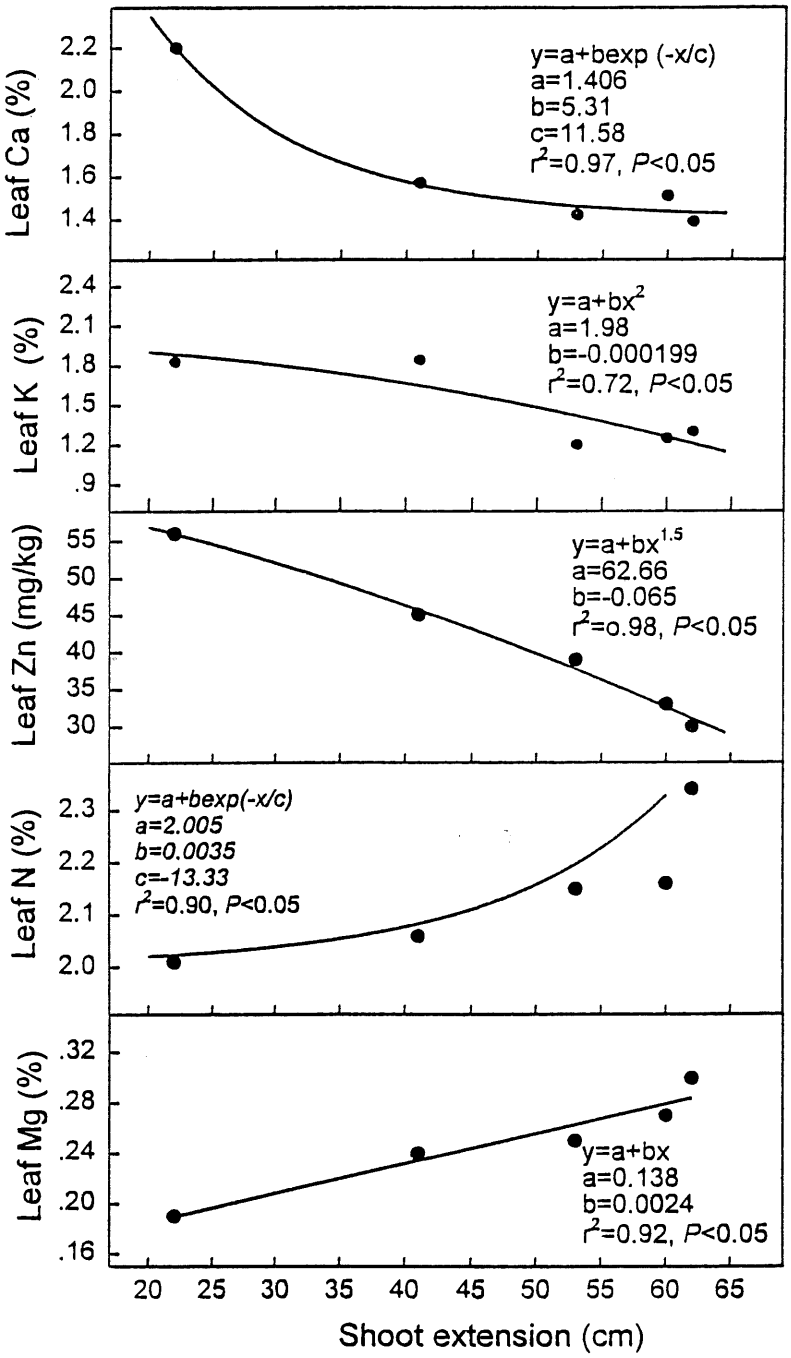

Fig. 3 The relationship between leaf nutrient concentrations for different shoot tipping treatments and shoot growth measured in March, 1 month prior to harvest. Data are the means of 10 trees.

EFFECTS OF CALCIUM, BORON AND TREE VIGOUR ON FRUIT QUALITY OF THE *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

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Summary

Two experiments were conducted to evaluate the interactive effects of soil and foliar applied Ca and B and tree and shoot vigour on fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Fruit, and to a lesser extent leaf Ca and B concentrations, were more influenced by tree vigour, and not by soil or foliar applications of Ca or B. At harvest, dwarfing sugar apple (*Annona squamosa*) inter-stock increased fruit Ca concentration by about double and total Ca content per fruit by 80%. Over 2 seasons, sugar apple inter-stock reduced the severity of two internal disorders `woodiness' and `brown pulp' by 30-70%. The severity of `brown pulp' disorder was six times greater with early-season fruit compared with the late-season fruit due to the strong competition between the developing fruitlet and the first major vegetative growth flush. Fresh weight of `woodiness' per fruit increased with shoot extension (r^2=0.62, P<0.05) and decreased with fruit Ca concentration in January, three months prior to harvest (r^2=0.57, P<0.05). Soil applied B reduced `brown pulp', but its effects were less than for Ca. Two sequentially applied, foliar sprays of calcium nitrate (2 g $l^{-1}$ ) at fruit set and 4 weeks later reduced fresh weight of `woodiness' per fruit and % `brown pulp' by 31 and 51%, respectively, but foliarly-applied B had no significant effect. Paclobutrazol significantly increased fruit fresh weight by 24 % and pulp recovery by 10.8%.

Introduction

Poor fruit quality is a major problem preventing more rapid expansion of the Australian *Annona* spp. hybrid industry. Small fruit size, irregular shape, skin roughness, skin russetting, excessive seediness and internal disorders are major fruit quality defects that will need to be reduced if *Annona* spp. hybrids are to better accepted by consumers. The effects of nutrition on fruit quality of tree fruits are poorly understood with many factors affecting the distribution of nutrients between competing organs, including tree vigour, rootstock, leaf:fruit ratios, and cultural practises such as pruning and use of growth retardants (Witney *et al.*, 1986, Hofman, 1996). Few or none of these practises have been evaluated for *Annona* spp. hybrids.

Several internal disorders have been observed in *Annona* spp. hybrids; the most common one being `woodiness' . The morphology of `woodiness' disorder of *Annona* spp. hybrids has been described in detail by Penn (1993). This disorder is characterised by the presence of woody seed pockets. A closely related disorder, often associated with `woodiness', is pulp discolouration. I have termed this disorder `brown pulp '. Penn (1993) found that `woodiness' was due to an overproduction of sclerids around some seeds. A complete histological description of the disorder is provided in her thesis. In severe cases, woody lumps may also appear in the flesh. In healthy fruit the seed pockets have the same melting texture as the rest of the flesh. There is no indication from the external appearance of the fruit that it is defective inside. Studies by Batten and Vimpany (1992) indicated that the severity of `woodiness' could be reduced through foliarly-applied B and Ca, but the responses to these applied nutrients were inconsistent. With other crops such as apples, avocado and mango internal fruit disorders such as corkiness and bitter pit are now known to be caused by Ca and B deficiencies during fruit development (Shear, 1975; Raese, 1989; Witney *et al.*, 1990 a,b; Hofman, 1996). These nutrients may be implicated in the incidence of `woodiness' and `brown pulp'.

Two experiments were conducted to evaluate the effects of soil and foliar applied Ca and B on fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. The influence of tree and shoot vigour on the response to these applied nutrients was also evaluated.

Materials and methods

Experiment 1

Experiment 1 was conducted at the Maroochy Horticultural Research Station (Latitude 26°S). A uniform block of five year old trees of the *Annona* spp. hybrid cv. African Pride were selected. Trees were spaced 3 m in rows

and 4 m between rows (833 trees ha $^{-1}$) on a sandy loam overlying a clay substratum. The rows were mounded to a depth

of 50 cm to improve drainage. The experimental design was a randomised block with factorial arrangement of treatments, viz ±Ca, ±B, ± sugar apple inter-stock applied to three replications of three-tree plots, over a two year period. Plots were guarded externally within the row. Both B (as borax) and Ca (as gypsum) were soil applied in early spring (first week of September) of 1991 and 1992 prior to the recommencement of tree growth after dormancy at rates of 5 g m^{-2} and 0.5 kg m^{-2} of projected canopy area, respectively. Trees with sugar apple inter-stock were grafted onto cherimoya (*Annona cherimola*) rootstocks; for all other treatments, trees were propagated as cuttings and not grafted onto rootstock.

Cultural practices (Experiment 2)

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees were fertilised in September and November with a complete fertiliser supplying 180 g N, 30 g P, 100 g K, and again in February with 250 g K per tree. Trees were trained to an open goblet system and they were moderately dormant-pruned (30% heading back of shoots) in 1991 and lightly pruned (10% heading back of shoots) in 1992.

Experiment 2

Experiment 2 was conducted at a commercial orchard at Palmwoods (Latitude 26°S). on a uniform block of four year old trees of the *Annona* spp. hybrid cv. African Pride. Trees were spaced 4 m in rows and 6 m between rows (416 trees ha^{-1}) on a sandy loam overlying a clay substratum.

The experimental design was a randomised block with eight treatments, applied in factorial combination, to one uniform lateral (about 30 cm in length) on each of 10 single-tree plots. Treatments were: ±Ca, ±B, ±paclobutrazol. One flower on each lateral was hand-pollinated (pollen cv. African Pride) on the 30 November 1993 to ensure adequate fruit set. Calcium as calcium nitrate and B as borax were foliarly applied to the selected laterals at rates of 2 g l^{-1} and 1 g l^{-1}, respectively, with 0.1 ml l^{-1} wetting agent (Agral 60®) added. Two sequential sprays of both nutrients were applied, the first on the date of hand-pollination and, the second, four weeks later. Fruitlets were thinned three weeks after fruit set to leave only one fruit per lateral. Paclobutrazol (Cultar®) at 10.0 g a.i. l^{-1} was applied on the same date as flowers were hand-pollination, to the terminal 4-5 nodes of new laterals which were about 30 cm long.

Cultural practices (Experiments 2)

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees were fertilised in November with a complete fertiliser supplying 300 g N, 86 g P, 226 g K, and again in February with ,130 g N, 383 g K per tree. Trees were trained to an open vase system and were winter-pruned in early Spring (15 September).

Measurements (Experiment 1)
Tree growth

For both years of the Experiment, tree height, diameter (N - S, E - W), and girth (30 cm above ground level) were measured in August, when trees were dormant. Tree canopy volume was calculated from the formula for determining the volume of a semi-ellipsoid (V = 2/3 pr^{2}h; V = tree volume, r = tree radius, h = tree height). Shoot extension was recorded at about fortnightly intervals in both growing seasons on six uniform laterals (pruned to 30 cm) on each datum tree. Flowering intensity and pattern was determined by counting, at about fortnightly intervals, the number of flowers at anthesis in a m^3 quadrat placed at a median tree height in the N and S sectors of each tree.

Fruit growth

Six fruit, one per lateral (similar size as those used for shoot extension measurements) were selected and fruit length and diameter (two directions) was measured at about fortnightly intervals.

Fruit quality

Trees were harvested at the normal commercial stage of fruit maturity (change in ground colour from green to yellow) at intervals of seven days for yield and fruit quality assessment. All fruit quality assessments, with the exception of `brown pulp' ratings, were made at peak harvest (mid-May) on 30 fruit randomly sampled from each tree. For the 1991-92 season only, `brown pulp' rating was also carried out for early- (April) and late- (July) season harvested fruit. Fruit were sectioned into flesh, skin and seed before fresh weight determinations of pulp. The fresh weight of the pulp affected by `woodiness' and the % weight of pulp affected by `woodiness' was determined. Two observers, working independently, visually rated the % of a vertical cross-section of fruit which appeared off-white or brown (`brown pulp' disorder). Fruit were also rated visually, on a scale of 1-5, for fruit symmetry (1=irregular, 5=regular shape) and skin type (1=lumpy, 5=smooth). For each fruit, skin thickness was measured at four points selected at the equator of the fruit. The number of days taken for fruit to ripen at ambient temperature (25°C) was also determined.

Leaf and fruit nutrient sampling and analyses

During the fruit development period (FDP), twenty recently-matured leaves (the 4th or 5th leaf from the growing point of fruiting laterals) and 20 average-size fruit were sampled at about monthly intervals for Ca and B nutrient analyses. Whole fruit including skin and seed were analysed.

Trees were also sampled in mid-March, the standard leaf sampling time for *Annona* spp. hybrids (George *et al*, 1989) so that comparisons between treatment effects and leaf nutrient standards set for *Annona* spp. hybrids (George *et al.*, 1997, unpublished data) could also be made. Twenty recently matured leaves were sampled from non-fruiting shoots on each datum tree for N, P, K, Ca, Mg, Fe, B, Cu, Zn and Mn analyses using analytical techniques previously described by George *et al.* (1989).

Measurements (Experiments 2)
Fruit quality

Fruit quality assessments and harvesting procedures were the same as for Experiment 1. In addition, pulp colour (Hunter L*a*b values) was also determined around the seed pocket which is the area normally most affected with `brown pulp', and for a median section of pulp, using the Minolta CR-210 chromameter.

Leaf and fruit nutrient sampling and analyses

At harvest (mid-May), all matured leaves on treated fruiting laterals and subtending fruit were sampled for Ca and B analyses. Analytical procedures were the same as for Experiment 1.

Results

Experiment 1

Vegetative growth and yield

Calcium or B, alone or together, did not significantly affect tree size, growth or yield. In contrast, sugar apple inter-stock was highly effective in dwarfing `African Pride' trees, significantly ($P<0.05$) reducing tree canopy volume by about 70% and shoot extension in 1991-92 and 1992-93 by 13.6% and 38.6%, respectively (Figure 1). Irrespective of treatment, moderate dormant pruning in 1991 resulted in strong compensatory regrowth (139.7 cm) in the subsequent growing season. In contrast, as a consequence of lighter dormant pruning in 1992, shoot extension was reduced by 42% (81.2 cm). Trees exhibited 2 peaks in vegetative flushing (Figure 1). Flowering and fruit growth patterns were similar for all treatments (data not presented). Tree yields were similar for both harvest seasons with 30% lower tree fruit weights on sugar apple inter-stock compared with trees on their own roots (15 vs. 213 kg).

Seasonal patterns in leaf and fruit nutrient concentrations

Seasonal changes in leaf and fruit Ca concentrations are presented in Figure 2. Leaf and fruit Ca concentrations were significantly reduced ($P<0.05$) for high vigour trees on their own roots compared with those on inter-stock. Leaf Ca concentrations were not significantly increased by soil Ca applications although the trend was towards higher leaf Ca concentrations particularly near harvest. This was reflected in significantly higher ($P<0.05$) fruit

Ca concentration during the harvest period in 1992 only (Figure 2). B alone, or in combination, did not significantly affect either leaf or fruit Ca concentrations. At harvest, sugar apple inter-stock increased fruit Ca concentration by about double and total Ca content per fruit by 80%. The overall trend was for fruit Ca concentrations to decline throughout the growing season and for total fruit Ca content to increase. In the 1992-93 season, a mid-season plateau in both leaf and fruit Ca concentration and content was probably a reflection of reduced fruit growth during Stage II of fruit development. Leaf Ca concentrations, in January, three months prior to harvest, were moderately correlated with fruit Ca concentrations (Figure 3); this relationship was weaker at other sampling times. Fruit Ca concentrations were also moderately correlated with fruit B concentrations (Figure 4).

Seasonal changes in leaf and fruit B concentrations are presented in Figure 5. For the 1992-93 season only, sugar apple inter-stock increased leaf but not fruit B concentrations, at the later sampling times. Soil applied B more than doubled leaf B concentrations but fruit B concentrations were either not affected (1992-93) or only slightly (25%) increased (1991-92). For 1991-92 only, fruit and leaf B concentrations were moderately correlated in January (r^2=0.41, P<0.05) but less so at other sampling dates. The overall trend was for fruit B concentrations to decline throughout the growing season and for total fruit B content to increase. For both seasons a small mid-season peak or plateau in fruit B content was observed, similar to Ca and probably a reflection of reduced fruit growth during Stage II of fruit development.

Leaf nutrient standards (mid-March sampling)

Irrespective of treatment, sugar apple inter-stock significantly reduced leaf N, P, K, Mn, Cu, Zn concentrations but increased leaf Ca compared with trees on their own roots (Table I). Soil-applied Ca did not significantly raise leaf Ca concentration but overall leaf Ca concentrations were 25% higher in 1993 compared with 1992. Soil applied B more than doubled leaf B concentrations in 1992, and increased leaf B concentration in 1993 by 51%. Irrespective of treatment, leaf Ca concentrations were in the upper end of the leaf nutrient standard range set for *Annona* spp. hybrids in subtropical Australia; in contrast, leaf B concentrations for trees not receiving B were at the lower end of the standard range (George *et al.*, 1998, unpublished data).

Fruit quality

For 1992 and 1993, sugar apple inter-stock increased skin thickness by 28 and 42% respectively (Table II). For 1992 only, Ca reduced skin thickness by 37%. For 1992 only, Ca and sugar apple inter-stock, alone, increased pulp recovery by about 5%. Sugar apple inter-stock improved fruit smoothness, slightly (Table II). Treatments did not significantly affect fruit symmetry, days to ripen or seed number per 100g of flesh.

Internal disorders - effects of season and harvest date

Irrespective of treatment, the severity of internal disorders at peak harvest (mid-May) was 5-7 times greater in the 1993 season compared with 1992 (fresh weight of woodiness, 1992, 40.8g; 1993, 8.7g; % 'brown pulp', 1992, 37.5%; 1993, 5.2%). For the 1992 harvest season, irrespective of treatment, early-season fruit had about 6 times the severity of 'brown pulp' than late season fruit (Figure 6). In contrast, in 1993, harvest date did not significantly (P>0.05) affect % 'brown pulp', presumably due to the low severity of the disorder.

Internal disorders- effects of tree vigour

For the 1992 and 1993 harvest seasons, sugar apple inter-stock reduced fresh weight of 'woodiness' per fruit at peak harvest by 32 and 63%, respectively (Table II) and for the 1992 harvest season only, % 'brown pulp' of early-, mid- and late-season fruit by 47, 71 and 40%, respectively (Figure 6). Fresh weight of 'woodiness' per fruit increased near linearly with shoot extension, (Figure 7), shoot growth increment from budbreak until one month after budbreak (r^2=0.49, P<0.05) and fresh weight of shoot attending the fruit (r^2=0.77, P<0.05).

Internal disorders- effects of Ca

For 1992 only, Ca significantly reduced fresh weight of 'woodiness' per fruit at peak harvest by 17% (Table II) and % 'brown pulp' of early-, mid-and late-season fruit by 35, 20 and 18%, respectively (Figure 6). Irrespective of treatment, fresh weight of 'woodiness' increased with decreasing fruit Ca concentrations (<0.10%) in January, three months prior to harvest, but this relationship was weaker at other sampling times (Figure 8).

Internal disorders- effects of B

For 1992 only, B reduced `brown pulp' of early-, mid- and late-season fruit by 50, 23 and 20%, respectively (Figure 6). For both harvest seasons B did not significantly reduce `woodiness' and severity of the disorder was not correlated with either leaf or fruit B concentrations.

Relationship between `woodiness' and % brown pulp'

For both harvest seasons, fresh weight of `woodiness' per fruit was moderately correlated with the percentage of total flesh weight affected with `woodiness' (r^2=0.73, P<0.05) and with % `brown pulp' (r^2=0.59, P<0.05).

Experiment 2

Irrespective of treatment, the fresh weight of `woodiness' per fruit was very low (<10 g) compared with the 1992 harvest in Experiment 1 (Table III). Foliar applied Ca, alone, reduced fresh weight of `woodiness' and % `brown pulp' per fruit by 31 and 55%, respectively and when applied in combination with B, by 55 and 63%, respectively. Paclobutrazol did not significantly reduce ($P$<0.05) `woodiness' but severity was less for treated shoots. Paclobutrazol prevented shoot growth immediately after application (control, 1.2 m; paclobutrazol treated, 32 cm). Leaf Ca but not fruit Ca concentrations were increased on paclobutrazol-treated shoots. Fruit Ca concentrations at harvest were significantly increased by foliar sprays of Ca applied at fruit set and one month later. In contrast, foliar sprays of B did not affect either leaf or fruit B concentrations at harvest. Paclobutrazol significantly increased fruit fresh weight by 24% and pulp recovery by 10.8% (Table III). Skin type, fruit symmetry and seed number per 100 g of flesh were not affected by treatments.

Discussion

These Experiments have shown that excessive tree and shoot vigour increase severity of internal disorders `woodiness' and `brown pulp' but external fruit quality is only slightly or not affected by treatments. Both `woodiness' and `brown pulp' appear to be closely related disorders with similar causes. It appears that the developing fruitlet does not compete satisfactorily with the leaves and shoots for assimilates, in particular for Ca and B. Early-season fruit appear to be the worst affected presumably because they develop from the earliest set flowers which compete concomitantly with the first strong vegetative growth flush. The severity of the `internal disorders was markedly greater in 1991-92 season compared with 1992-93. This may have been due to the younger age of trees but, more likely, to greater compensatory regrowth induced by severe dormant pruning. Severity of `woodiness' is greater under warmer growing conditions particularly because the first vegetative flush is more vigorous than in cooler growing regions (George *et al.*, 1997, unpublished data).

In these studies Ca and B concentrations and content per fruit decreased as fruit size and age increased. The Ca response is similar to that reported for avocado (Witney *et al.,* 1990). The decrease in Ca concentration is primarily a result of the continuing Ca accumulation to counteract the rapid increase in fruit size. For a period of six weeks after fruit set, fruit Ca concentrations were negatively correlated with leaf Ca (data not shown) but at later stages of fruit development were positively correlated. The data indicates that in the early stages of fruit development, fruit sink strength for Ca is weaker than for other tissues, presumably developing leaves and shoots. Competition between sinks is intensified when Ca^{++} in xylem is low and transpiration high. Tissues with greater evapo-transpiration will generally accumulate more Ca (Bangerth, 1979; Witney *et al.,* 1990a,b). In addition, the greater the number of immature leaves (which typically exhibit greater transpiration loss per unit leaf area) would result in greater transpiration flow to vegetative organs in vigorous trees (Clarkson, 1984). The developing leaves would also have a higher demand for structural Ca.

The lack of leaf nutrient response to soil-applied Ca may have been due to the initial slow movement of this fertiliser through the soil profile and to the existing high Ca leaf levels. In contrast, the leaf concentration response to applied B was rapid but increased leaf B concentrations did not equate to higher fruit B concentrations. However, this apparent lack of response may be due to the our inability to detect very low, concentration differences between treatments, particularly near harvest (<2 mg g^{-1}) and the variability in the data.

The data indicates that it is necessary to control overall tree vigour before responses to Ca or B are likely. Post-set foliar applications of Ca were partially successful in controlling `woodiness' and `brown pulp' disorders.

Batten and Vimpany (1992) also found responses, in one year out of two, to foliar applications of Ca when applied in

conjunction with B. In contrast, soil applied Ca raised leaf and fruit Ca only slightly. Fruit Ca concentrations need to be maintained at >0.15% and leaf Ca >1.6%. The current leaf nutrients standards for *Annona* spp. hybrids appear to be set too low.

Seasonal shoot extension growth be restricted to less than 60 cm to keep `woodiness' to an acceptable level of <10g per fruit. The critical period when growth needs to be reduced is during the first major vegetative growth flush. Current observations indicate that tipping all shoots on the tree reduces internal disorders and improves fruit size (George *et al.*, 1998, unpublished data). On a whole tree basis, control of shoot and tree vigour also can be achieved through the use of dwarfing inter-stocks of sugar apple and through the application of either foliar or trunk-injected paclobutrazol (George *et al.*, 1997, unpublished data). Paclobutrazol foliarly-applied post-fruit set, when new shoot were about 30 cm long, was shown to increase fruit size. In the long term, dwarfing rootstocks of cherimoya (*Annona cherimola*) may be the most efficient method of controlling `woodiness' and improving fruit quality. For other tree crops, vigour may also be controlled using regulated deficit irrigation, tip pruning and manipulating N status so as to reduce the strength of the summer vegetative flush. Further studies are needed to evaluate all these factors, either singly, or in combination.

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Table. ***Effects of tree vigour, Ca and B on leaf nutrient concentrations of the Annona spp. hybrid cultivar `African Pride' in subtropical Australia. Data are the means for three trees per treatment.***

	Major nutrients											Minor nutrients									
Treatment	Level	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		Cu (mg g-1)		Zn (mg g-1)		B (mg g-1)		Fe (mg g-1)		Mn (m g g-1)	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Inter-stock	+	2.18	1.19	0.15	0.11	1.84	1.64	1.63	2.16	0.25	0.27	10.1	6.8	19.8	34.4	98.3	103.1	72.4	63.8	281	335
	-	2.55	1.36	0.17	0.12	3.29	2.95	1.45	1.70	0.23	0.26	13.8	9.1	22.9	37.9	92.3	85.1	77.8	58.5	364	419
Ca	+	2.39	1.11	0.16	0.12	2.61	2.28	1.58	1.86	0.24	0.27	11.9	7.8	20.9	37.1	101.4	91.0	79.6	55.3	361	392
	-	2.34	1.16	0.16	0.12	2.52	2.32	1.50	2.00	0.23	0.28	11.9	8.1	21.8	35.2	89.1	97.9	70.7	66.9	283	363
B	+	2.39	1.28	0.15	0.11	2.67	2.56	1.53	1.84	0.23	0.25	11.9	8.0	21.5	31.8	135.3	113.8	79.2	60.0	351	367
	-	2.34	1.27	0.16	0.12	2.46	2.04	1.55	2.03	0.24	0.29	11.9	7.9	21.2	40.5	55.3	75.2	71.1	62.2	294	386
LSD (P=0.05)																					
Inter-stock		0.13	0.11	0.006	n.s.	0.21	0.33	0.11	0.17	n.s.	n.s.	1.08	0.8	2.2	n.s.	n.s.	13.4	n.s.	n.s.	71	n.s.
Ca		n.s.	0.11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
B		n.s.	n.s.	0.006	n.s.	0.21	0.33	n.s.	0.17	n.s.	n.s.	n.s.	n.s.	n.s.	4.9	24.4	13.4	n.s.	n.s	n.s.	n.s.
Inter-stock X Ca		n.s.	n.s.	n.s.	0.015	n.s.	n.s.	n.s.	0.24	n.s.	n.s.	1.5	n.s.	n.s.	n.s.	n.s.	18.9	n.s.	n.s.	n.s.	n.s.
Inter-stock X B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.29	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	6.9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca X B		n.s.	n.s.	0.009	n.s.	0.30	0.46	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	13.8	n.s.	n.s.	n.s.

Table. ***Effects of inter-stock, Ca and B on fruit quality of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means for three trees per treatment.***

Treatment	Level	Fruit quality parameter: % recovery		pulp Skin thickness (mm)		Skin type[1]		Fresh weight of woodiness per fruit (g)		% 'brown pulp'	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Inter-stock	+	83.1	67.1	1.22	0.58	-	2.8	24.3	4.2	26.7	3.9
	-	78.8	65.9	0.95	0.41	-	2.5	35.5	11.3	43.3	7.5
Ca	+	82.3	66.1	0.84	0.51	-	2.7	27.1	8.1	28.8	6.6
	-	79.6	66.8	1.33	0.48	-	2.6	32.6	7.6	41.2	4.8
B	+	80.7	67.7	1.14	0.58	-	2.7	25.8	8.1	25.6	6.3
	-	81.1	65.3	1.04	0.41	-	2.6	34.0	7.4	44.4	5.1
LSD (P =0.05)											
Inter-stock		1.7	n.s.	0.21	0.09		n.s.	6.5	3.7	8.6	1.1
Ca		1.7	n.s.	0.21	n.s.		n.s.	6.5	n.s.	8.6	n.s.
B		n.s.	n.s.	n.s.	0.09		n.s.	n.s.	n.s.	8.6	n.s.
Inter-stock X Ca		n.s.	n.s.	0.30	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.
Inter-stock X B		n.s.	n.s.	n.s.	0.12		0.34	n.s.	n.s.	n.s.	n.s.
Ca X B		2.4	n.s.	0.30	n.s.		0.34	n.s.	n.s.	n.s.	n.s.

[1] 1=lumpy, 5=smooth

Table. ***Effects of foliar applied paclobutrazol, Ca and B on fruit quality variables of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means for 10 trees per treatment.***

Treatment	Level	Average fruit weight (g)	% pulp recovery	Skin thickness (mm)	Fresh weight of woodiness per fruit (g)	% 'brown pulp'	Leaf Ca (%)	Fruit Ca (%)	Leaf B (mg g^{-1})	Fruit B (mg g^{-1})
Paclobutrazol	+	494.2	66.6	1.19	7.17	15.3	1.51	0.08	146	9.1
	-	399.5	60.1	1.21	7.94	13.3	1.39	0.09	135	9.6
Ca	+	445.3	62.4	1.32	6.16	9.4	1.44	0.09	142	9.1
	-	448.5	64.3	1.07	8.95	19.2	1.46	0.07	139	9.6
B	+	409.0	62.7	1.14	7.14	12.3	1.43	0.09	149	10.7
	-	484.7	63.9	1.25	7.97	16.3	1.47	0.08	132	8.7
LSD (P =0.05)										
Paclobutrazol		80.5	5.1	n.s.	n.s.	n.s.	0.09	n.s.	n.s.	n.s.
Ca		n.s.	n.s.	0.16	2.1	7.9	n.s.	0.009	n.s.	n.s.
B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Paclobutrazol X Ca		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Paclobutrazol X B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca X B		n.s.	n.s.	n.s.	4.2	11.2	n.s.	n.s.	n.s.	n.s.

Captions for figures

Figure. 1 Effects of season and pruning severity on flushing patterns of the *Annona* spp. hybrid cv. African Pride at Nambour, Queensland. Pooled data for Ca and B treatments only.

Fig.ure 2 Seasonal changes in fruit and leaf Ca concentrations and fruit Ca content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means of 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure. 3 The relationship between leaf and fruit Ca concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for all treatments means for the 1992 and 1993 harvest seasons.

Figure. 4 The relationship between fruit Ca and B concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for the 1992 and 1993 harvest seasons.

Figure. 5 Seasonal changes in fruit and leaf B concentrations and fruit B content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure. 6. Effects of harvest date on % 'brown pulp' of the *Annona* spp. hybrid cv. African Pride in the 1992 harvest season. Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure.7 The relationship between shoot extension recorded in March, 1 month prior to harvest, and fresh weight of 'woodiness'. Pooled data for 1991-92 and 1992-93 seasons.

Figure. 8 The relationship between fruit Ca concentration in January, 3 months prior to harvest, and fresh weight of 'woodiness' of the *Annona* spp. hybrid African Pride. Pooled data for the 1991-92 and 1992-93 seasons.

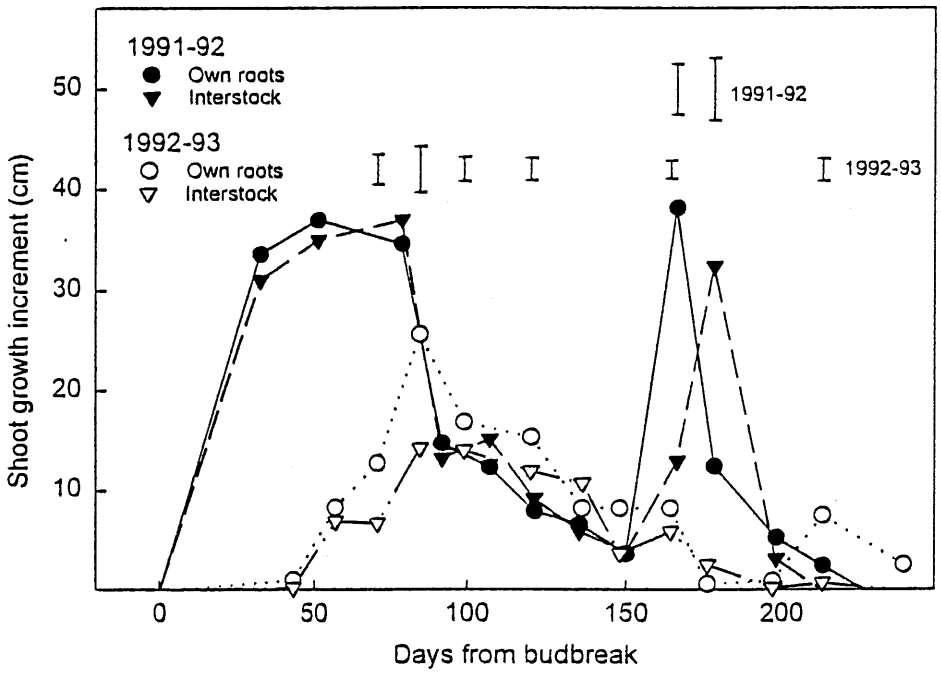

Fig. 1 The effects of season and pruning severity on flushing patterns of the *Annona* spp. hybrid cv. African Pride at Nambour, Queensland. Pooled data for Ca and B treatments only. Vertical bars represent LSDs (P=0.05)

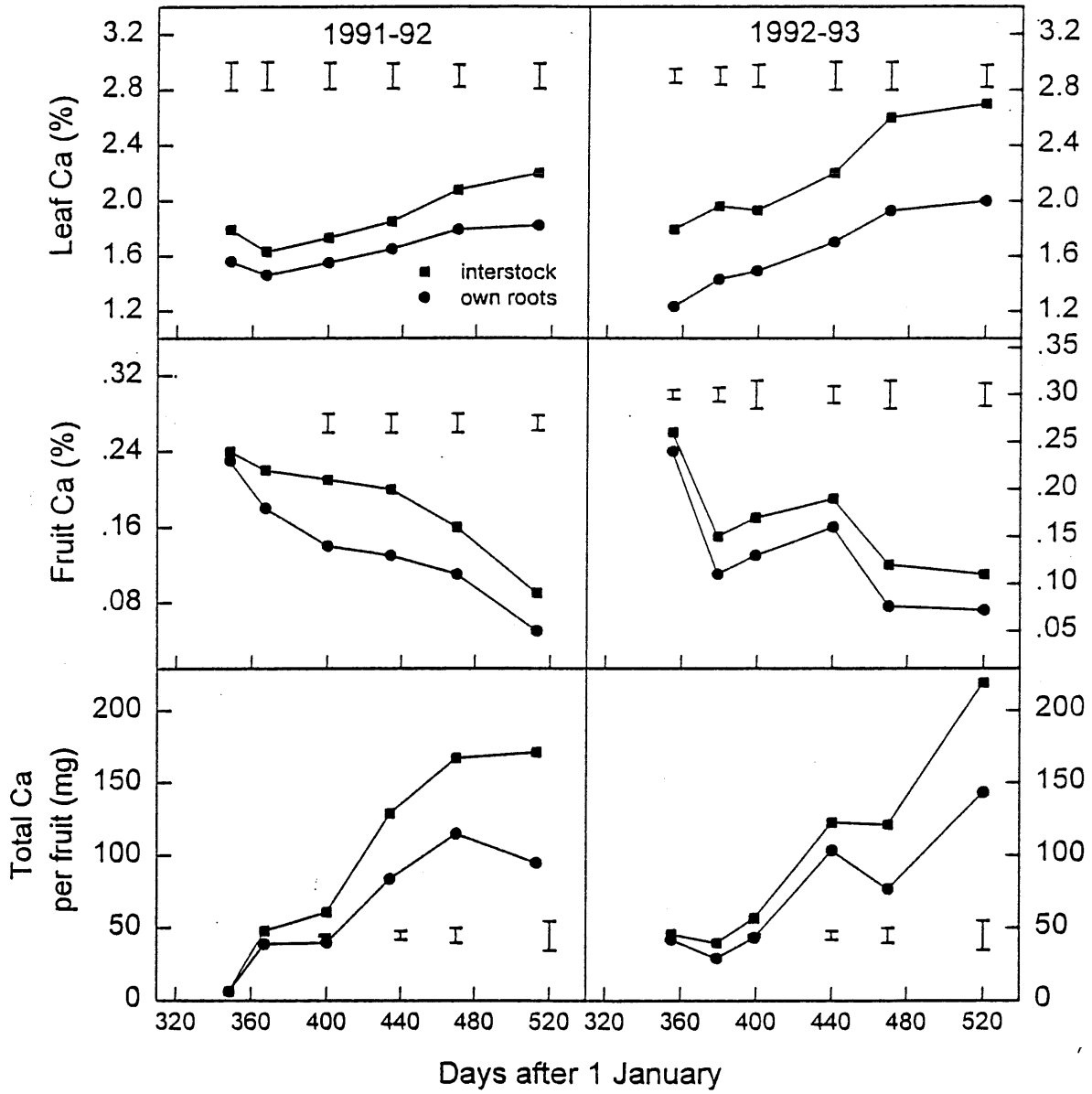

Fig. 2 Seasonal changes in fruit and leaf Ca concentrations and fruit Ca content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means of 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

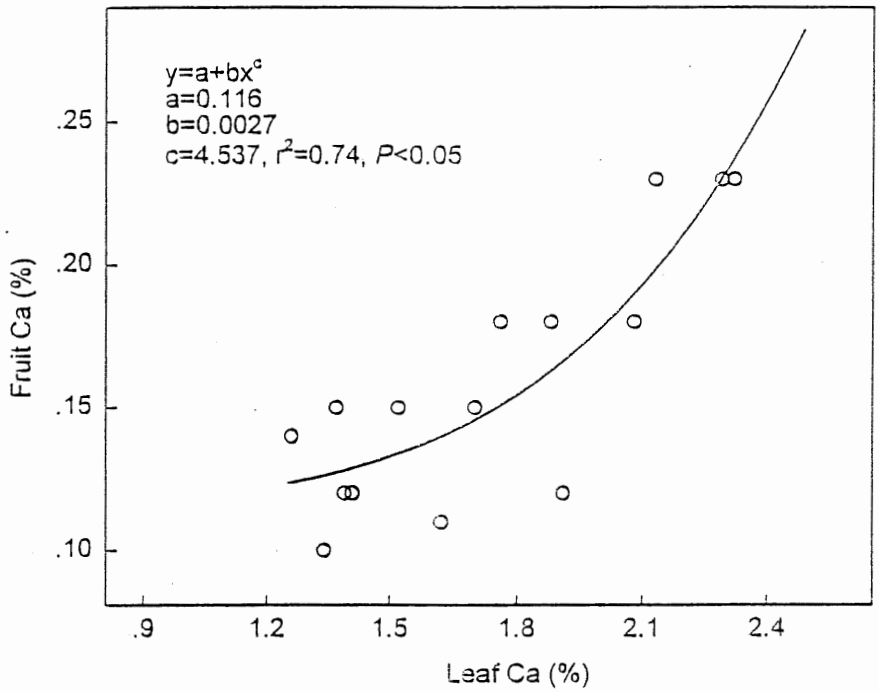

Fig. 3 The relationship between leaf and fruit Ca concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for all treatment means for the 1992 and 1993 harvest seasons.

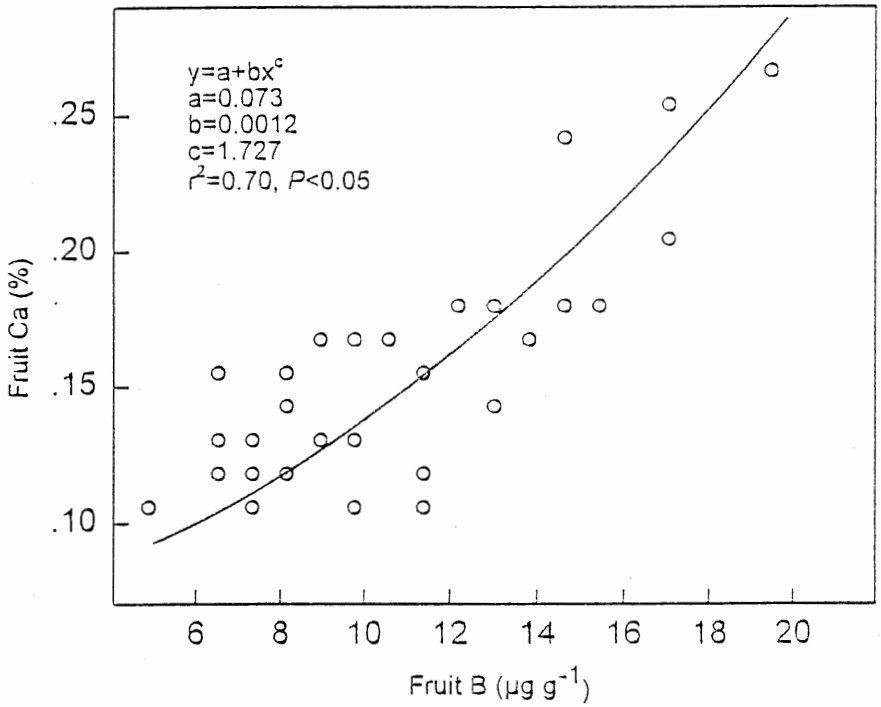

Fig. 4 The relationship between fruit Ca and B concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for the 1992 and 1993 harvest seasons.

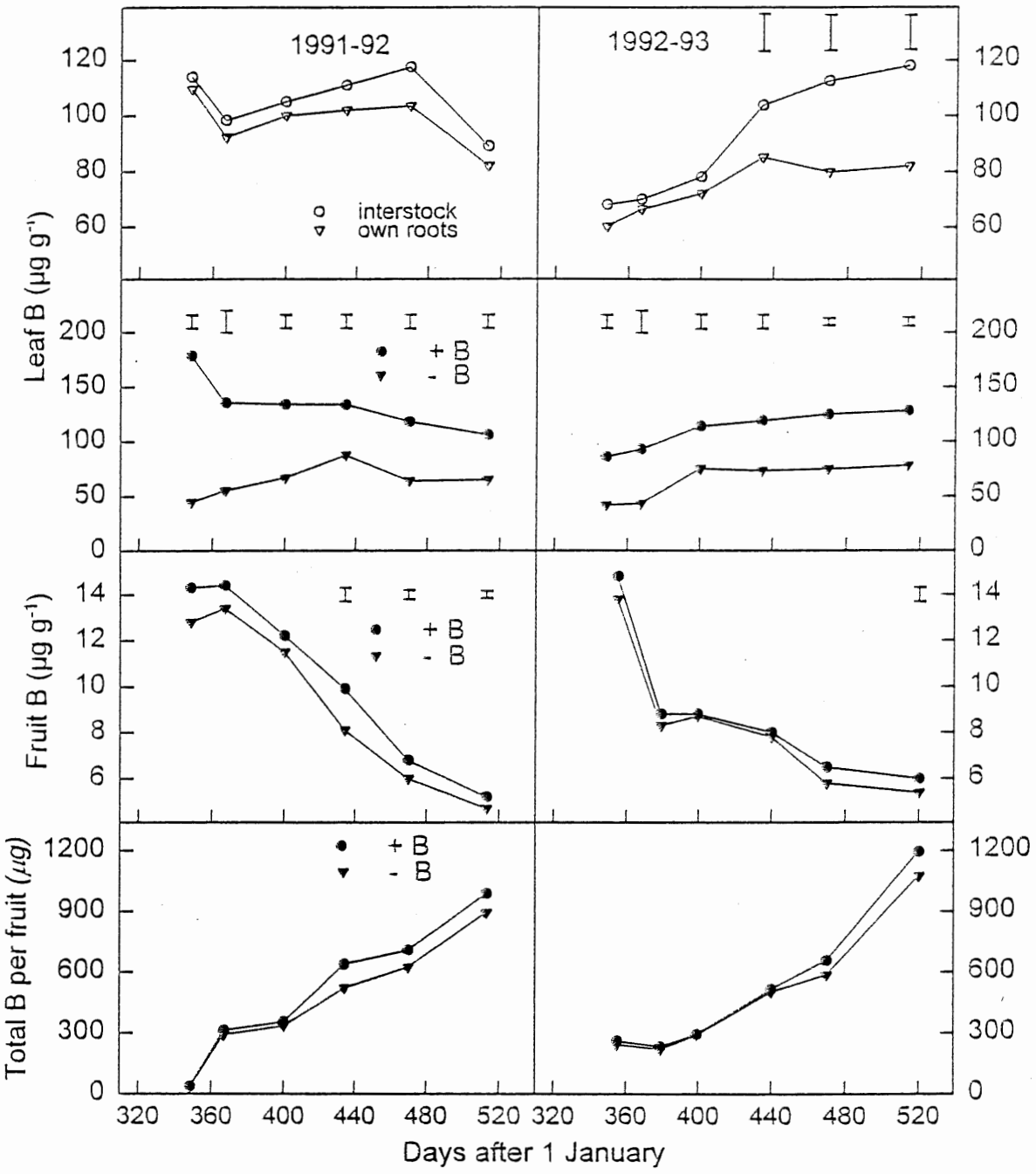

Fig. 5. Seasonal changes in fruit and leaf B concentrations and fruit B content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

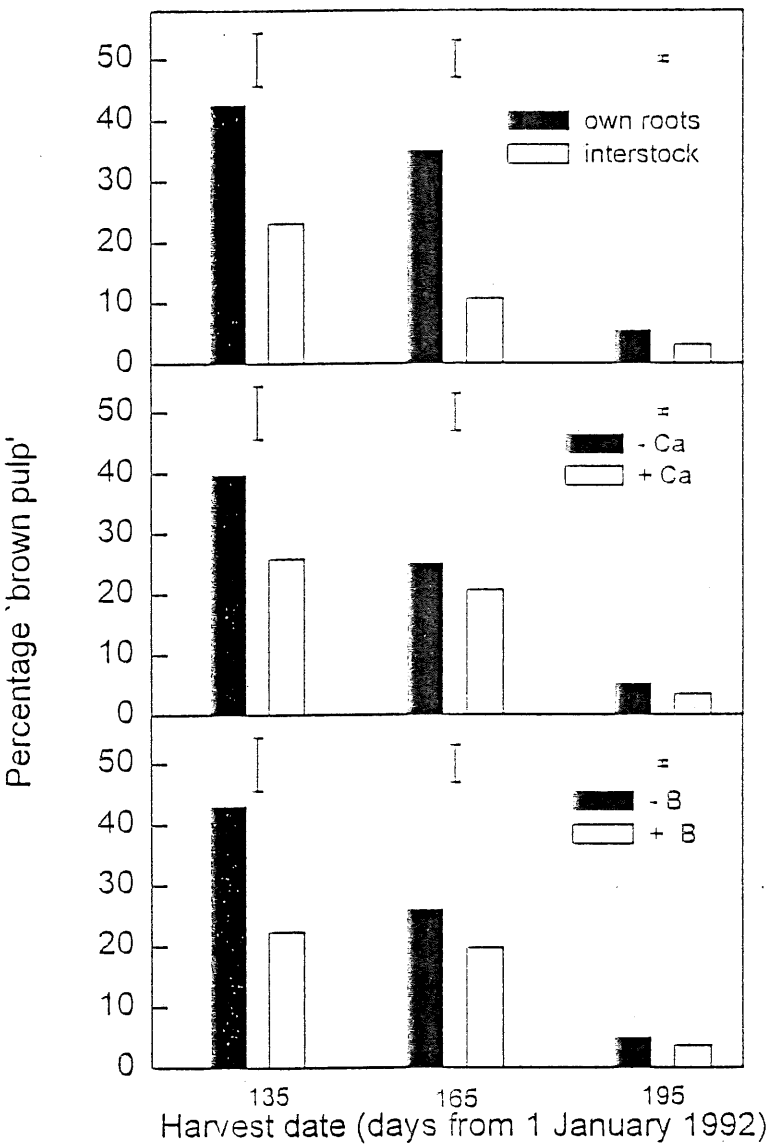

Fig. 6 Effects of harvest date on % 'brown pulp' of the *Annona* spp.hybrid cv. African Pride in the 1992 harvest season. Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

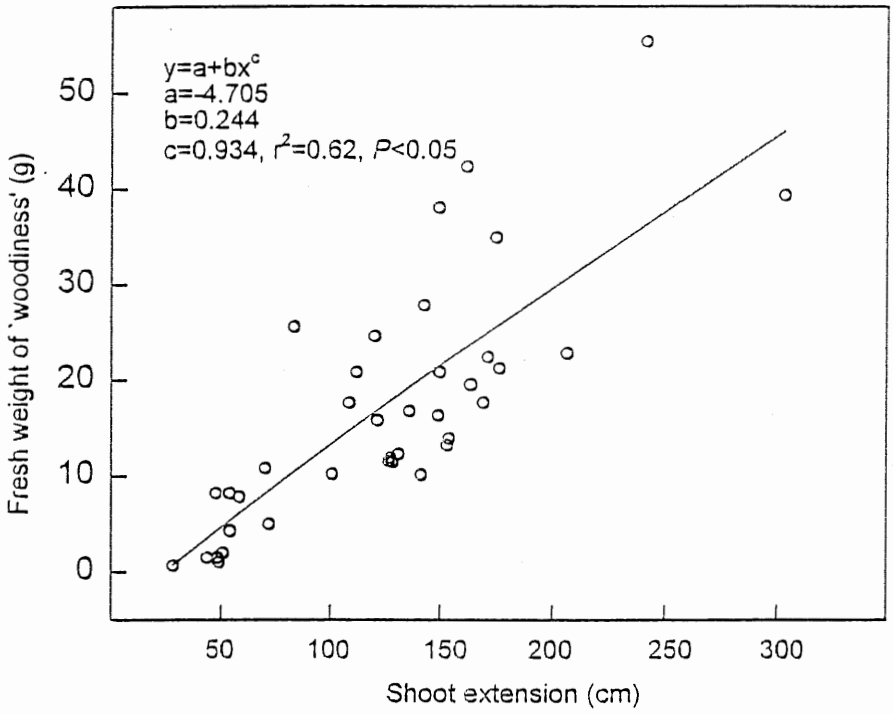

Fig 7. The relationship between shoot extension recorded in March, 1 month prior to harvest, and fresh weight of 'woodiness' of the *Annona* spp. hybrid cv. African Pride. Pooled data for 1991-92 and 1992-93 seasons.

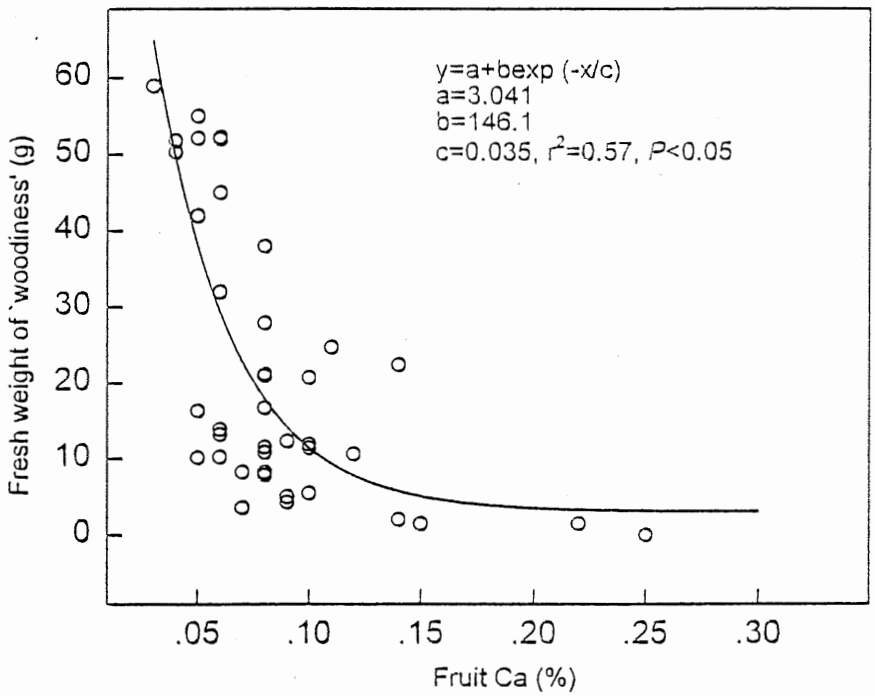

Fig.8 The relationship between fruit Ca concentration in January, 3 months prior to harvest, and fresh weight of 'woodiness' of the *Annona* spp. hybrid African Pride. Pooled data for 1991-92 and 1992-93 seasons.

SEASONAL LEAF NUTRIENT PATTERNS AND LEAF NUTRIENT STANDARDS FOR *ANNONA* SPP. HYBRIDS INSUBTROPICAL AUSTRALIA

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Summary

Several studies were conducted to determine the influence of variety and rootstock on seasonal leaf nutrient patterns and to set new leaf nutrient standards and sampling times for *Annona* spp. hybrids in subtropical Australia. Seasonal leaf nutrient patterns were established for the two, main commercial *Annona* spp. hybrids cv. African Pride and Hillary White. Overall, seasonal leaf nutrient patterns for both cultivars and rootstocks were similar to one another and to those previously established for *Annona* spp. hybrids. The current leaf sampling time, about 1 month prior to harvest, was found to be appropriate. In addition, a leaf nutrient survey was also conducted over three years for twelve, high-yielding orchards, representative of the range of soil types in Queensland and northern NSW, the major *Annona* spp. hybrid producing regions of Australia. Based on this survey, new, leaf nutrient standards have been set which will replace existing standards. Leaf nutrient standards for B have doubled and those for Ca increased by 58% compared with those previously set. Leaf Ca concentrations were negatively correlated with shoot growth (r^2=-0.64, P<0.05) which, in turn, was positively correlated with leaf N (r^2=0.73, P<0.05).

Introduction

Leaf analyses is the most important tool for diagnosing nutrient deficiencies and establishing fertiliser recommendations for tree crops. Several factors including leaf age and position, fruiting status, and phenological stage need to taken into account in the interpretation of leaf analyses (Smith, 1986). Sampling for diagnostic leaf analyses is normally conducted during the phase of plant development corresponding to the least variation in leaf nutrient concentrations (Cresswell and Wickson, 1986). Ideally one sampling time can be established for all nutrients. Most interpretations of leaf analyses in tree crops are based on surveys where the ranges in nutrient concentration in high production orchards are determined (Kenworthy, 1961; Leece, 1968; Menzel, *et al.*, 1992). An alternative, but more laborious approach is to develop critical leaf values giving 90% of maximum growth in pot or field experiments (Smith, 1962).

A scarcity of information exists on the nutritional requirements of *Annona* spp. hybrids grown under subtropical conditions of Australia. Few or no fertiliser experiments have been conducted to determine optimum rates of nutrients to apply. Consequently current fertilising practises are based on grower experience with fertiliser rates occasionally adjusted according to tentative leaf nutrient standards set by Sanewski (1991). Previous studies by George *et al.* (1989) have established seasonal leaf nutrient patterns for the cv. Pinks Mammoth but no studies have been conducted to determine the influence of rootstock or cultivar on this pattern. Current leaf nutrient standards also need to be revised as they were based on limited grower surveys (George *et al.*, 1989; Sanewski, 1991).

Several studies were conducted to determine the influence of variety and rootstock on seasonal leaf nutrient patterns and to subsequently assess if the current sampling time in mid-March, about 1 month prior to harvest, is appropriate. In addition, a more intensive survey of high-yielding orchards of the two most important commercial cultivars, Hillary White and African Pride, was also conducted to set new standard leaf nutrient concentrations for *Annona* spp. hybrids in subtropical Australia and to determine if the same standards can be used with different cultivars/rootstocks. The effects of tree vigour on leaf nutrient concentrations were also evaluated.

Materials and methods

Seasonal leaf nutrient patterns

Project jointly funded by HRDC (FR425) and RIRDC(DAQ-167A), and Australian custard apple growers

Leaf samples were collected throughout one growing season from two orchards in Queensland, one located at Palmwoods (Lat.26° S) and the other at Nambour (Lat. 26°S). Both sites can be classified as subtropical and have similar climate; mean annual maximum temperature of 25.8°C and a mean annual minimum of 14.1°C. Mean annual rainfall is 1758 mm. Soil types are gleyed podsolic with a sandy loam surface horizon, 20 cm in depth, overlying a medium clay sub-horizon. For both sites, rows were slightly mounded to improve external drainage.

At Nambour, ten, five year old, uniformly-sized trees of the *Annona* spp. hybrid cv. African Pride either propagated as cuttings, on their own roots, or grafted onto cherimoya (*Annona cherimola*) rootstock with a sugar apple (*Annona squamosa*) inter-stock were selected for sampling. At Palmwoods, ten, eight-year old, uniformly-sized trees of the *Annona* spp. hybrid cv. African Pride and Hillary White, both on cherimoya rootstock, were selected for sampling.

Cultural practices – Nambour

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Trees were fertilised each year in September and November, each year, with a complete fertiliser supplying 34 g N, 10 g P, 25 g K, and, in February, 35 g K (as K_2SO_4) per tree. Trees were trained to an open goblet system and were winter-pruned in July of each year.

Cultural practices – Palmwoods

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. Trees were fertilised each year in October with a complete fertiliser supplying 300 g N, 86 g P, 220 g K, and, in February, 820 g K (as K_2SO_4) per tree. Trees were trained to an open goblet system and were spring-pruned in October of each year.

Leaf nutrient survey

Twelve commercial orchards with mature 5-7 year-old trees of both cvs. African Pride and Hillary White were selected in Queensland and northern NSW. The orchards were selected because they had a high level of management and high yields, averaging between 15-25 t ha^{-1} and were representative of the range of soil types and growing conditions in the major *Annona* spp. hybrid production regions of Australia. Orchards were sampled in Queensland and NSW in mid-March and mid-April, respectively, about one month prior to harvest over three seasons (1995-1997, inclusive). For each orchard, two blocks of about 80 trees each, of both cultivars, were selected for leaf sampling. Each orchard cultivar block was divided into four blocks of 20 trees based on slope and possible soil fertility gradients. Each of the 20 trees in each cultivar block was leaf sampled by taking one leaf from each quadrant. Leaves selected for sampling were the first, fully mature, taken from actively growing, non-fruiting shoots. As a measure of tree vigour, shoot length was also measured after the completion of vegetative flushing on four representative shoots on each of four trees in each block for the 1997 season only.

Analytical techniques

Leaf samples were washed in a solution of mild detergent (1 mL L^{-1}) , rinsed in distilled in distilled water, dried at 52°C for three days, milled and redried at 105°C. Nitrogen was determined using a Kjeldahl digest of sulphuric acid, sodium sulphate and selenium catalyst (McKenzie and Wallace, 1954). The digestate was diluted prior to automatic colorimetric analysis using the indophenol reaction with salicylate and sodium dichloroisocyanurate (Berthelot, 1959), P by nitric-perchloric acid digestion (Allan, 1971) followed by the vanadomolybdate-yellow colorimetric method (Chapman and Pratt, 1961), B by the azomethine H method (Gaines and Mitchell, 1979); K, Ca, Mg, Na, Mn, Fe, Zn and Cu by nitric-perchloric acid digestion and atomic absorption spectroscopy (Allan, 1971).

Statistical analyses

Seasonal leaf nutrient concentrations for each sampling date were analysed using one-way ANOVA. The leaf nutrient survey data was analysed by three-way ANOVA (variety X orchard X year). The normal or standard leaf nutrient range was set by selecting values that fell between the lower and upper confidence limits (95%).

Results

Seasonal leaf levels

The seasonal pattern of leaf nutrient concentrations were not greatly affected by inter-stock/rootstock (Figure 1). At Palmwoods, cv. Hillary White exhibited higher concentrations of K but lower concentrations of Ca and B at most sampling times (Figure 2).

Leaf N and P

Both N and P showed rapid decline initially after budbreak. At Nambour leaf N concentrations rose again slightly in February, after the completion of the first vegetative flush and then declined during the second vegetative flush. At Palmwoods, with the exception of a few sampling times, leaf concentrations for both cultivars were similar.

Leaf K

At both sites, leaf K concentrations remained relatively stable for a period of two months after budbreak before concentrations declined rapidly. At Palmwoods, varietal differences in leaf K concentrations were apparent with African Pride leaf concentrations about 20% lower than Hillary White at most sampling times.

Leaf Ca and Mg

Calcium leaf levels increased gradually for about three months after budbreak before plateauing for the rest of the season. At both sites, Mg concentrations initially declined presumably as a consequence of strong vegetative flushing before plateauing in late autumn.

Leaf B

At Nambour, leaf B concentrations increased more than 3-fold throughout the season plateauing in late autumn. At Palmwoods, leaf B levels fluctuated more widely with no apparent seasonal trend.

Leaf Mn

At Nambour only, leaf Mn concentrations increased gradually throughout the season while, at Palmwoods, concentrations initially rose before stabilising.

Leaf Fe

Concentrations of Fe increased rapidly after budbreak before plateauing in late summer and autumn.

Leaf Cu and Zn

Leaf Cu and Zn concentrations remained relatively constant within a narrow range throughout the growing season. There were no significant differences between cultivars.

Leaf nutrient survey

No significant differences in mean leaf nutrient concentrations were found between cultivars or years (Table I). With the exception of B, Cu and Mn, variation in leaf nutrients between orchards were relatively low (C.V.<15%) (Table I). Figures 3 and 4 indicate the distribution of samples for nutrient concentration in the 12 orchards over 3 years. As there were no significant differences ($P>0.05$) in leaf nutrient concentrations for cultivars and years data pooled. Leaf Ca concentrations were negatively related to shoot growth which, in turn, was positively related to leaf N (Figure 5). Leaf Ca was positively correlated with leaf B (Figure 6). New Australian standard levels which have been set (values that fell between the lower and upper confidence limits (95%) are compared with current standards in Table II.

Discussion

Seasonal leaf levels

Irrespective of cultivar and orchard site, seasonal leaf nutrient patterns for all nutrients were similar to those previously established for *Annona* spp. hybrids and other temperate, deciduous fruit species (Smith, 1962, Oberly and Boynton 1966; Ballinger *et al.*, 1966; Clark and Smith, 1990). One group of nutrients (N, P, K,) showed a general decline in concentration, another group showed an increase (Ca, Mg, B), whilst another group remained relatively constant (Cu, Zn). The pattern of nutrient decline over the growing season has been associated with growth dilution effects whilst the pattern of increase is associated with nutrients such as Ca which have little phloem mobility (Smith, 1962; Leece and Gilmour, 1974; Shear and Faust, 1980).

At Palmwoods, leaf K declined markedly in the latter half of the growing season falling below 1%, a level which is considered deficient in temperate, deciduous fruits such as apples and peaches (Robinson, 1986). The effects of heavy fruiting inducing K deficiency has been shown for a range of fruit crops including peaches (Popenoe and Scott, 1956); citrus (Jones and Embleton, 1968); and pecan (Sparks (1977). The fall in leaf K levels may be due to remobilisation of leaf K and the increasing sink force of the developing fruit for this nutrient as they near harvest. More recent studies (George *et al.*, 1994, unpublished data) have shown leaf K levels pre-harvest to be highly correlated ($r>-0.70$, $P<0.05$) with increasing yield per canopy surface area.

With the exception of a short period of six weeks after budbreak, concentrations of Ca and Mg levels increased in the leaves as the season progressed, a pattern typical for nutrients of low or intermediate mobility (Leece and Gilmore, 1974; Leece, 1975a, 1975b). Concentrations of Cu and Zn in *Annona* spp. hybrid leaves, irrespective of cultivar, were similar to those for pome and stone fruits (Robinson, 1986).

Leaf sampling procedures

The practise of standardising sampling at a time during the season when nutrient concentrations are relatively static is common (Cresswell and Wickson, 1986). This is also the case for *Annona* spp. hybrids. In this study, leaf nutrient concentrations for most nutrients, one month prior to harvest, were relatively stable as indicated by low C.V.s. This finding indicates that one month prior to harvest is an appropriate time to leaf sample and confirms a previous study by George *et al.* (1989). The advantage in sampling at this time is that in the event of a sub-optimum concentration being recorded, fertiliser amendments can still be applied prior to harvest to prevent yield and quality decline in that season and also for the following season. In studies to develop phenological models for *Annona* spp. hybrids in subtropical Australia, George *et al.* (1998, unpublished data) found that trees normally exhibit three peaks in root flushing in late spring, mid-summer and early winter, respectively. The time of root flushing has important implications for the timing of fertiliser application, with the ideal times to apply fertiliser just prior to peak root growth periods. Consequently, fertiliser applied in March may still be taken up during the fruit development period and be available for new growth in the following season. The data shows that the range in C.V.s of nutrient concentration was not markedly different between varieties and seasons and no nutrients exceeded the 40% limit set by Kenworthy (1961) above which a shortage or excess of nutrient could be shown.

Leaf nutrient standards

Leaf analysis is a widely used tool for monitoring nutritional status of *Annona* spp. hybrids in Australia. The preferred tissue for assessing nutrient status is the youngest-mature leaves on non-fruiting shoots, sampled approximately one months prior to harvest. Interpretation of leaf analysis is by comparison against optimum concentrations established from surveys of high-producing commercial orchards in the major production areas.

In this study, leaf levels for N, P, K, Cu, Fe, Zn, Mn are in good agreement with the concentration ranges previously established for *Annona* spp. hybrids by Sanewski (1988). Although the nutrient survey was confined to two cultivars, the leaf nutrient standards set for other cultivars should be similar due to the same phenology and physiology. Calcium and B concentrations were consistently higher than previously set indicating that growers had become more aware of the need to maintain higher concentrations of these nutrients so as to improve internal fruit quality.

Nutrient/shoot growth relationships

The positive relationship between leaf N and shoot growth, measured after the completion of flushing, suggests that increasing rates of soil-applied N increases shoot growth. The negative relationship between leaf Ca and shoot growth and the positive relationship with leaf B may have important implications for reducing the severity of internal fruit disorders such as `woodiness'. This disorder has been found to be highly correlated with low fruit Ca and, indirectly, with leaf Ca concentrations (George *et al.*, 1998, unpublished data). Many studies have shown that Ca uptake and distribution to fruiting organs to be reduced under low B availability (Brown, 1979; Tang and De la Fuente, 1986)

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Table. ***Mean leaf nutrient concentrations for 12 Annona spp. hybrids orchards in subtropical Australia over 3 years. Data are the means of 4 trees.***

Leaf nutrients	Cultivar					
	Hillary White			African Pride		
	Mean	CV (%)	S.D.	Mean	CV (%)	S.D.
N (%)	2.76	9.1	0.33	2.78	11.3	0.45
P (%)	0.22	7.8	0.017	0.184	12.4	0.032
K (%)	1.26	10.2	0.16	1.27	16.1	0.27
Ca (%)	1.23	14.6	0.26	1.29	20.6	0.33
Mg (%)	0.32	10.0	0.035	0.36	21.2	0.10
Cu (g/g)	16.8	57.5	6.7	13.8	25.6	3.1
Zn (g /g)	23.3	10.4	4.3	22.1	14.9	5.7
Fe (g /g)	53.6	14.1	14.3	61.5	16.5	12.7
B (g/g)	78.2	18.9	36.1	88.1	14.0	30
Mn (g/g)	83.8	21.9	25.3	97.5	18.5	15.6

*No significant differences (P>0.05) between cultivars or years

Table ***Tentative Australian leaf nutrient standards for Annona spp. hybrids compared with current leaf standards***

Nutrient	Existing standards*	Tentative Australian standard**
N (%)	2.5-3.0	2.4-3.2
P (%)	0.16-0.2	0.15-0.21
K (%)	1.0-1.5	1.0-1.50
Ca (%)	0.6-1.0	1.0-1.6
Mg (%)	0.35-0.5	0.3-0.4
Cu (mg g^{-1})	10-20	10-22
Fe (mg g^{-1})	40-70	41-66
B (mg g^{-1})	15-40	53-107
Zn (mg g^{-1})	15-30	18-27
Mn (mg g^{-1})	30-90	59-137

*
Sanewski, G.M. (1991)

** Range set by constructing 95% confidence interval about the mean for pooled nutrient concentration data for cultivars presented in Table I.

CAPTIONS FOR FIGURES

Figure 1. Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cv. African Pride on its own roots and with sugar apple inter-stock and cherimoya rootstock at Nambour, Queensland, Australia. Open symbols represent African Pride on its own roots; closed symbols represent sugar apple inter-stock/cherimoya rootstock . No significant differences between cultivars.

Figure 2. Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cvs. African Pride and Hiliary White at Palmwoods, Queensland, Australia. Open symbols represent African Pride; closed symbols represent Hillary White. Vertical bars represent LSDs (P=0.05).

Figure 3. Distribution of leaf N, P, K, Ca, Mg samples collected from 12 *Annona* spp. hybrid orchards in March or April over three years. Pooled data for years and cultivars.

Figure 4. Distribution of leaf Cu, Zn, Fe, Mn, B samples collected from 12 *Annona* spp. hybrid orchards in March or April over three years. Pooled data for years and cultivars.

Figure 5. The relationship between shoot growth and leaf Ca and N concentrations in march, about 1 month prior to harvest in 1997. Pooled data for cultivars and orchards. Data points are the means of 4 trees.

Figure 6. The relationship between leaf B and Ca concentrations in March, about 1 month prior to harvest. Pooled data for 12 orchards sampled over 3 seasons. Datum points are the means of 4 trees.

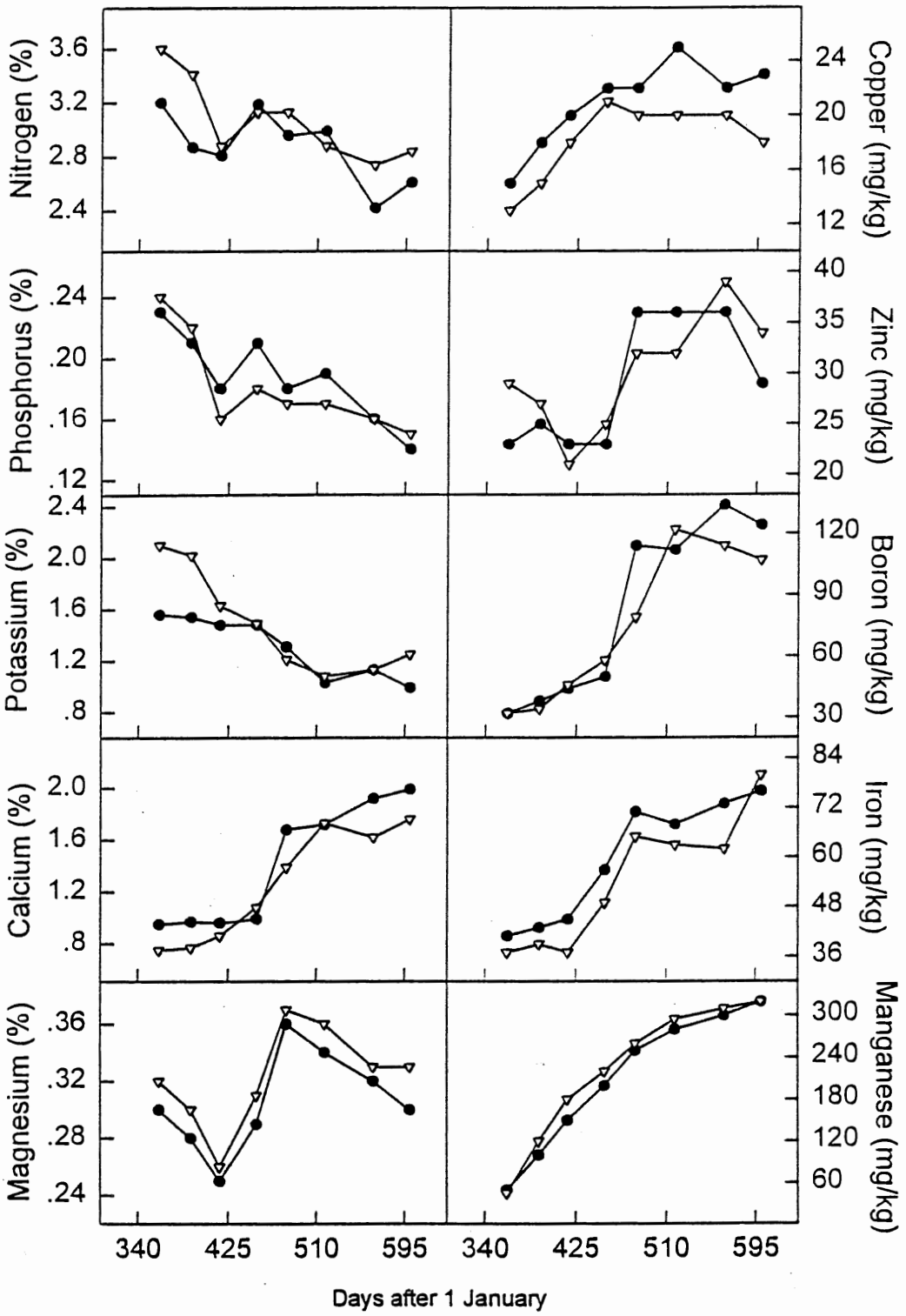

Fig. 1 Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cv. African Pride on own roots and with sugar apple interstock and cherimoya rootstock at Nambour, Queensland, Australia. Open symbols represent African Pride on its own roots; closed symbols represent sugar apple interstock/cherimoya rootstock. No significant differences ($P<0.05$) between cultivars.

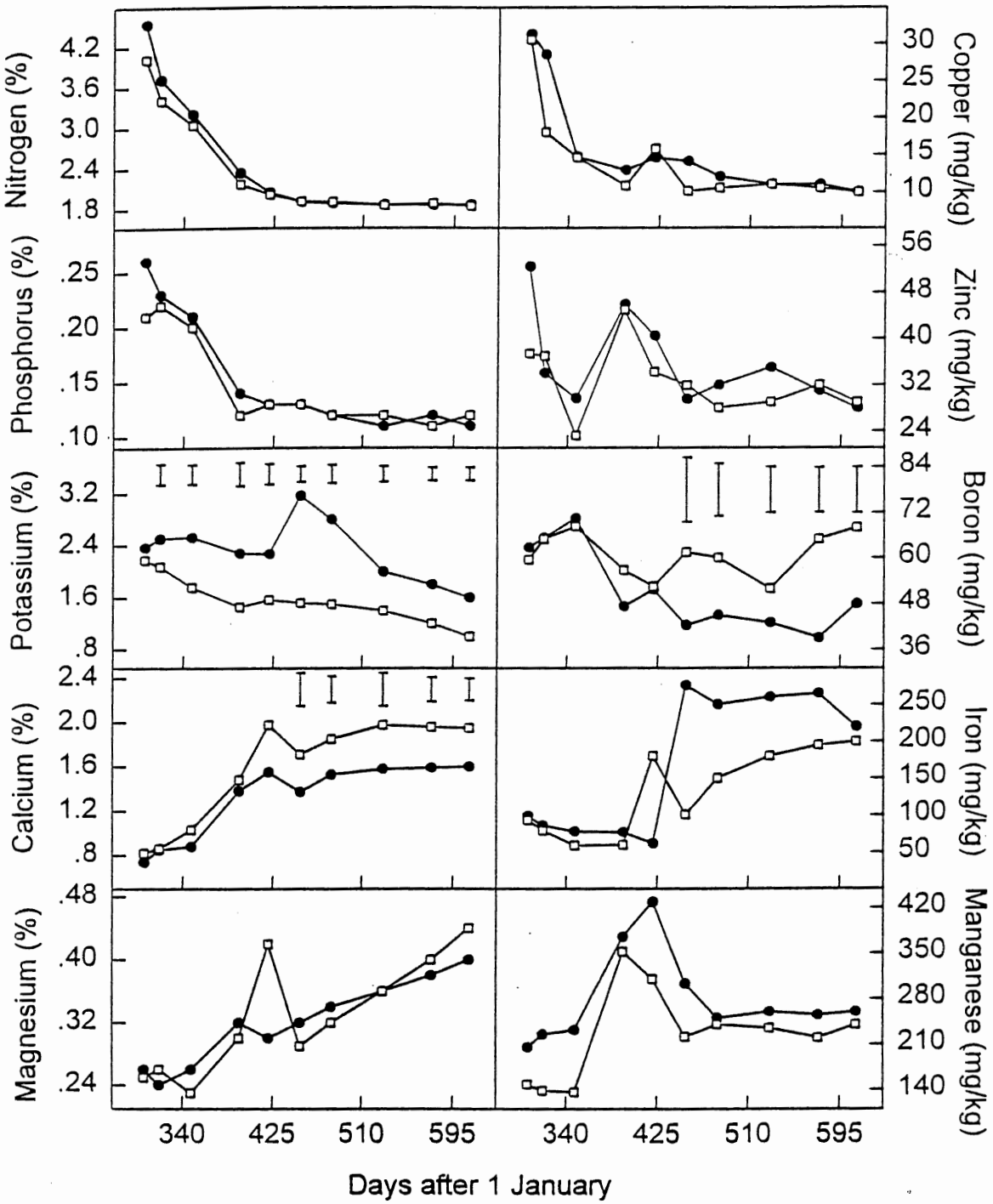

Fig. 2 Seasonal changes in leaf nutrient concentrations of the *Annona* spp. hybrid cvs. African Pride and Hillary White at Palmwoods, Queensland, Australia. Open symbols represent African Pride; closed symbols represent Hillary White. Vertical bars represent LSDs (P=0.05).

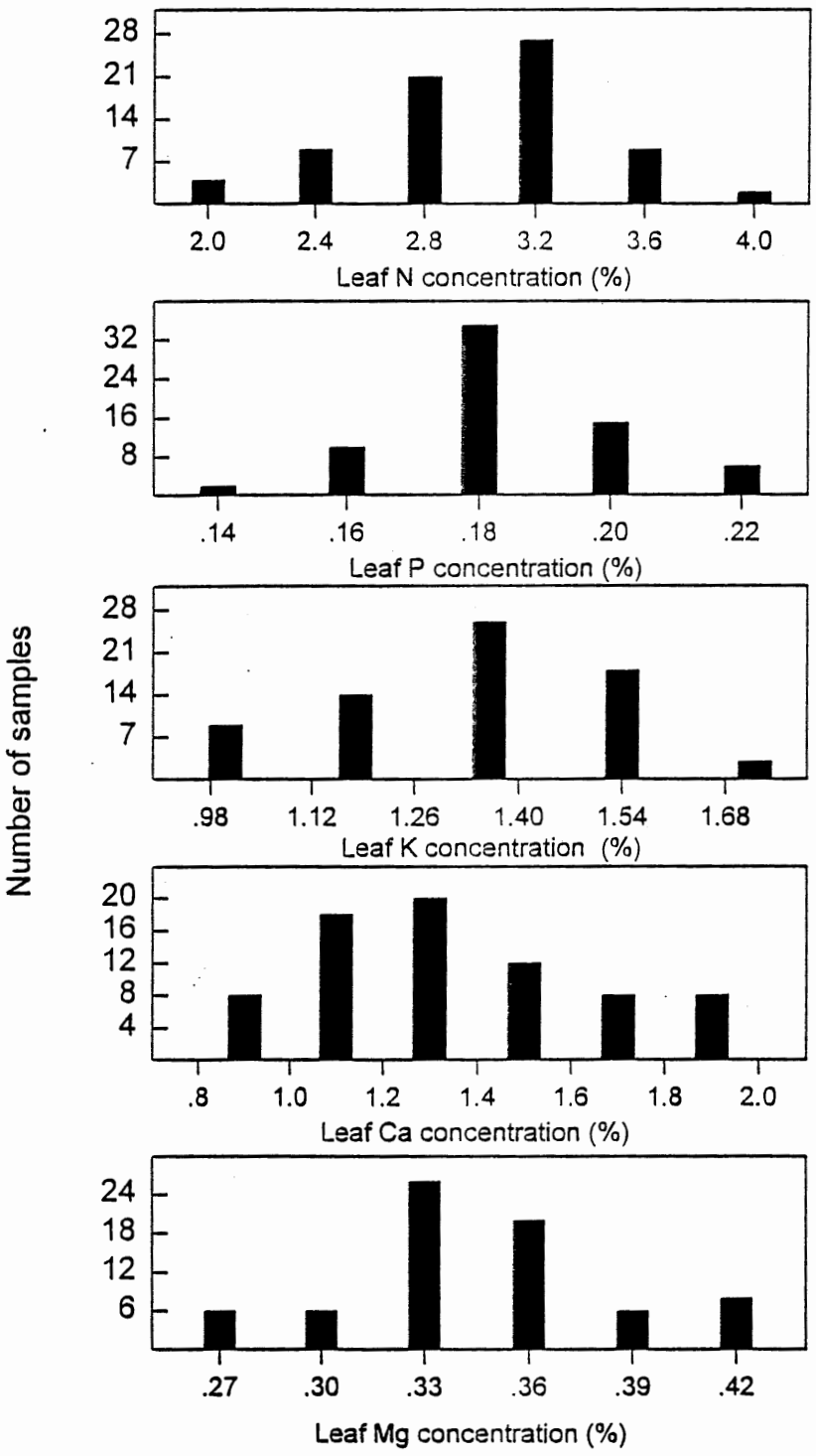

Fig.3 Distribution of leaf N, P, K, Ca and Mg samples collected from 12 *Annona* spp. hybrid orchards in March or April over three years. Pooled data for years and cultivars.

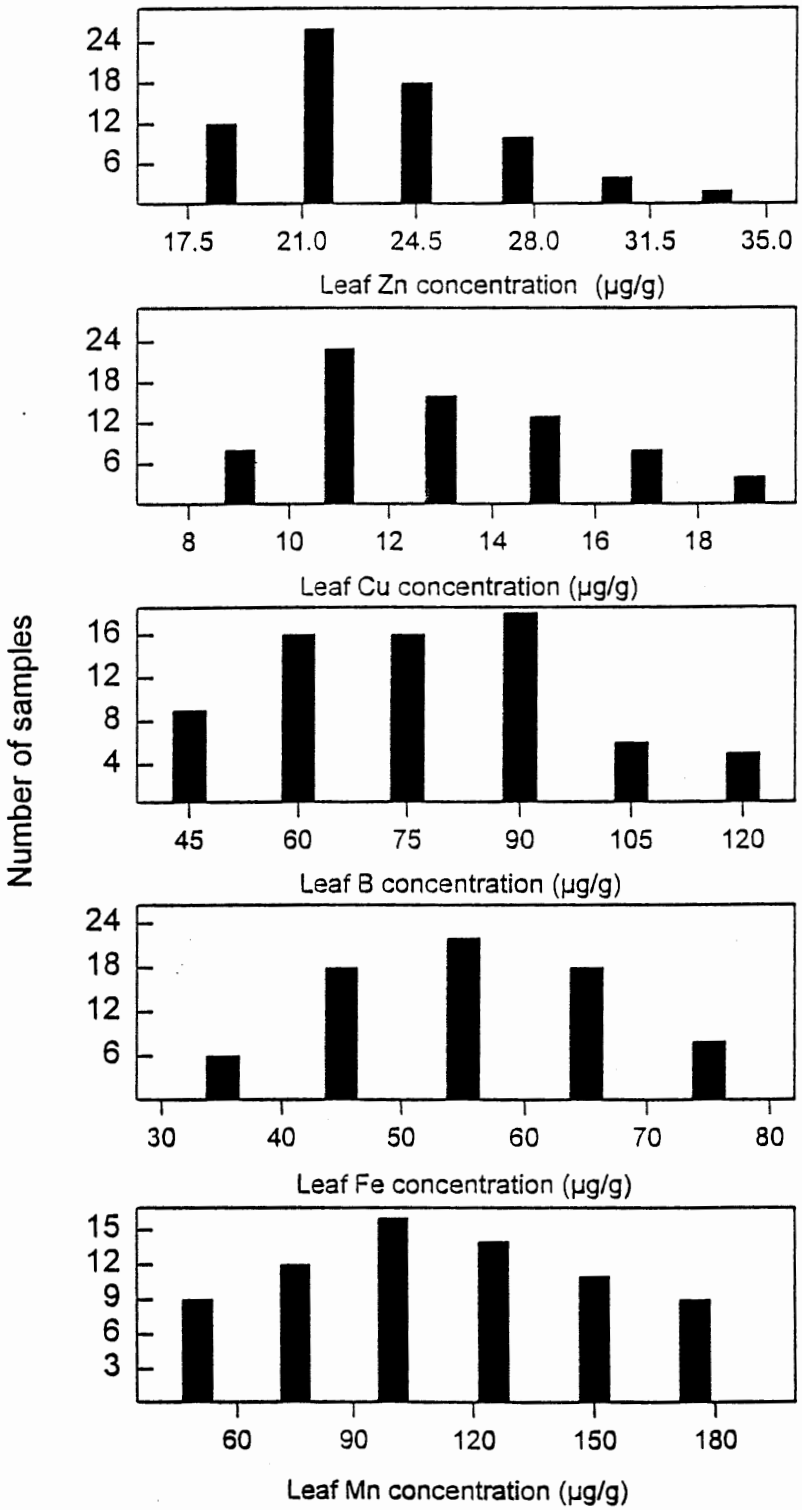

Fig. 4 Distribution of leaf Cu, Zn, Fe, Mn and B samples collected from 12 *Annona* spp. hybrid orchards in March or April over three years. Pooled data for years and cultivars.

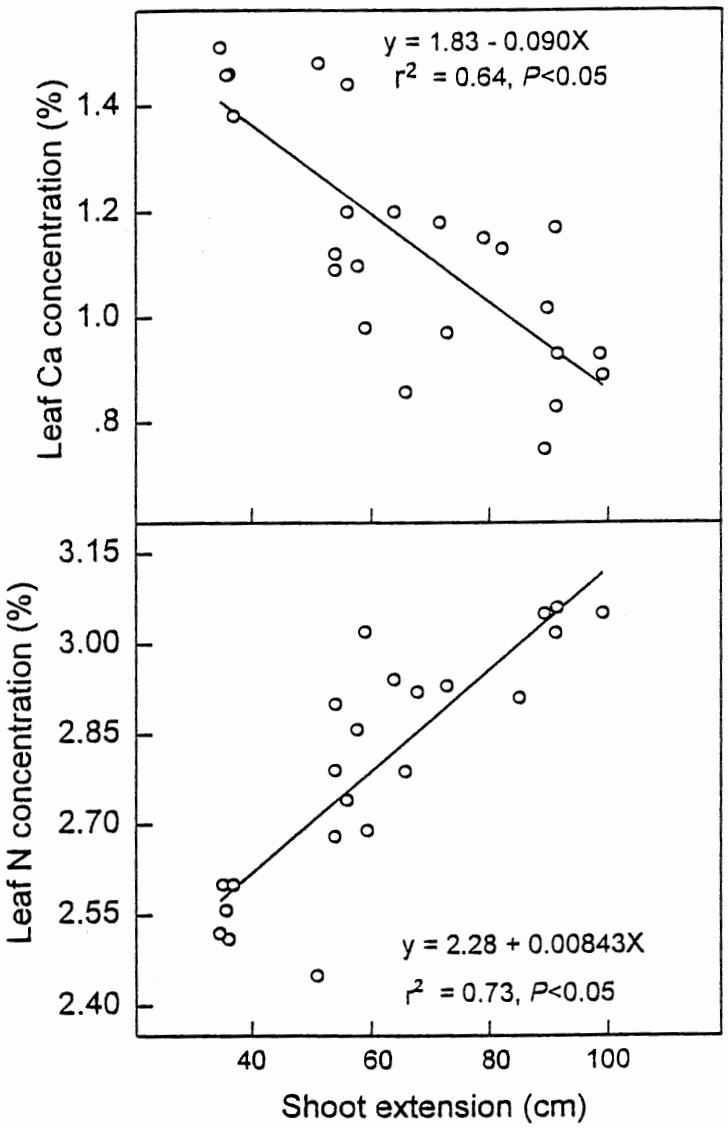

Fig. 5 The relationship between shoot extension and leaf Ca and N concentrations in March, about 1 month prior to harvest in 1997. Pooled data for cultivars and orchards. Data points are the means of 4 trees.

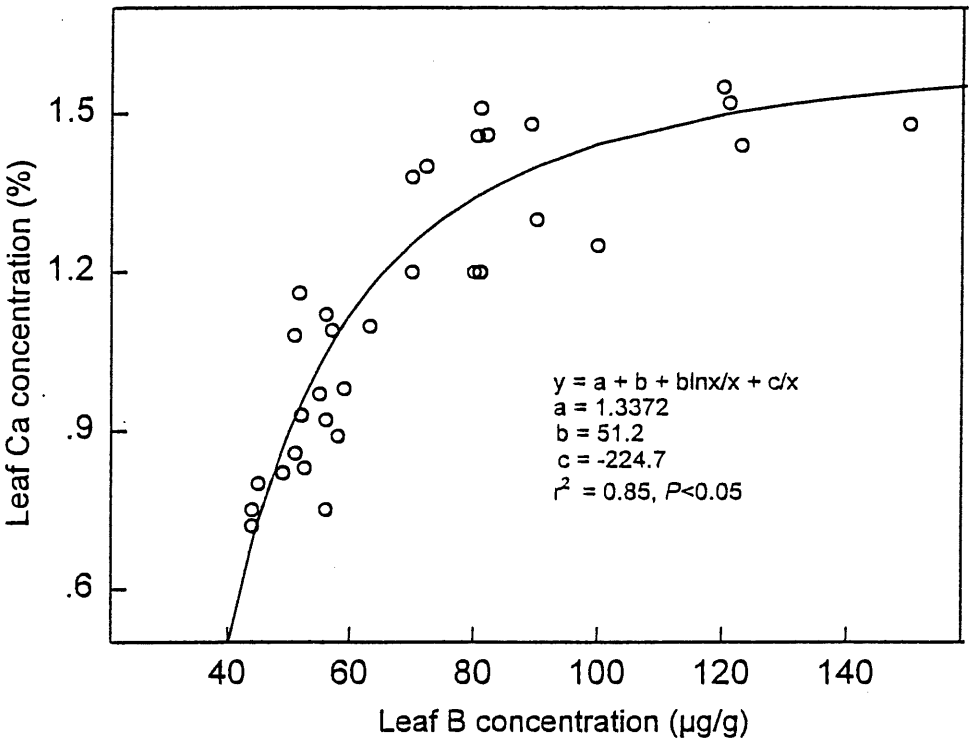

Fig. 6 The relationship between leaf Ca and B concentrations in March, about 1 month prior to harvest. Pooled data for 12 orchards sampled over 3 seasons. Datum points are the means of 4 trees.

EFFECTS OF WATER STRESS ON FRUIT SET, YIELD AND FRUIT QUALITY OF CONTAINER-GROWN *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE

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Summary

Two glasshouse experiments were conducted to evaluate the effects of drought on container-grown *Annona* spp. hybrid cv. African Pride, the main cultivar currently grown in Australia. The first experiment primarily evaluated the effects of water stress applied during flowering on subsequent flowering intensity and fruit set; the second experiment evaluated the effects of water stress applied during the fruit development period on subsequent fruit growth, yield and fruit quality. For both Experiments, trees were either watered daily to field capacity (about 20% v/v, 0 day drying cycle) or allowed to dry out to one of three levels of available soil moisture contents (before rewatering to field capacity. At the completion of the stress period for both Experiments, severe soil water stress (about 20% of available water) had reduced shoot growth by about 30%. In Experiment 1, mild soil water stress only (14.8% v/v) during flowering almost doubled the number of flowers per tree compared with well-watered trees.

This response appears to be due to a reduction in apical dominance and increased floral initiation. Other stress treatments did not significantly affect flowering intensity. Water stress increased fruit set with the severely-stressed trees setting 27% more fruit than well-watered controls. Due to both increased flowering and fruit set, mildly-stressed trees produced the greatest total weight of fruit per tree, more than double that of severely-stressed trees, and 25% more than well-watered controls. Severe water stress either during flowering or fruit development reduced average fruit weight by 81 and 50%, respectively. The reduction in fruit weight appears to be due to stomatal closure with increasing leaf ($_L$) and soil water potential ($_S$) with stomatal conductance (g_s) and net CO_2 assimilation (A) declining rapidly with the onset of stress. There appeared to be no threshold stress value, above which there was no response of A to stress. In conclusion, mild to moderate water stress during the flowering period appears to be beneficial to increasing flowering and fruit set, but fruit size was adversely affected irrespective of the level of stress applied.

Introduction

Water stress has been shown to promote floral induction in a range of tropical and subtropical evergreen crops but not all (Tatt, 1976; Chaikiatiyos *et al.*, 1994). With lychee and mango the role of water stress in floral induction was found to be indirect, and consisted of the repression of vegetative growth during the warm weather until temperatures below a critical value induced floral morphogenesis and floral initiation ensued (Menzel and Simpson, 1990; Pongsomboon, 1991; Nunez-Elisea and Davenport, 1994). However, stress applied during the early fruit set and fruit development period has generally been found to be detrimental to both fruit set and fruit growth of lychee (Menzel and Simpson, 1994) and mango (Pongsomboon, 1991). However, Chalmers *et al.* (1981) found that moderate water stress applied during stage II of peach fruit growth was beneficial to fruit growth due to the suppression of competing vegetative sinks.

In controlled environment experiments, at high day temperatures (28°C) flowering and fruit set of the *Annona* spp. hybrid cv. African Pride was severely reduced at leaf water potentials ($_L$) <-2.0 MPa (George and Nissen, 1988). Flowers and fruit are more sensitive to water stress exhibiting lower $_L$s with increasing stress than leaves (George *et al.*, 1992). Crop load may also alter the response to water stress with bearing trees exhibit higher stress levels than non-bearing trees. This response may indicate that cropping may restrict root growth and consequently water uptake by the roots.

Carbon dioxide assimilation (A) is often independent of plant water status until a threshold $_L$ value is reached, and as the water deficit increases, A decreases markedly falling to zero when the leaves wilt (Hsiao, 1973;

Kumar and Tieszen, 1980; Roe *et al.*, 1995). Roe *et al.* (1995) suggests that the critical value where A starts to decline is of particular interest because it defines the range in plant water status above which productivity is likely to be maintained. Although no studies have been made on the effects of water stress on A, George *et al.* (1989) showed that at high RH (90% RH), there was a continuous but decreasing decline in g_S over a range of $_L$ from - 0.8 MPa to - 4.0 MPa. At 60% RH, g_S was extremely low, irrespective of the level of water stress imposed. They concluded from their study that the stomata of *Annona* spp. hybrids appear to be more sensitive to changes in RH than they are to changes in $_L$.

Few or no studies have been conducted to evaluate the effects of water stress of fruit set, fruit growth and fruit quality of *Annona* spp. hybrid in subtropical regions of Australia. Conducting water stress experiments under controlled-environment conditions has the advantage that plant water status can be readily manipulated but the disadvantage that rate of soil drying may be too rapid, and consequently the trees physiological responses will be different to those in the field. For this reason both container and field water stress experiments need to be conducted. Two glasshouse experiments were conducted to evaluate the effects of drought on container-grown *Annona* spp. hybrid cv. African Pride, the main cultivar currently grown in Australia. The first experiment primarily evaluated the effects of water stress applied during flowering on subsequent flowering intensity and fruit set; the second experiment evaluated the effects of water stress applied during the fruit development period on subsequent fruit growth, yield and fruit quality.

Materials and methods

Site description and treatments (Experiment 1)

Three-year old, *Annona* spp. hybrid trees cv. African Pride were grown in 40 l containers as cuttings and transferred to a naturally-lit glasshouse in late October about two weeks prior to the anticipated date of first flowering. The containers held 72 kg of potting medium; a soil, peat moss, sand mixture (1:2:4 v/v). Tree were 1.2 m high and 1.5 m in diameter at the commencement of the experiment. Day/night temperature in the glasshouse bay was 30/20±2°C and day duration was about 11.9 h. Relative humidity ranged from 75 to 90% (VPD<1.2 kPa). Maximum photon flux density (PPF) in the glasshouse at solar noon was 1800 µmol quanta m^{-2} s^{-1}. Four levels of soil moisture stress were applied for the duration of flowering (7 November-20 February) (Table I). Data are the means of six trees per treatment.

Site description and treatments (Experiment 2)

Four-year old, *Annona* spp. hybrid trees cv. African Pride were grown in 40 l containers as cuttings and transferred to naturally-lit glasshouse at the completion of fruit set (26 January). The containers held 72 kg of potting medium; a soil, peat moss, sand mixture (1:2:4 v/v). Tree were 1.5 m high and 1.5 m in diameter at the commencement of the experiment. Day/night temperature in the glasshouse bay was 30/20±2°C and day duration was about 11.0 h. Relative humidity ranged from 75-90% (VPD<1.2 kPa). Maximum photon flux density (PPF) in the glasshouse at solar noon was 1400 µmol quanta m^{-2} s^{-1}. Treatments were similar to those used for Experiment 1 except that water stress was applied post-flowering for the duration of Stage II and III of fruit growth (26 January to 28 May) (Table I).

Measurements

For Experiment 1, $_L$, g_S and A were measured at 0900 h on 2 leaves on each datum tree over three stress cycles. For Experiment II, $_L$s only were measured. Leaf water potential was measured with a pressure chamber using the precautions outlined by Ritchie and Hinckley (1975) and g_S and A with a LiCor 6200 photosynthesis meter using a 1l chamber. During A measurements, PPF was maintained above the light saturation point of 1200 µmol quanta m^{-2} s^{-1} established for *Annona* spp. hybrids (George *et al.*, unpublished data, 1997), air temperature varied between 28-32°C and RH between 75 to 95%. For Experiment 1 only, one gypsum block was placed in the root zone (20 cm depth) of each datum tree and soil moisture tension ($_S$) was read daily with a WaterMark meter (Irricrop, USA).

Tree and shoot growth

Tree girths (10 cm above ground level) were measured at the commencement and the completion of both Experiments. Shoot extension was recorded at about fortnightly intervals on 4 uniform shoots (pruned to 30 cm) tagged on each datum tree. At the commencement and completion of the Experiments the number of new lateral shoots on each tree was also recorded.

Flowering, fruit set and fruit quality

For Experiment 1 only, the total number of flowers at anthesis on each datum tree was recorded daily. At the completion of the water stress period the number of fruit set and their individual weights and symmetry were recorded. Six additional fruit were left on each tree and at full maturity these were harvested for further fruit quality assessments. For Experiment 2, trees were thinned to leave eight fruit per tree prior to the imposition of water stress and these fruit were harvested at full maturity for quality assessments.

Brix was determined on expressed juice using an Abbe refractometer (American Optical model 10460). Severity of internal browning ('brown pulp') was visually rated as a percentage of the surface area of vertical cross-section of fruit which was discoloured. Severity of internal 'woodiness' was determined by extracting hard lumps from the flesh and determining their fresh weight. Internal colour (L^*a^*b values) around the seed core and for the flesh was also determined using a chromometer (Minolta model CR-200). Fruit symmetry was rated on a scale of 1-5; 1, poorly symmetrical, 5, highly symmetrical. Skin roughness was rated on a scale of 1-5; 1, lumpy, 5, completely smooth. Skin thickness was measured at three points on the skin surface. The number of seed per fruit was also recorded.

Starch sampling and analyses

For Experiment 1 only, at the completion of the water stress period, four shoots were sampled from each datum tree and dissected into stem and leaves prior to starch analyses using the enzymic-colorimetric procedure (Rasmussen and Henry, 1990.).

Leaf and fruit nutrient sampling and analyses

For both Experiments, leaves (the first fully mature leaf sampled from 10 non-fruiting shoots on each tree) and 6-8 fruit were sampled from each datum tree at the completion of the stress period and analysed for N, P, K, Ca, Mg, Fe, B, Cu, Zn, and Mn.

Experimental design and analyses

Data were analysed using ANOVA and significant differences between the means tested at the $P = 0.05$ level. Linear and non-linear regression analyses were carried out to define the relationships between selected yield, fruit quality and tree growth variables.

Results

Tree and shoot growth

For both Experiments the pattern of shoot flushing was similar for all treatments with trees exhibiting one growth flush only (Figure 1). At the completion of the stress period, severe water stress had reduced shoot growth in Experiments 1 and 2 by about 30 and 35%, respectively, compared with well-watered controls. For both Experiments there was no significant differences between treatments in the number of new shoots produced per tree or on tree girth increment, presumably due to the short duration of the Experiments (Table II).

Flowering and fruit set

For Experiment 1, mild stress was very beneficial in increasing the number flowers per trees, almost doubling the number compared to controls (Table II). This response was presumably due to a reduction in apical dominance and shoot vigour and an increase in the number of flowers initiated. Compared with controls, the trend was for greater fruit set with increasing stress but only the severe water stress treatment was significantly greater (27%) than the well-water controls (Table II). Fruit set was highly correlated with seed number per fruit

at harvest (r=0.95, $P<0.05$). However, in terms of total weight of fruit harvested per tree, mildly-stressed trees produced more than double that of severely-stressed trees, and 25% more than well-watered controls (Table II).

Fruit size

For Experiment 1, lower yields at the higher stress levels were due to more than a 80% reduction in individual fruit weight particularly in the larger-sized classes (Figure 2). As expected, fruit weight of early-set fruit were more severely affected by stress than later-set fruit presumably due to the longer duration of water stress that fruit were exposed to (Figure 3). For Experiment 2, average fruit weight was reduced by 50% with increasing water stress. Average fruit weight was highly negatively correlated with $_L$ and with only slight increases in $_L$s and s resulting in a mark decline in fruit weight (Figure 4).

Fruit quality

For Experiment 1 only, fruit symmetry was reduced by about 12% with increasing $_L$s and (Figure 4). For Experiment 1, severe water stress increased severity of 'woodiness' and 'brown pulp'. In contrast, increasing water stress decreased severity of 'brown pulp' by a maximum of 66%. For Experiment 1 only, severe water stress increased skin thickness. For both Experiments, Brix, internal colour, and skin roughness were not significantly affected by water stress.

Leaf and soil water status

For Experiment 1 only, after withholding water there was an initial slow decline in after which values declined rapidly. These was a similar pattern for $_L$ with a lag of 1-2 days (Figure 5). Trees recovered to $_L$s of well-watered controls 1 day after rewatering. Similar patterns were observed for water-stressed trees in Experiment 2 (data not presented).

A and g_S

African Pride stomata were sensitive to even slight changes in $_L$ or , with g_S and A declining rapidly with the onset of stress (Figures 6 and 7). At the end of the stress cycle, A and g_S values were less than half of those of well-watered plants. There appeared to be no threshold stress value, above which there was no response to stress. There were only slight changes in $_L$ with $_S$ after withholding water for 2 -3 days, there after, $_L$ decline rapidly with increasing $_S$ and . Changes in $_L$ with $_S$ and were less sensitive than either A or g_S suggesting that root signals may be involved in stomatal closure.

Starch

For Experiment 1 only, increasing water stress reduced shoot starch concentrations from 1.4 to 0.7%. Leaf starch concentrations were not significantly affected.

Leaf and fruit nutrients

For Experiment 1, fruit nutrient concentrations of N, P, K, Ca and Zn and leaf nutrient concentrations of N, K and Zn increased with increasing $_L$s with $_S$s (Figure 8). Other leaf and fruit nutrients were not significantly ($P>0.05$) affected. Similar patterns in leaf and fruit nutrient concentrations with increasing $_L$s with $_S$s were recorded in Experiment 2 (data not presented). Compared to the other nutrients, the effects of severe water stress were most apparent on fruit Ca levels, these being increased by 55% compared with well-watered controls. However, there was no significant relationship between fruit Ca levels and severity of 'woodiness' at harvest.

Discussion

Mild water stress was highly beneficial in increasing increased flowering and consequently overall tree yield. The beneficial effects of water stress on increasing set were partially offset by the negative effects of even mild stress on fruit size. In field drought studies, George *et al.* (1996) found that increased flowering, as a consequence of water stress being applied during the flowering period, was primarily a response of reduced shoot growth and a concomitant increase in number of small lateral shoots per branch, with these small lateral

shoots producing more flowers. In these studies the flowering response appears to be due to increased floral initiation, presumably as a result of reduced shoot growth. The yield response was not due to increased fruit set which only slightly increased with increasing water stress and which, in field studies, has been shown not to be affected by moderate water stress (George *et al.*, 1997, unpublished data). Batten *et al.* (1994) found with lychee that drought-treated 'Bengal' trees produced almost twice the number of fruit as trees irrigated weekly although fruit size was reduced by 16%.

In contrast to other subtropical fruit crops such as lychee (Menzel and Simpson, 1991) and citrus (Kriedemann and Barrs, 1981), water stress was beneficial in increasing fruit set. This may have been due to moderate level of stress applied ($_L$ = 1.8 MPa) compared with other experiments or perhaps due to the effects of water stress on reducing vegetative growth which has been suggested for lychee (Cull and Paxton, 1983). Both container and field studies have now shown that fruit set is not adversely affected by moderate to severe water stress except under high VPD conditions (George *et al.*, 1989).

Water stress during the flowering and early fruit development adversely affected fruit size. The effects of water stress on fruit size may have been due to either the adverse effects of water stress on cell division, which is normally greatest in the first 4-6 weeks after fruit set, or a reduction in A. Similarly, water stress has been shown to reduce fruit size of mango (Pongsomboon, 1991).

Annona spp. hybrid stomata are particularly sensitive to water stress with stomatal closure occurring even with mild water stress. George *et al.*(1989) recorded a similar finding under controlled-environment conditions but only for trees grown under low VPD conditions. At high VPD, g_S were low and there was no response to water stress. In this study there was no threshold value below which there was no stomatal closure. This finding is similar to that reported for avocado with stomata virtually closed when $_L$ falls to -0.9 MPa (Bower, 1979). In contrast, stomatal closure of apple does not occur until $_L$ falls to -16.0 MPa (Lakso, 1979). However, the relationship between A and $_L$ and g_S may depend on the rate of drying, soil type and previous stress history (McCree, 1974; Ackerson and Herbert, 1985; Ludlow, 1987; Menzel *et al.*, 1995). Consequently the extrapolation of the results of this study to the field situation should be made with caution. These responses were obtained with container-grown plant. The greater sensitivity of stomatal conductance to $_S$ and not $_L$ indicates that *Annona* spp. hybrids may be extremely sensitive to root signal effects as has been shown for other crops (Davies and Zhang, 1991). Measurements of $_L$ for determining irrigation needs may therefore be misleading.

Severe water stress during flowering increased severity of 'woodiness' and 'brown pulp' d isorders, but water stress during the later stages of fruit development had the opposite affect. The beneficial effects of post-flowering water stress may be explained by the reduction in vegetative flushing. However, the adverse effects of water stress during flowering are more difficult to explain since Ca concentrations in the fruit were increased with increasing water stress.

For stressed trees, the reduction in shoot starch concentrations during the early fruit development periods may indicate a shift in nutrient source from current season's photosynthesis to those of stored reserves in the trunks and roots. In conclusion, mild to moderate water stress during the flowering period appears to be beneficial to increasing flowering and fruit set, but fruit size is adversely affected irrespective of the level of stress applied.

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Table. ***Treatment description***

Stress level	Length of stress cycle (days)*	No of stress cycles	(% v/v)	% of available water	Max. ψ_S (kPa)	Max. ψ_L (MPa)
Experiment 1						
Non-stressed	0	0	19.8	100	1.0	0.83
Mild	4	15	14.8	61.6	8.8	1.07
Moderate	6	10	10.8	34.8	58.3	1.34
Severe	8	7.5	8.5	18.0	83.7	1.88
Experiment 2						
Non-stressed	0	0	22.9	100	-	0.79
Mild	4	24	16.0	68.8	-	1.05
Moderate	8	12	10.8	36.3	-	1.46
Severe	12	8	7.1	22.9	-	1.95

*±2 day, depending on weather conditions

Table ***Effects of water stress on flowering, fruit set and of the Annona spp. hybrid cv. African Pride under controlled temperature conditions of Experiment 1. Data are the means of 6 trees per treatment.***

Stress level	Lateral shoot no per tree	Flower no. per tree	Fruit set (%)	Total fruit weight per tree (g)
Non-stressed	38.8	18.5	54.1	159.1
Mild	36.7	34.8	54.9	198.5
Moderate	34.1	17.6	57.0	112.5
Severe	33.5	16.3	68.8	75.2
LSD (P=0.05)	n.s.	14.1	4.5	75.4

Table. ***Effects of water stress on fruit quality of the Annona spp. hybrid cv. African Pride under controlled temperature condition. Data are the means of 6 trees per treatment.***

Stress level	Average fruit weight (g)	Symmetry* (1-5)	Skin thickness (mm)	Seed no per fruit	Fresh weight of 'woodiness' per fruit (g)	'Brown pulp' per fruit (%)
Experiment 1						
Non-stressed	45.40	3.14	1.51	24.0	1.53	6.2
Mild	19.81	3.06	1.47	27.9	3.90	7.8
Moderate	16.85	2.80	2.18	27.2	6.98	11.0
Severe	8.69	2.78	1.90	34.4	7.20	12.3
LSD (P=0.05)	19.01	0.24	0.50	4.5	3.3	4.3
Experiment 2						
Non-stressed	156.0	3.5	1.75	28.5	-	10.3
Mild	136.9	3.4	1.65	30.5	-	7.3
Moderate	128.2	3.6	1.82	29.0	-	5.0
Severe	77.7	3.5	1.73	31.0	-	3.4
LSD (P=0.05)	21.5	n.s.	n.s.	n.s.	-	2.6

*Scale 1-5, 1=poorly symmetrical, 5, highly symmetrical

CAPTIONS FOR FIGURES

Figure 1. Effects of water stress on shoot extension in Experiments I and II and fruit growth in Experiment II only of container grown *Annona* spp. hybrid cv. African Pride. Data are the means of 4 shoots on each of 6 datum trees. Vertical bars indicate LSDs ($P = 0.05$).

Figure 2. Effects of water stress on the percentage of fruit in different size groups in Experiment I. Data are the means of 6 datum trees. Vertical bars indicate LSDs ($P = 0.05$).

Figure 3. Changes in average fruit weight of non-stressed and severely-stressed trees in with date of pollination in Experiment I. Effects of mildly-stressed and moderately-stressed trees are not shown but responses are intermediate to those presented. Data are the means of 6 trees per treatment. Vertical bars indicate LSDs ($P = 0.05$).

Figure 4. Effects of water stress applied during flowering on fruit symmetry and average fruit weight in Experiment I and water stress applied during fruit development on average fruit weight only in Experiment II. Fruit symmetry rated on 8- george420 fruit on a scale of 1-5, 1= poorly symmetrical, 5=highly symmetrical. Datum points are the means of 6 trees per treatment.

Figure 5. Changes in leaf water potential ($_L$), soil water potential ($_S$), net CO_2 assimilation rate (A) and stomatal conductance (g_S) with days after withholding water in Experiment I. Data are the means of 2 measurements on each of 6 datum trees over 3 stressing cycles. Data for non-stressed and severely stressed trees only presented as mildly and moderately stressed trees followed the same stress path as for severely-stressed trees before rewatering. Vertical bars indicate LSDs ($P = 0.05$).

Figure 6. Changes in leaf water potential ($_L$), soil water potential ($_S$), net CO_2 assimilation rate (A) and stomatal conductance (g_S) with soil water potential ($_S$) in Experiment I. Data are the means of 2 measurements on each of 6 severely-stressed datum trees over 3 stressing cyles.

Figure 7. Changes in net CO_2 assimilation rate (A) and stomatal conductance (g_S) with leaf water potential ($_L$) in Experiment I. Data are the means of 2 measurements on each of 6 severely stressed datum trees over 3 stressing cycles.

Figure 8. The relationship between maximum $_L$ and leaf and fruit nutrient concentrations. Data are the means of 6 trees per treatment.

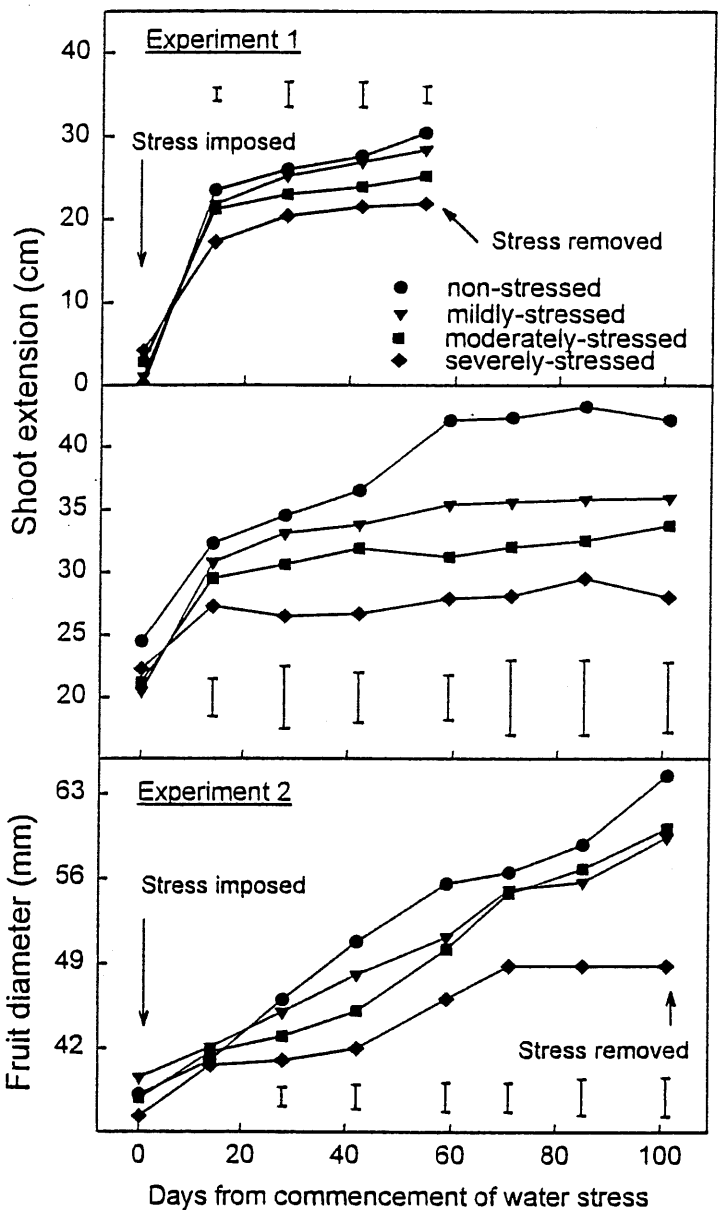

Fig. 1 Effects of water stress on shoot extension in Experiments I and II and fruit growth in Experiment II only of container grown *Annona* spp. hybrid cv. African Pride. Data are the means of 4 shoots on each of 6 datum trees. Vertical bars indicate LSDs ($P = 0.05$).

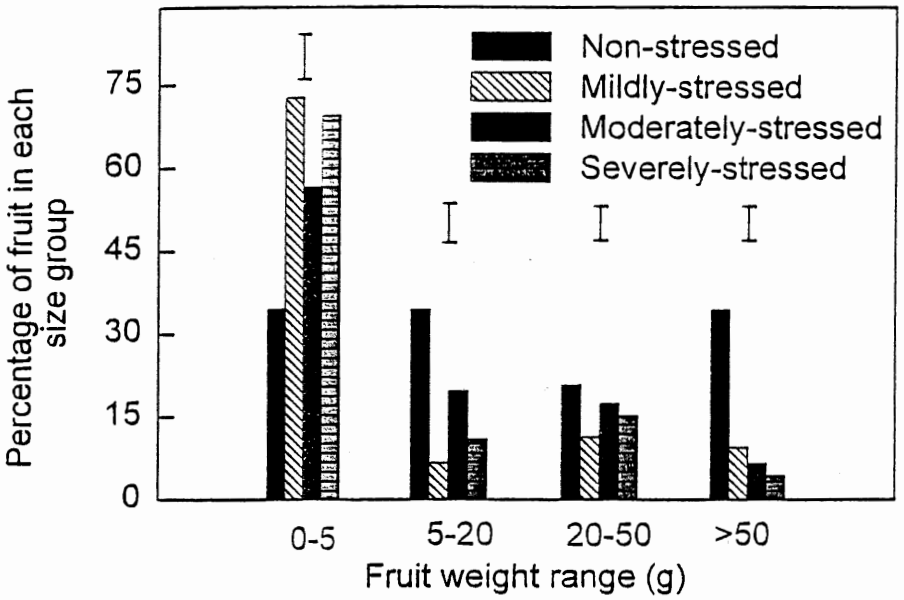

Fig. 2 Effects of water stress on the percentage of fruit in different size groups in Experiment 1. Data are the means of 6 datum trees. Vertical bars indicate LSDs (P = 0.05).

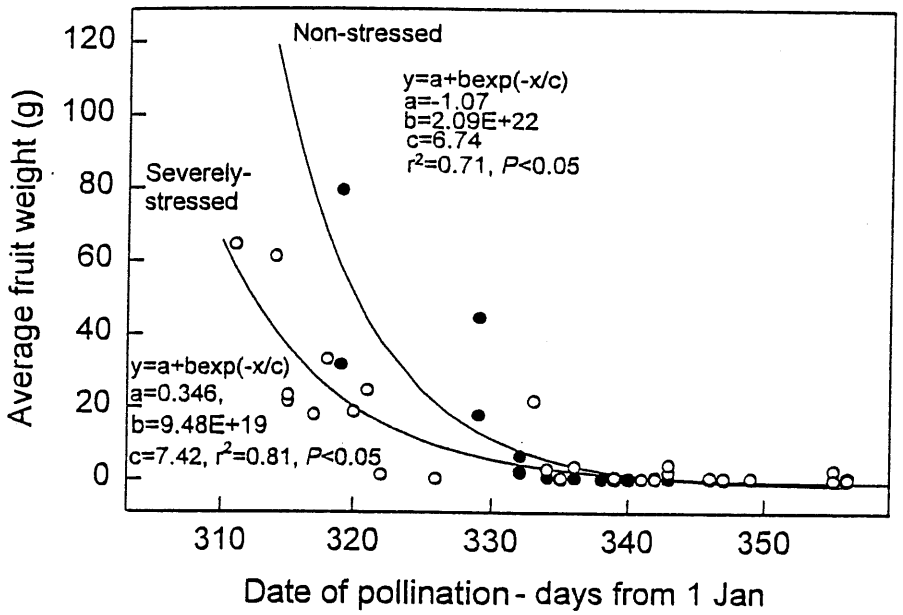

Fig. 3. Changes in average fruit weight of non-stressed and severely-stressed trees with date of pollination in Experiment 1. Effects of mildly-stressed and moderately-stressed trees are not shown but responses are intermediate to those presented. Data are the means of 6 datum trees.

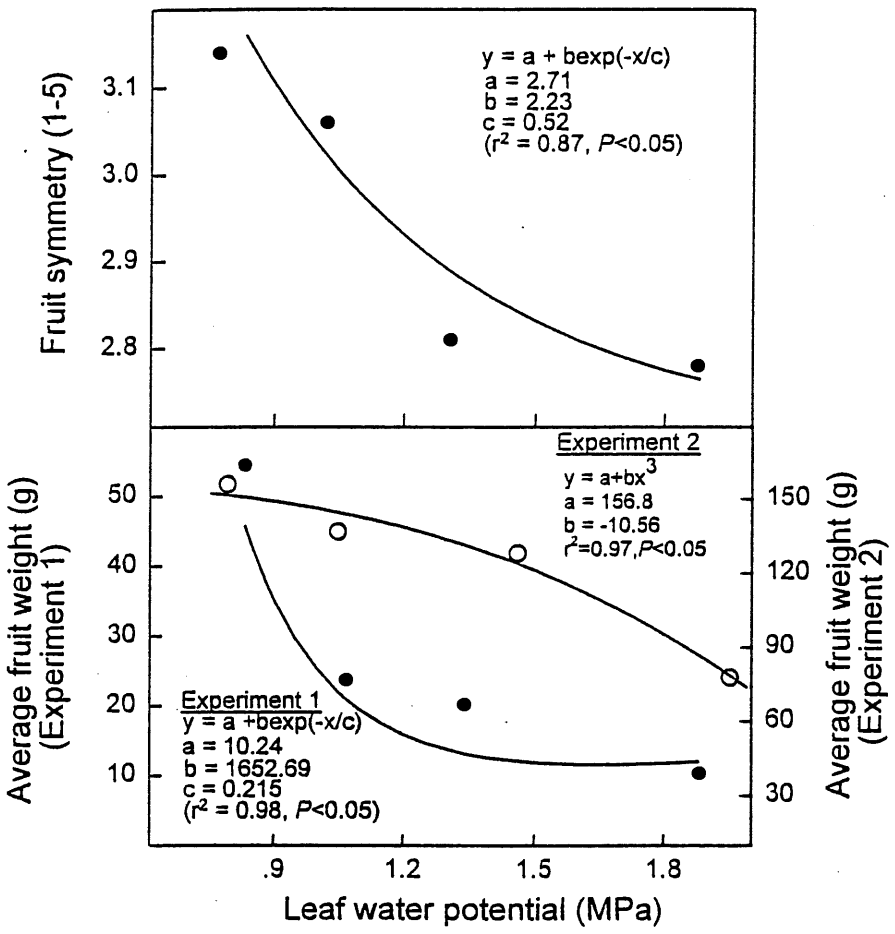

Fig. 4 Effects of water stress applied during flowering on fruit symmetry and average fruit weight in Experiments 1 and water stress applied during fruit development on average fruit weight only in Experiment 2. Fruit symmetry rated on 8-20 fruit on a scale of 1-5, 1= poorly symmetrical, 5=highly symmetrical. Datum points are the means of 6 trees.

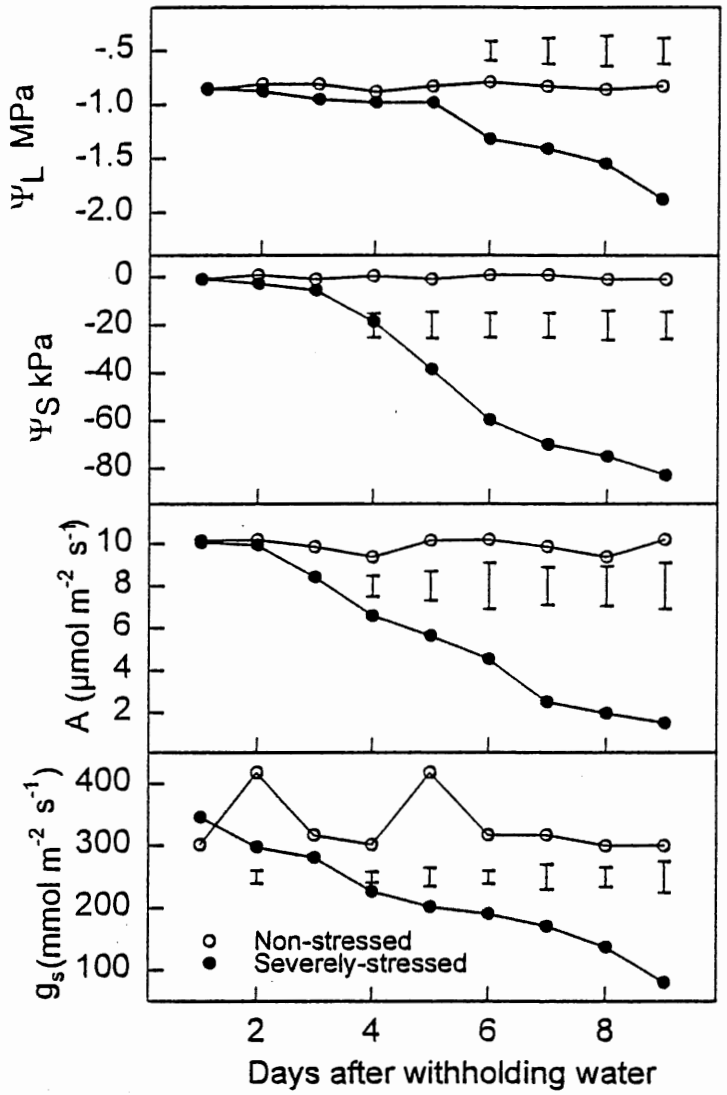

Fig. 5 Changes in leaf water potential (Ψ_L), soil water potential (Ψ_S), net CO_2 assimilation rate (A) and stomatal conductance (g_s) with days after withholding water in Experiment 1. Data are the means of 2 measurements on each of 6 datum trees over 3 stressing cyles. Data for non-stressed and severely-stressed trees only presented as mildly- and moderately-stressed trees followed the same stress path as for severely-stressed trees before rewatering. Vertical bars indicate LSDs (P = 0.05).

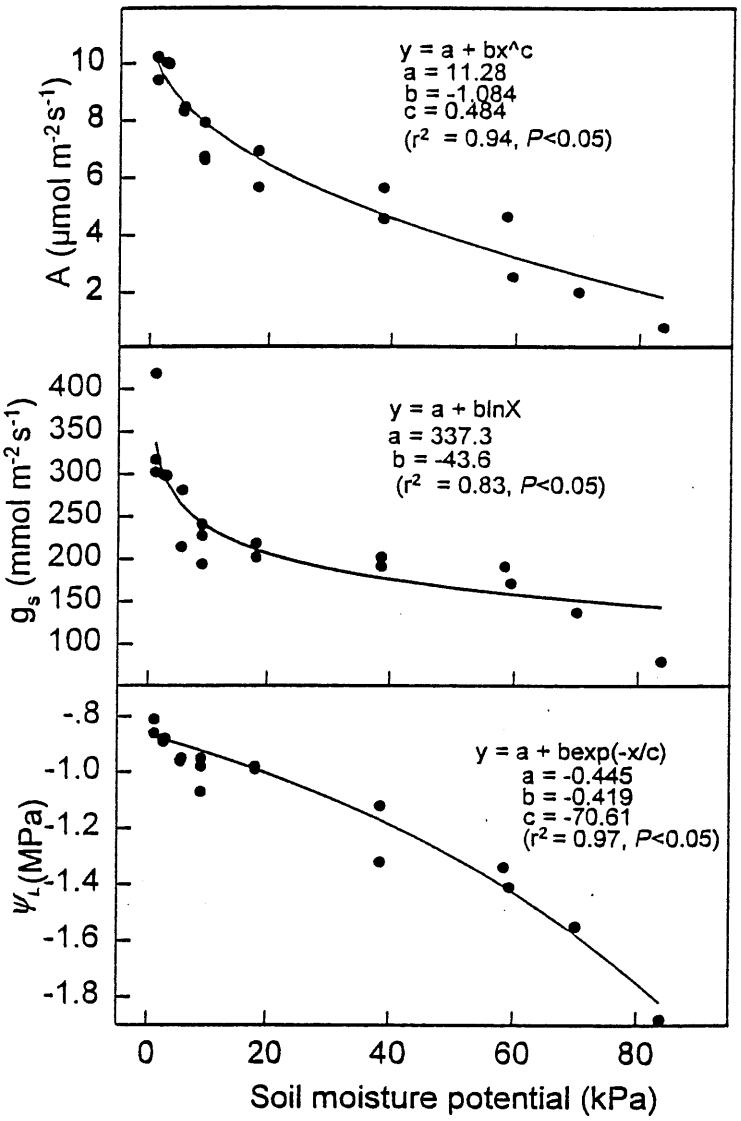

Fig.6 Changes in leaf water potential (Ψ_L), net CO_2 assimilation rate (A) and stomatal conductance (g_S) with soil water potential (Ψ_S) in Experiment 1. Data are the means of 2 measurements on each of 6 severely-stressed datum trees over 3 stressing cyles.

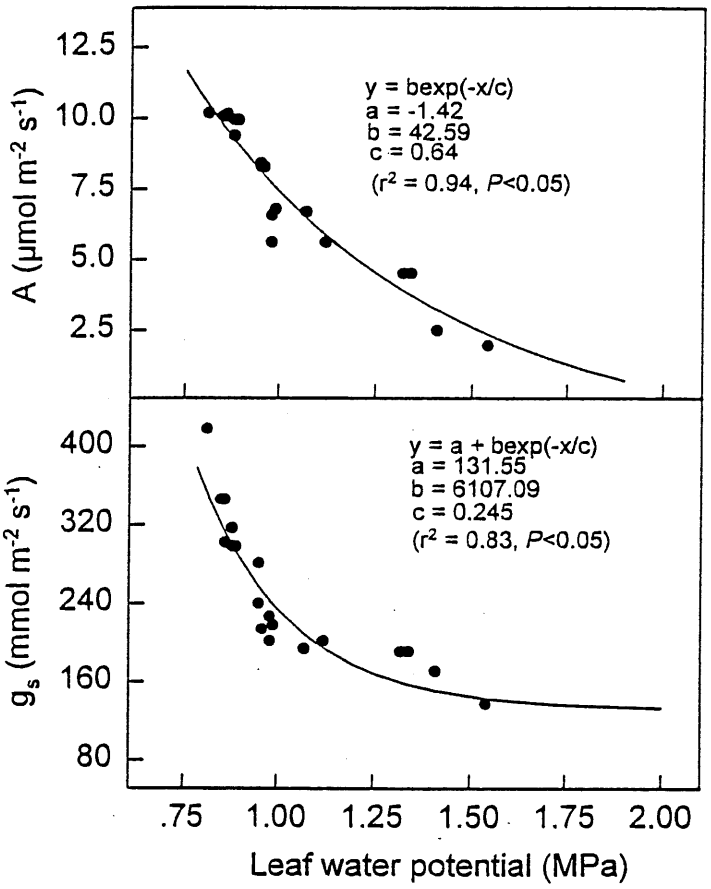

Fig. 7 Changes in net CO_2 assimilation rate (A) and stomatal conductance (g_s) with leaf water potential (Ψ_L) in Experiment 1. Data are the means of 2 measurements on each of 6 severely-stressed datum trees over 3 stressing cycles.

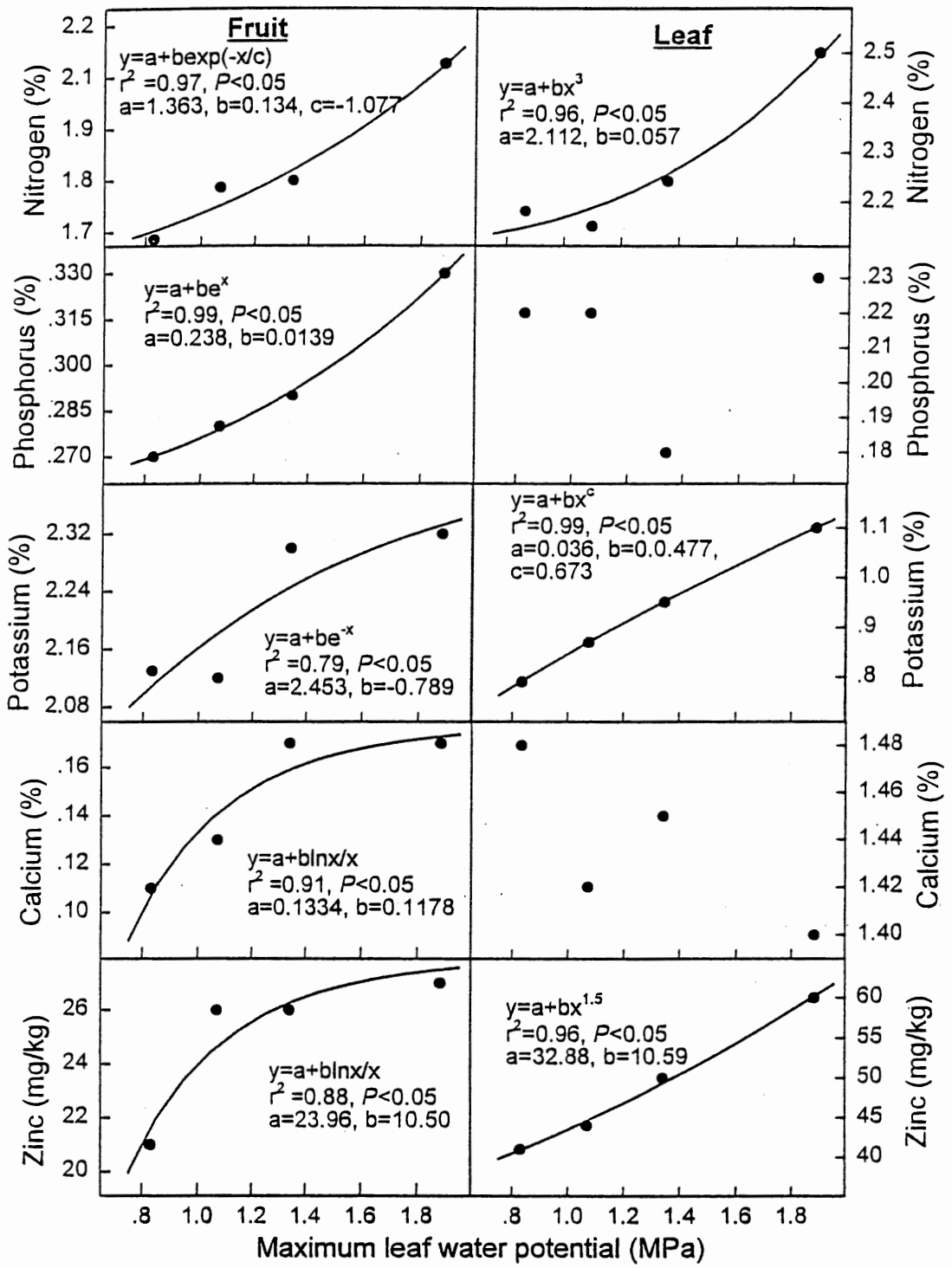

Fig. 8 The relationship between maximum Ψ_L and leaf and fruit nutrient concentrations in Experiment 1. Data are the means of 6 trees per treatment.

FIELD RESPONSE OF *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE TO WATER STRESS

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Summary

A field study was conducted to evaluate the effects of water stress applied during the flowering and early fruit set period on subsequent fruit set, yield and fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Treatments were: wet plots irrigated weekly to replace E_t to bring the profile close to field capacity (16%, v/v) and a dry treatment which was allowed to dry out slowly during the 10 weeks flowering period (11%, v/v), before trees were rewatered. Water was mainly extracted from the top 20-40 cm of the soil profile and to a much lesser extent from deeper levels, indicating that the majority of roots are located in the surface zone. The effects of soil moisture stress on leaf water potential ($_L$) did not become apparent until about 3 weeks after withholding irrigation. At the completion of the stress period, the differences in $_L$s between the wet and dry treatments was about 0.7 MPa. Stressed trees produced 35% more flowers than with well-watered trees as a consequence of reduced apical dominance, a doubling of small lateral shoots per branch and increased floral initiation. Although fruit set patterns were different for the wet and dry treatments there was no significant difference in overall percentage fruit set (av.55%). Water stress increased tree fruit weight and numbers by about 26 and 47%, respectively. Yield efficiency as measured on a butt cross-sectional and canopy volume basis was increased by 17 and 37%, respectively, but stress reduced average fruit weight by 11%. In conclusion, moderate water stress during the flowering period appears beneficial to increasing flowering and subsequent yield but this yield increase may be partially negated by reduced fruit size.

Introduction

Both atemoya (*Annona* spp. hybrids) and cherimoya (*Annona cherimola*) appear to sensitive to water stress during the flowering and fruit development period (George and Nissen, 1988, 1991). In contrast, the sugar apple (*Annona squamosa*) has the reputation, particularly in India, of being hardy (George and Nissen, 1991). This is only partly correct. Although the rest period and leaf fall enable survival during a severe dry season, the tree responds to adequate moisture during the growing season.

In subtropical Australia, flowering of *Annona* spp. hybrids occurs during the summer (November - January, inclusive) (George and Nissen, 1992). This period is often characterised by high temperatures, low humidity and low rainfall. Most *Annona* spp. hybrid orchards are planted at low density, without adequate windbreaks and are irrigated infrequently. These management techniques are conducive to high atmospheric and soil moisture stress in the orchard (George and Nissen, 1989,1992).

Both container and field water stress studies are needed to elucidate on the effects of water stress on fruit set, yield and fruit quality. Under field conditions, *Annona* spp. hybrid trees may tolerate higher levels of stress than trees growing in containers due to both diurnal and long term osmotic adjustment, although the level of osmotic adjustment has been shown to be very small (George and Nissen, 1992). Bearing trees exhibit higher stress levels than non-bearing trees, indicating that cropping may restrict root growth and consequently water uptake by the roots. The objectives of this study were to determine the influence of field drought on fruit set, fruit growth and fruit quality of the *Annona* spp. hybrid cv. African Pride, the main cultivar grown in Australia. This study will complement the findings from glasshouse drought studies currently in progress.

Materials and methods

Site description and treatments

Sixteen, six-year old, uniformly-sized trees of the *Annona* spp. hybrid cv. African Pride, propagated on their own roots, were selected for the experiment at the Maroochy Horticultural Research Station, Nambour,

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Queensland. Trees were spaced 6 m in rows and 8 m between rows (208 trees ha^{-1}) on a sandy loam overlying a clay substratum. The rows were mounded to a depth of 50 cm to improve drainage.

There were two treatments: wet plots irrigated weekly to replace E_t to bring the profile close to field capacity (,v/v, 16%) and a dry treatment which was allowed to dry out slowly over a 10 week period commencing just after the start of flowering (15 November) until the completion of flowering, when trees were rewatered. Treatments were applied to eight, single tree plots. Weather data during the duration of the experiment was recorded at a standard meteorological weather station located on site (Figure 1).

Cultural practices

Trees were irrigated using two under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. In attempt to exclude rainfall from the plots, plastic sheets were placed over the soil to a distance of about 1 m from the edge of the canopy and small ditches constructed to drain away excess water from the trees. The plastic sheets also prevented evaporation from the soil surface.

Trees were fertilised each year in September and November, with a complete fertiliser supplying 250 g N, 50 g P, 125 g K, and, in February with 120 g K per tree. Trees were trained to an open goblet system and were winter pruned in July of each year.

Soil water content

Soil water content was measured weekly, prior to irrigation, with a neutron moisture probe (Campbell Pacific Nuclear, California, Model CPN 503DR Hydroprobe). Readings were taken weekly, at 20 cm intervals to a maximum soil depth of 80 cm, from one access tube per tree placed half-way between the trunk and the drip line of each tree. Soil cores were extracted to a depth of 80 cm from wet and dry sites to give a range of (v/v) of 8 to 18% for calibration of the count ratios (n) from the neutron probe. The soil samples were dried at 105°C to determine gravimetric water content, dry bulk density and volumetric water content. Count ratios and volumetric water content were highly linearly related ($r^2 = 0.80$, $P<0.05$).

Tree water status

During the water stress period, leaf ($_L$) and flower water potential ($_F$) were measured weekly with a pressure chamber, using the precautions outlined by Ritchie and Hinckley (1975), on two leaves and two flowers randomly sampled from each datum tree at 0900 h.

Measurements

Tree growth and development

Tree height, diameter (N - S, E - W), and girth (30 cm above ground level) were measured at the commencement and the completion of the experiment. Tree canopy volume was calculated from the formula for determining the volume of a semi-ellipsoid ($V = 2/3\ r^2h$; V = tree volume, r = tree radius, h = tree height). Flowering intensity and pattern was determined by counting the number of flowers at anthesis in a m^3 quadrat placed randomly in each quadrant of each tree at peak flowering.

Shoot extension was recorded at about fortnightly intervals on four uniform lateral shoots (pruned to 30 cm) tagged on each datum tree. Six fruit, one per lateral shoot (of similar size as those used for shoot extension measurements) were selected and fruit length and diameter (two directions) was measured at about 14 day intervals. Fruit volume was also calculated from a previously established calibration curve between fruit diameter and fruit volume.

Fruit quality assessments

Trees were harvested at the normal commercial stage of fruit maturity (change in ground colour from green to yellow) at intervals of seven days for yield and fruit quality assessment. Fruit quality assessments were made on 20 fruit randomly sampled from each tree at each harvest time. For each individual fruit sampled, Brix was

determined on expressed juice using an Abbe refractometer (American Optical model 10460). Severity of internal browning ('brown pulp') was visually rated as a percentage of the surface area of a vertical cross-section of fruit which was discoloured. Severity of internal 'woodiness' was determined by extracting hard lumps from the flesh and determining their fresh weight. Internal colour (L^*a^*b values) around the seed core and for the flesh was also determined using a chromameter (Minolta model CR-200). Fruit length and breadth were also determined. Fruit symmetry was rated on a scale of 1-5, (1, poorly symmetrical, 5, highly symmetrical).

Shoot:fruit relationships

Shoots selected for fruit samples were removed and the following variables recorded: shoot length, shoot base diameter, leaf area, leaf number, leaf fresh and dry weight, and specific leaf weight. Correlation and regression analyses were carried out to determine if there were significant (P=0.05) relationships between fruit quality and shoot variables.

Starch sampling and analyses

At the completion of flowering, leaves, shoot and trunk were sampled from each of 4 datum trees for starch analy ses using the enzymic-colorimetric procedure (Rasmussen and Henry, 1990.). Leaf and shoot samples were taken from the middle third section of six fruiting laterals per tree. Core trunk samples ($6cm^3$) were taken from the trunks about 30 cm above ground level.

Leaf nutrient sampling and analyses

Leaves, the first fully mature leaf, were sampled from 10 non-fruiting shoots on each datum tree at the completion of the stress period. Ten fruit, of similar weight, were also sampled from datum trees at the completion of the stress period and again at harvest. Fruit and leaves were analysed for N, P, K, Ca, Mg, Fe, B, Cu, Zn and Mn.

Net CO_2 assimilation and stomatal conductance

At the completion of the stress period, stomatal conductance (g_s) and net CO_2 assimilation rate (A) were measured with a LiCor 6200 photosynthesis meter using a 1l chamber. Measurements were made at 1100 h on 2 leaves on each datum tree. During A measurements, PPF was maintained above the light saturation point of 1200 µmol quanta m^{-2} s^{-1} established for *Annona* spp. hybrids (George *et al.*, 1997, unpublished data).

Experimental design and analyses

Treatments were arranged in eight randomised blocks with single tree plots.

Data were analysed using ANOVA and significant differences between the means tested at the P=0.05 level. Linear and non-linear regression analyses were carried out to determine if there were significant relationships between starch reserves at harvest and other tree growth variables.

Results

Soil water status

With the dry treatment, there was a slow decline in soil moisture content (20 cm depth) from 16 to 11%, v/v, over the 10 week period from withholding of irrigation (Figure 2). Water was mainly extracted from the top 20-40 cm of the soil profile and to a much lesser extent from deeper levels, indicating that the majority of roots are located in the surface zone. Although the weight distribution of roots with depth has not been examined for *Annona* spp. hybrids, visual observations indicate, that for vegetatively propagated trees the fibrous root system is predominantly located in top 30 cm surface layer.

Leaf and flower water potentials

Only slight differences between treatments in $_L$s and $_F$ s were recorded up to three weeks after the withholding of irrigation, after which the differences between wet and dry treatment became more apparent (Figure 3). At

the completion of the stress period, the differences in $_L$s between the wet and dry treatments was about 0.7 MPa. Short-term fluctuations in $_L$s and $_F$ s were probably due to changes in VPD (not recorded) at the time of measurement.

Tree and shoot growth

Water stress had no significant effect on tree girth, however tree height, spread and canopy volume were reduced by about 8, 12% and 19%, respectively (Table I). The pattern of shoot flushing was similar for both treatments with three growth flushes, the first growth flush being the strongest (Figure 4). At the completion of the stress period, water stress had reduced shoot growth by about 30%. Stressed trees had greater number of leaves per shoot, but leaves were smaller and of higher specific leaf weight (Table II).

Flowering and fruit set

The flowering and fruit set patterns for both treatments were similar and exhibited three distinct peaks which were associated with vegetative flushing (Figure 4). Stressed trees produced 35% more flowers than well-watered trees. The increase in flower number per tree was due to a doubling of small lateral shoots per branch presumably as a consequence of reduced apical dominance (Table II, Figure 5). Although there was no significant difference in the overall percentage fruit set between treatments (stressed 54%; non-stressed 57%) there were significant differences in the pattern of fruit set (Figure 4). Irrespective of treatment, the level of initial fruit set was low presumably due to poor pollen viability (Figure 6). For stressed trees fruit set was significantly higher during the first vegetative growth flush, presumably due to the beneficial effects of water stress in restricting shoot growth. However, later in the flowering season, as the severity of stress increased, fruit set was reduced by more than half.

Fruit growth

Irrespective of the date of fruit set, water stress reduced fruit growth by 20-50% (Figure 7). For well-watered trees, the pattern of fruit growth for early-set fruit was sigmoidal, but later-set fruit grew more rapidly and did not exhibit a distinct lag stage (Figure 7). In contrast, for stressed trees, irrespective of the time of fruit set, all fruit exhibited a distinct sigmoidal growth pattern. Surprisingly, later-set fruit exhibited greater fruit growth rates so that, by the time of harvest, the differences in fruit weight between the earliest- and latest-set fruit were relatively small.

Tree yield

Water stress increased tree fruit weight and numbers by about 26 and 47%, respectively (Table I). Yield efficiency as measured on a butt cross-sectional and canopy volume basis was increased by 17 and 37%, respectively. Stress reduced average fruit size by 11% (Table I). For well-watered trees there was poor correlation (r=-0.3, n.s.) between fruit number per tree and average fruit size, in contrast, for stressed trees, average fruit size was negatively correlated (r^2=0.83, P<0.05) with increasing fruit number (Figure 8). Fruit weigh and other quality variables were not correlated with individual shoot variables such as leaf area, leaf number, shoot dry weight and shoot length. The harvest patterns for both treatments was similar (data not presented).

Fruit quality

With the exception of fruit size, no significant differences were found between treatments in fruit symmetry, skin thickness, skin type, internal 'woodiness', 'brown pulp', seed number or Brix.

Net CO_2 assimilation rate

At the end of the stress period, water stress had significantly reduced A (well-watered, 6.3 μmol m^{-2} s^{-1}; stressed, 2.0 μmol m^{-2} s^{-1}) and g_s (well-watered, 205.6 mmol m^{-2} s^{-1}; stressed 39.4 mmol m^{-2} s^{-1}). Net CO_2 assimilation rate was highly correlated with g_s (Figure 9).

Starch

Irrespective of treatment, trunk starch concentrations fell by similar amounts during the first vegetative flushing period. However during the second vegetative flushing period, water stress reduced trunk starch concentrations by more than 50% and increased shoot starch concentrations by about 30% (Figure 10). Stressed trees had slightly higher concentrations of leaf starch at all sampling periods but these effects were not significant ($P>0.05$).

Leaf nutrients

Fruit Ca concentration at the end of the stress period were double those of well-watered trees and at harvest about 38% higher (Table III). Stress also increased fruit Zn and B concentrations by about 30 and 16%, respectively. Stress increased leaf Ca concentrations but lowered N, P, K, Mg, S, and B concentrations (Table III).

Discussion

Water stress was highly beneficial in increasing tree yield. This response was due to a reduction in apical dominance, and a concomitant increase in lateral shoot and flower number, this latter response leading to increased yield. Water stress has been shown to promote floral induction in a range of tropical and evergreen crops but not all (Tatt, 1976; Chaikiatiyos, *et al.*, 1994). The yield response in this Experiment is comparable to that reported for lychee with water stressed trees producing almost twice the number of fruit, although fruit size was reduced by 16% (Batten *et al.*, 1994). The level of apical dominance in *Annona* spp. hybrids varies considerably with some cultivars such as Pink's Mammoth exhibiting very low budbreak. A limited number of techniques are currently available to reduce this phenomenon. These include the application of rest-release chemicals such as hydrogen cyanamide (G. Stino, pers. comm., 1993) and post-budbreak defoliation to stimulate budbreak (George and Nissen, 1985).

Compared to other subtropical fruit crops such as lychee (Menzel and Simpson, 1991) and citrus (Kriedemann and Barrs, 1981), water stress did not adversely affect the average seasonal fruit set. The improvement in fruit set early in stress period was probably due to beneficial effects of water stress on reducing vegetative growth, with similar responses have been reported for lychee (Cull and Paxton, 1983). The adverse affects of water stress on fruit set during the later stages of flowering were due to the increasing severity of stress applied. Irrespective of treatment, low initial fruit set was probably due to poor pollen viability of early-season flowers.

Water stress during the flowering and early fruit development adversely affected fruit growth with final size reduced with increasing crop load. Stress during flowering probably adversely affected cell division which is normally greatest in the first 4-6 weeks after fruit set. This response was similar to that obtained with mango (Pongsomboon, 1995, unpublished data). In contrast, there was no similar trend in fruit size reduction with well-watered trees with increasing crop load, indicating that nutrients were non-limiting. The sigmoidal fruit growth patterns of both treatments were relatively similar. Surprisingly, later-set fruit exhibited higher growth rates than earlier-set fruit and were nearly able to catch up in fruit size. The slower growth rates of earlier-set fruit may be due to competition between fruit and strong vegetative growth flushes occurring concomitantly. Fruit size and fruit quality and individual shoot characteristics were poorly correlated indicating these are not reliable indices for determining final fruit size and/or quality. Similar finding have been found for non-astringent persimmon (George *et al.*, 1994).

Water stress doubled the fruit Ca concentrations presumably as a consequence of reducing the translocation to vegetative shoots. Increased leaf and fruit Ca concentrations were not associated with reduced internal 'woodiness' which has been shown to be the case in other studies (George *et al.*, 1997, unpublished data), but this may been due to both the very low incidence of the disorder in the orchard/region in the season of study and the low overall vigour of lateral shoots.
The relatively slow development of leaf and flower water stress in this experiment may have been due to either stomatal closure and consequently water conservation by *Annona* spp. hybrid trees or the ability of *Annona* spp. hybrid trees to extract some water from depth. Similar findings have been found for lychee (Menzel *et al.*, 1995). Since most extraction of water appears to have occurred from the surface horizons the former explanation is more probable.

For stressed trees, the reduction in starch concentrations in the trunk, the major storage organ, during the early stages of fruit development indicates a shift in nutrient source from current season's photosynthesis, , to stored reserves in the trunks. In conclusion, moderate stress during the flowering period appears beneficial to increasing flowering and subsequent yield but this yield increase may be partially negated by reduced fruit size. Similar responses have been recorded with container-grown trees.

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CAPTIONS FOR FIGURES

Figure 1. Changes in weather during the experimental period.

Figure 2. Change in average soil water content (%, v/v) in the wet and dry treatments over a 10 week period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs (P=0.05).

Figure 3. Changes in mean $_L$ and $_F$ for the wet and dry treatments over a 10 week period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs (P=0.05).

Figure 4. Seasonal changes in shoot extension, number of flowers at anthesis and fruit set for wet and dry treatments over the experimental period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs (P=0.05).

Figure 5. The relationship between number of flowers per branch and lateral shoot number per branch. Data are the means of 4 branches on each of 8 datum trees.

Figure 6. Changes in pollen viability during the flowering period. Data are the pollen germination percentages of 100 pollen grains sampled from 20 flowers.

Figure 7. Effects of soil moisture stress on seasonal changes in fruit diameter. Data are the means of 6 fruit on each of 8 datum trees. Vertical bars indicate LSDs (P=0.05).

Figure 8. Effects of crop load on average fruit weight of wet and dry treatments. Data are the means of 8 datum trees. Regression line for stressed tree data only.

Figure 9. The relationship between net CO_2 assimilation rate (A) and stomatal conductance (g_s). Data are the means of readings taken at 0900 h. on 2 leaves on each of 8 datum trees

Figure 10. Seasonal changes in starch concentration in different tree organs. Data are the means of 8 datum trees. Vertical bars indicate LSDs (P=0.05).

Table. ***Effects of water stress during flowering on subsequent tree growth and yield of the Annona spp. hybrid cv. African Pride in subtropical Australia***

Treatment	Tree height (m)	Tree spread (m)	Tree canopy volume (m^3)	Fruit weight per tree (kg)	Fruit no per tree	Average fruit weight (g)	Fruit weight per butt cross-sectional area (g/cm^2)	Fruit weight Per Unit canopy volume (kg/m^3)
Stressed	4.46	4.57	37.3	78.4	193	405.1	165	1.88
Non-stressed	4.84	5.21	46.6	59.9	131	455.2	141	1.37
LSD ($P = 0.05$)	0.37	0.48	4.9	16.5	42	39.2	19	0.4

Table. ***Effects of water stress during flowering on branch and shoot growth variables and flowering of the Annona spp. hybrid cv. African Pride in subtropical Australia***

Treatment	Lateral shoot no. per branch	Floral bud No per lateral shoot	Floral bud number per m^3	Lateral shoot length (cm)	Leaf no. per lateral shoot	Leaf area per lateral shoot (cm^3)	Dry weight of leaf (g)	Dry weight of lateral shoot (g)	Specific leaf weight (g/cm^2)
Stressed	42.4	2.4	40.4	57.2	18.0	951.7	8.1	6.2	8.5
Non-stressed	18.6	1.7	30.0	93.8	13.3	990.5	7.0	5.8	7.1
LSD ($P = 0.05$)	23.1	0.4	9.1	38.1	3.8	28.5	0.5	n.s.	0.4

Table ***Effects of water stress on the nutrient composition of fruit and leaves of the Annona spp. hybrid cv. African Pride. Fruit nutrient concentrations are the means of 10 fruit and leaf nutrient concentrations are the means of 10 leaves sampled from each of 8 datum trees***

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Cu (mg g^{-1})	Zn (mg g^{-1})	B (mg g^{-1})	Fe (mg g^{-1})	Mn (mg g^{-1})
Fruit (completion of stress period)											
Stressed	1.71	0.21	2.14	0.24	0.26	0.26	13.4	20.2	11.4	54.5	43.6
Non-stressed	1.75	0.22	2.19	0.12	0.23	0.23	13.0	15.9	9.6	41	25.6
LSD (P=0.05)	n.s.	n.s.	n.s.	0.007	n.s.	n.s.	n.s.	4.1	1.04	n.s.	6.6
Fruit (at harvest)											
Stressed	1.31	0.13	1.65	0.11	0.14	0.10	11.1	11.5	22.0	33.1	9.3
Non-stressed	1.21	0.12	1.64	0.08	0.14	0.10	9.4	8.7	19.3	37.8	8.6
LSD (P=0.05)	n.s.	n.s.	n.s.	0.01	n.s.	n.s.	n.s.	2.5	n.s.	n.s.	n.s.
Leaf (completion of stress period)											
Stressed	2.59	0.16	1.17	1.30	0.31	0.18	10.3	17.9	29.2	79	79.0
Non-stressed	2.98	0.20	1.41	0.96	0.34	0.20	11.9	14.7	32.0	52.4	52.4
LSD (P = 0.05)	0.38	0.003	0.19	0.14	0.002	0.015	n.s.	n.s.	2.7	n.s.	n.s.

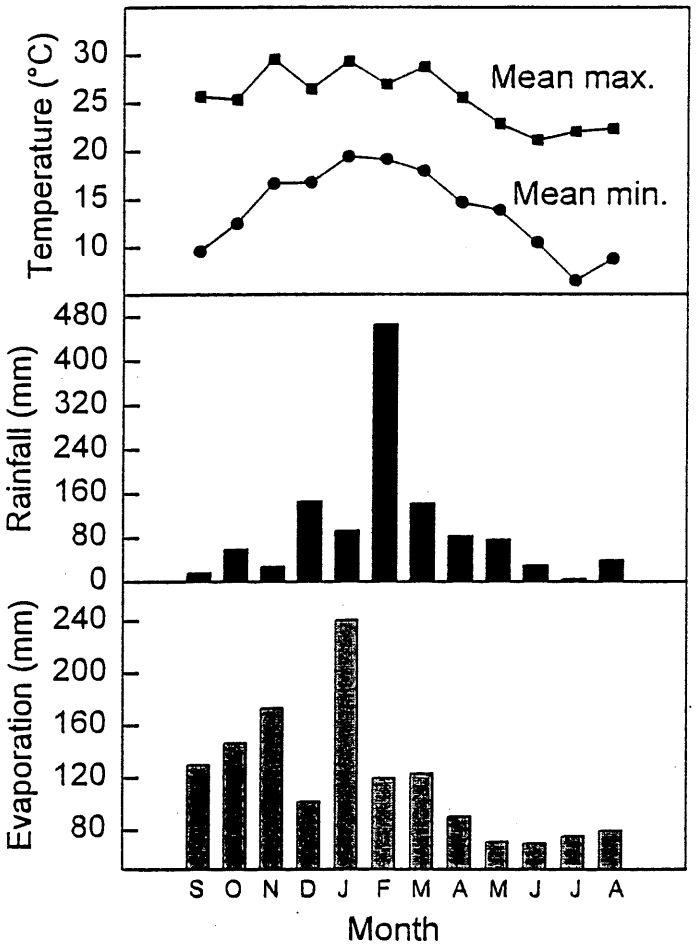

Fig. 1 Changes in weather during the experimental period.

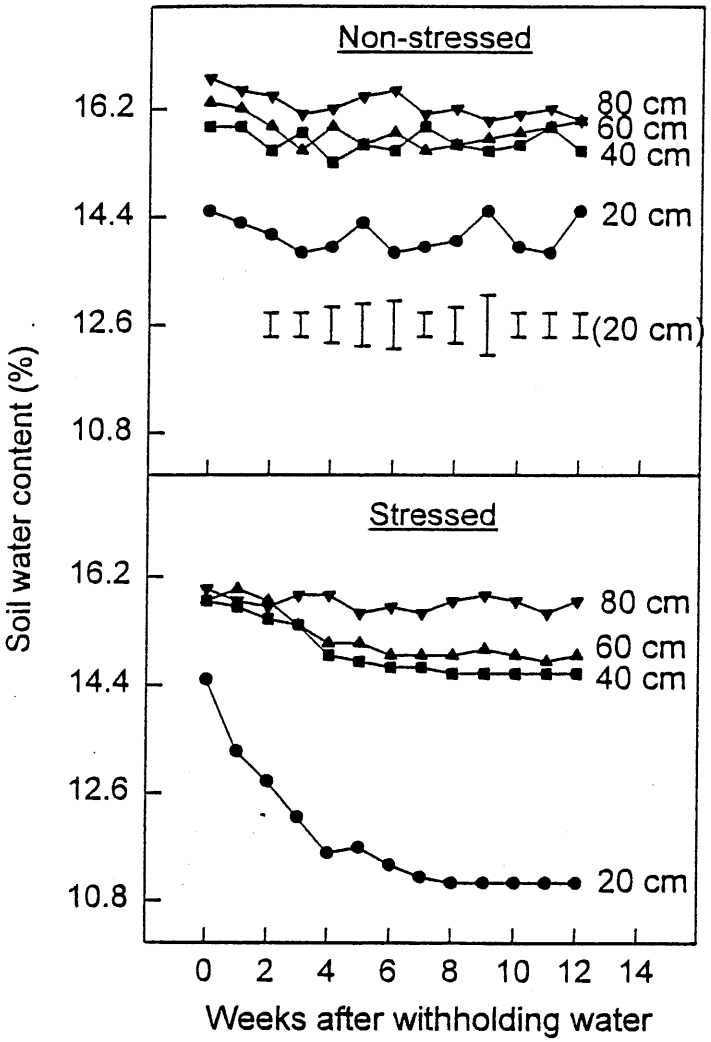

Fig. 2 Change in average soil water content (%,v/v) in the wet and dry treatments over a 10 week period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs (P = 0.05).

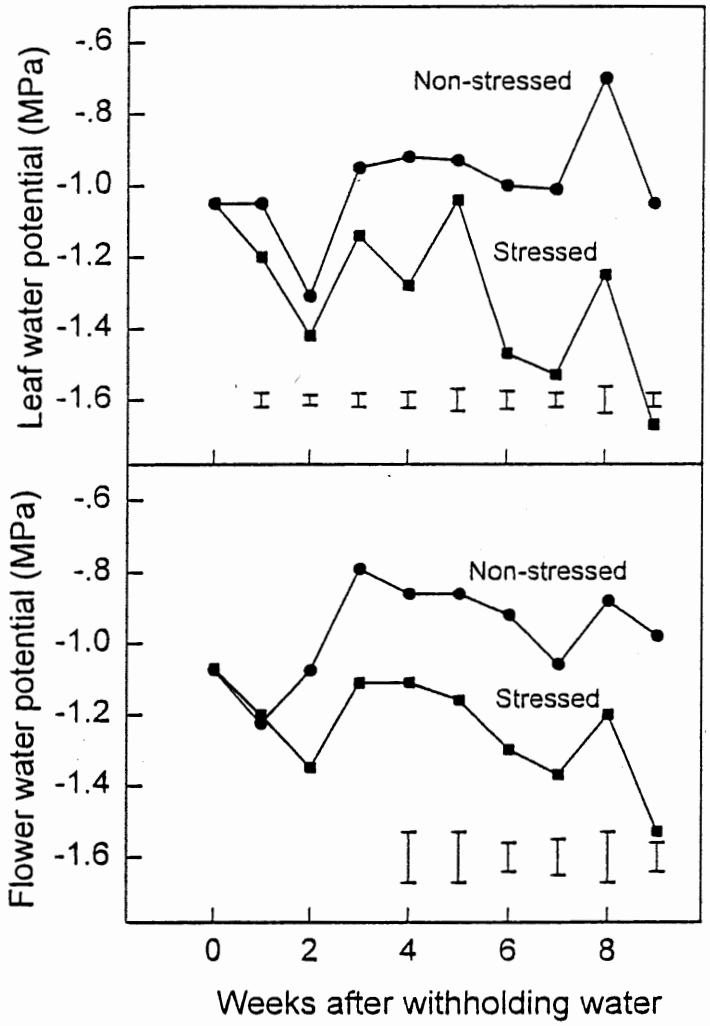

Fig. 3 Changes in mean ψ_L and ψ_F for the wet and dry treatments over a 10 week period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs ($P = 0.05$).

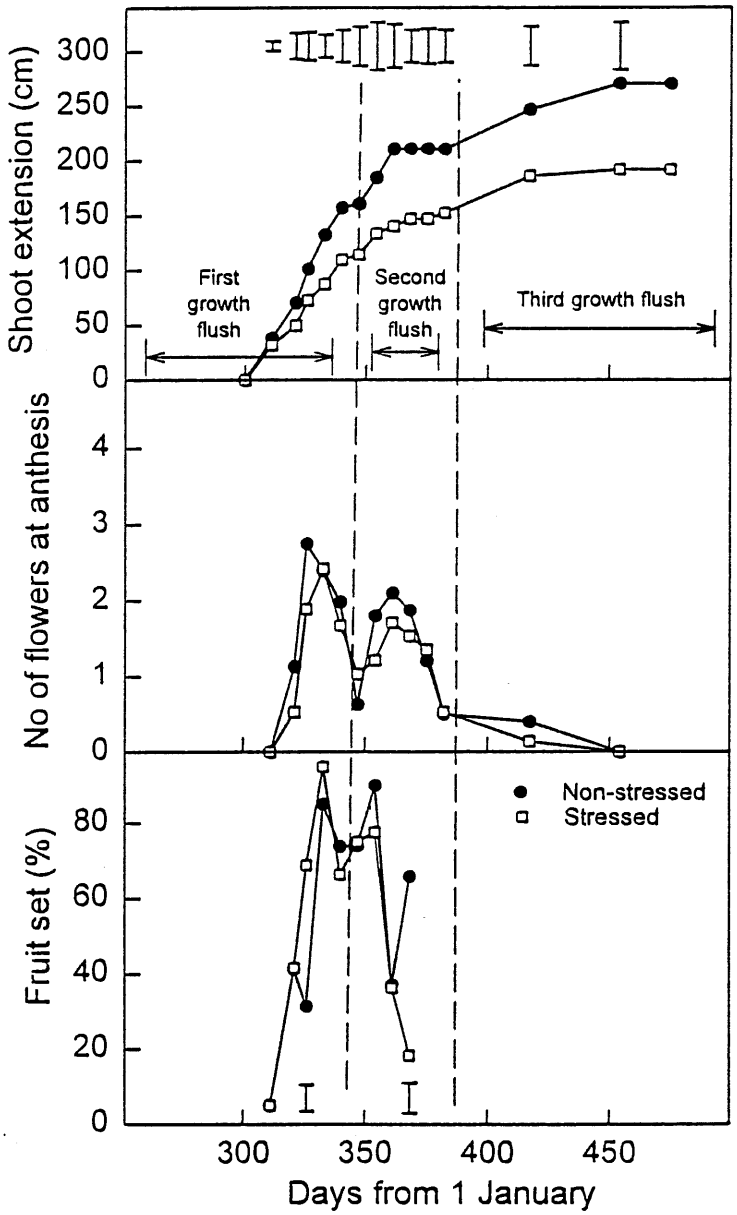

Fig.4 Seasonal changes in shoot extension, number of flowers at anthesis and fruit set for wet and dry treatments over the experimental period. Data are the means of 8 trees per treatment. Vertical bars indicate LSDs. (P= 0.05).

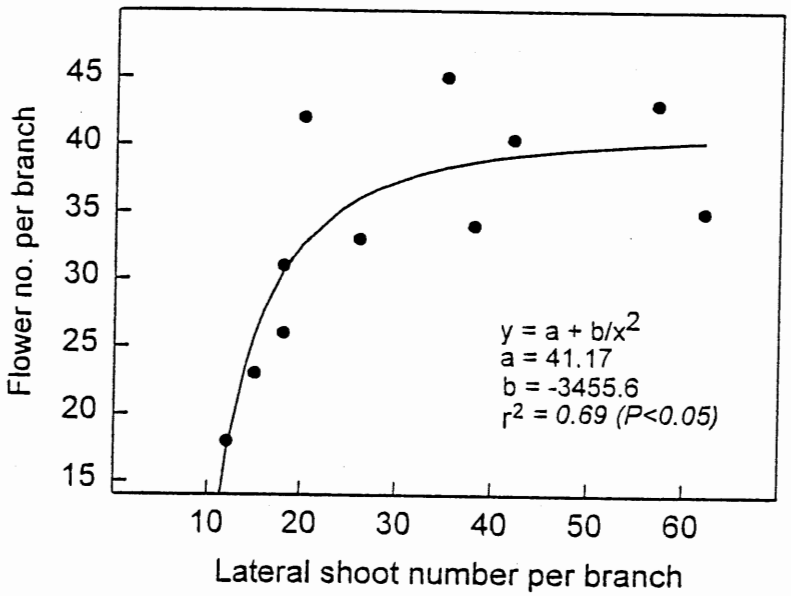

Fig. 5 The relationship between flower number per branch and lateral shoot number per branch. Data are the means of 4 branches on each of 8 datum trees.

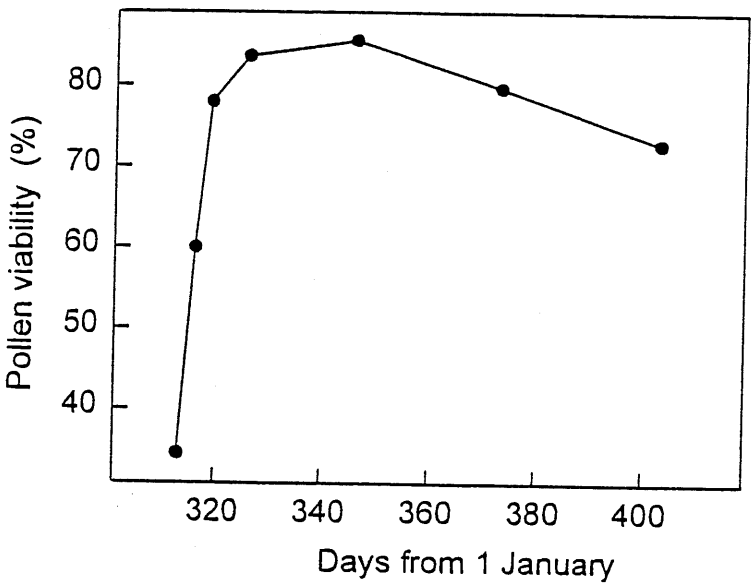

Fig. 6 Changes in pollen viability during the flowering period. Data are the pollen germination percentages of 100 pollen grains sampled from 20 flowers.

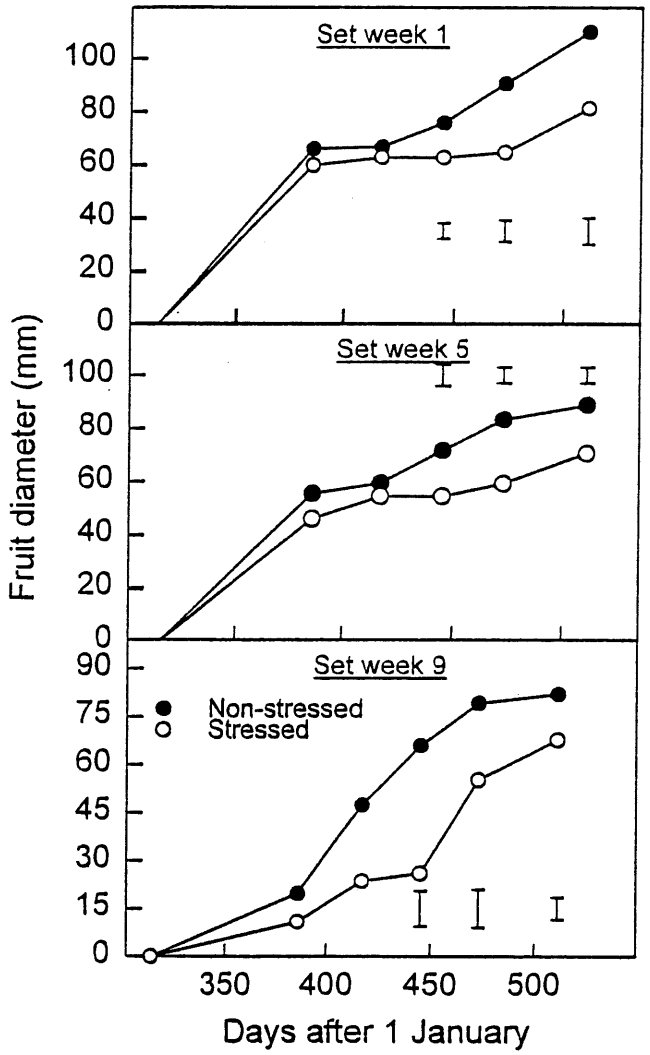

Fig. 7 Effects of soil moisture stress on seasonal changes in fruit diameter. Data are the means of 6 fruit on each of 8 datum trees. Vertical bars indicate LSDs ($P = 0.05$).

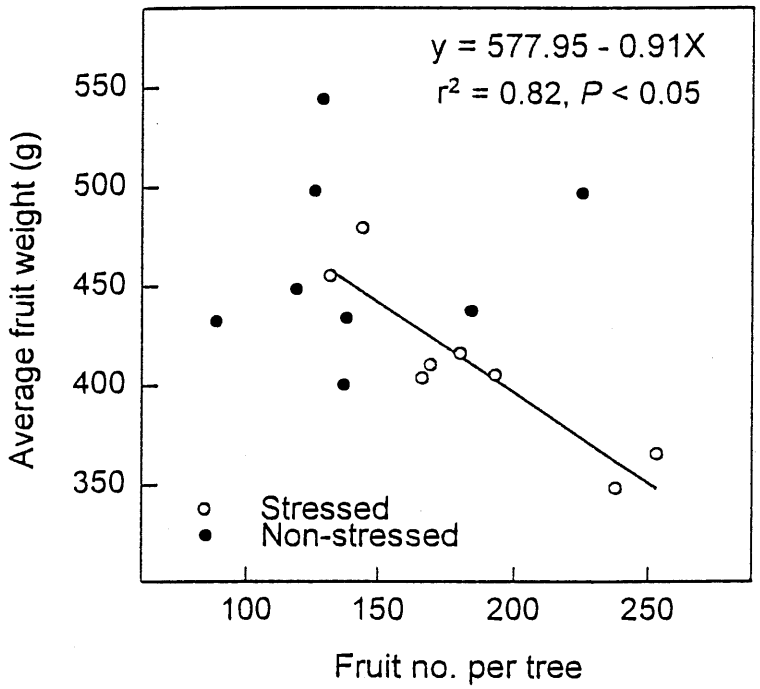

Fig.8 Effects of crop load on average fruit weight of wet and dry treatments. Data are the means of 8 datum trees. Regression line for stressed tree data only.

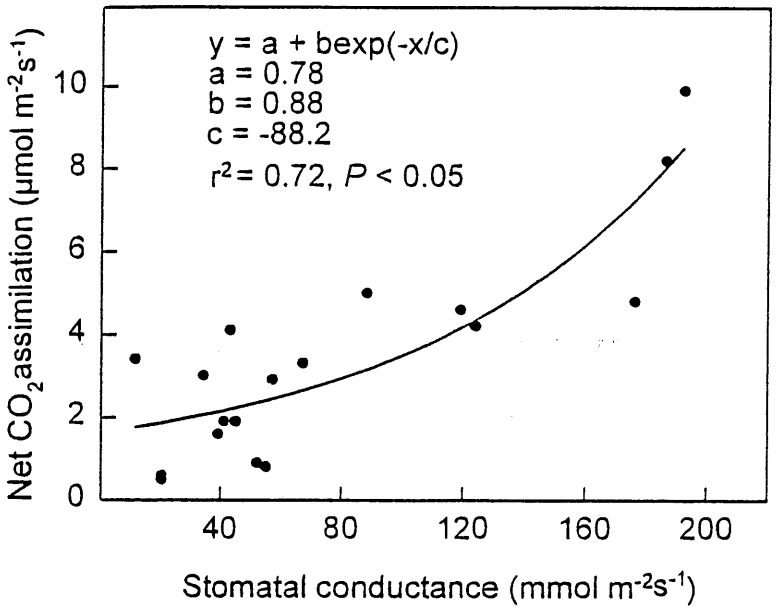

Fig.9 The relationship between net CO2 assimilation rate (A) and stomatal conductance (gs). Data are the means of readings taken at 0900 h. on 2 leaves on each of 8 datum trees.

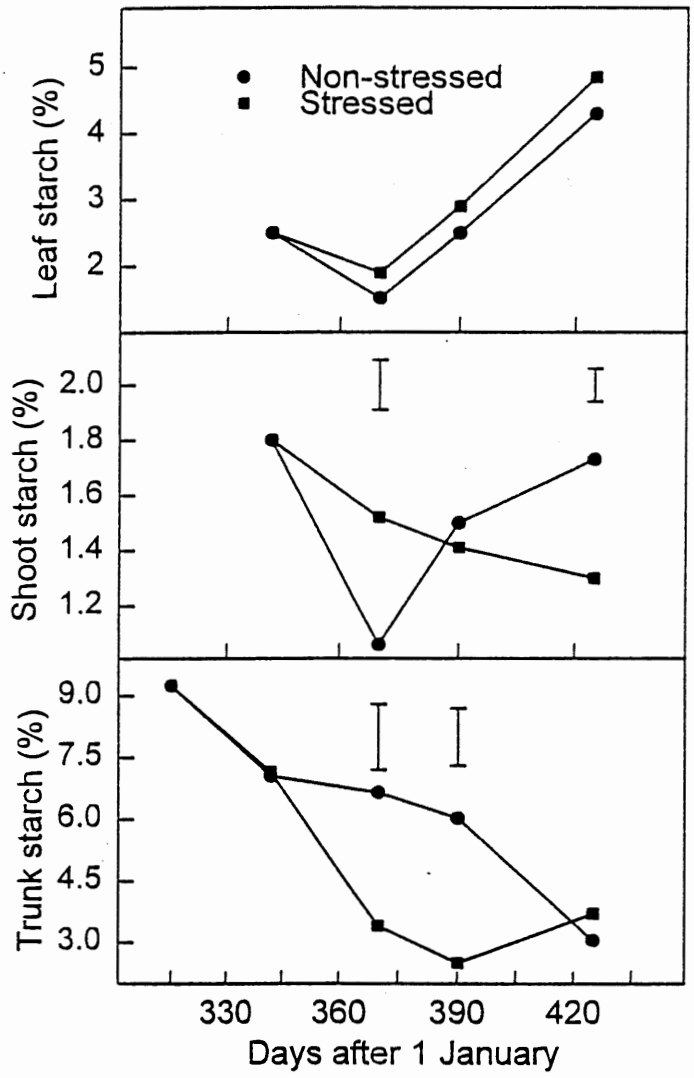

Fig. 10 Seasonal changes in starch concentration in different tree organs. Data are the means of 8 datum trees. Vertical bars indicate LSDs ($P = 0.05$).

EFFECTS OF CALCIUM, BORON AND TREE VIGOUR ON FRUIT QUALITY OF THE *ANNONA* SPP. HYBRID CV. AFRICAN PRIDE IN SUBTROPICAL AUSTRALIA

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Summary

Two experiments were conducted to evaluate the interactive effects of soil and foliar applied Ca and B and tree and shoot vigour on fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. Fruit, and to a lesser extent leaf Ca and B concentrations, were more influenced by tree vigour, and not by soil or foliar applications of Ca or B. At harvest, dwarfing sugar apple (*Annona squamosa*) inter-stock increased fruit Ca concentration by about double and total Ca content per fruit by 80%. Over 2 seasons, sugar apple inter-stock reduced the severity of two internal disorders `woodiness' and `brown pulp' by 30-70%.

The severity of `brown pulp' disorder was six times greater with early-season fruit compared with the late-season fruit due to the strong competition between the developing fruitlet and the first major vegetative growth flush. Fresh weight of `woodiness' per fruit increased with shoot extension (r^2=0.62, P<0.05) and decreased with fruit Ca concentration in January, three months prior to harvest (r^2=0.57, P<0.05). Soil applied B reduced `brown pulp', but its effects were less than for Ca. Two sequentially applied, foliar sprays of calcium nitrate (2 g $l^{-1}$ ) at fruit set and 4 weeks later reduced fresh weight of `woodiness' per fruit and % `brown pulp' by 31 and 51%, respectively, but foliarly-applied B had no significant effect. Paclobutrazol significantly increased fruit fresh weight by 24 % and pulp recovery by 10.8%.

Introduction

Poor fruit quality is a major problem preventing more rapid expansion of the Australian *Annona* spp. hybrid industry. Small fruit size, irregular shape, skin roughness, skin russetting, excessive seediness and internal disorders are major fruit quality defects that will need to be reduced if *Annona* spp. hybrids are to better accepted by consumers. The effects of nutrition on fruit quality of tree fruits are poorly understood with many factors affecting the distribution of nutrients between competing organs, including tree vigour, rootstock, leaf:fruit ratios, and cultural practises such as pruning and use of growth retardants (Witney *et al.*, 1986, Hofman, 1996). Few or none of these practises have been evaluated for *Annona* spp. hybrids.

Several internal disorders have been observed in *Annona* spp. hybrids; the most common one being `woodiness' . The morphology of `woodiness' disorder of *Annona* spp. hybrids has been described in detail by Penn (1993). This disorder is characterised by the presence of woody seed pockets. A closely related disorder, often associated with `woodiness', is pulp discolouration. I have termed this disorder `brown pulp'. Penn (1993) found that `woodiness' was due to an overproduction of sclerids around some seeds. A complete histological description of the disorder is provided in her thesis. In severe cases, woody lumps may also appear in the flesh. In healthy fruit the seed pockets have the same melting texture as the rest of the flesh. There is no indication from the external appearance of the fruit that it is defective inside. Studies by Batten and Vimpany (1992) indicated that the severity of `woodiness' could be reduced through foliarly-applied B and Ca, but the responses to these applied nutrients we re inconsistent. With other crops such as apples, avocado and mango internal fruit disorders such as corkiness and bitter pit are now known to be caused by Ca and B deficiencies during fruit development (Shear, 1975; Raese, 1989; Witney *et al.*, 1990 a,b; Hofman, 1996). These nutrients may be implicated in the incidence of `woodiness' and `brown pulp'.

Two experiments were conducted to evaluate the effects of soil and foliar applied Ca and B on fruit quality of the *Annona* spp. hybrid cv. African Pride in subtropical Australia. The influence of tree and shoot vigour on the response to these applied nutrients was also evaluated.

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Materials and methods

Experiment 1

Experiment 1 was conducted at the Maroochy Horticultural Research Station (Latitude 26°S). A uniform block of five year old trees of the *Annona* spp. hybrid cv. African Pride were selected. Trees were spaced 3 m in rows and 4 m between rows (833 trees ha $^{-1}$) on a sandy loam overlying a clay substratum. The rows were mounded to a depth of 50 cm to improve drainage. The experimental design was a randomised block with factorial arrangement of treatments, viz ±Ca, ±B, ± sugar apple inter-stock applied to three replications of three-tree plots, over a two year period. Plots were guarded externally within the row. Both B (as borax) and Ca (as gypsum) were soil applied in early spring (first week of September) of 1991 and 1992 prior to the recommencement of tree growth after dormancy at rates of 5 g m^{-2} and 0.5 kg m^{-2} of projected canopy area, respectively. Trees with sugar apple inter-stock were grafted onto cherimoya (*Annona cherimola*) rootstocks; for all other treatments, trees were propagated as cuttings and not grafted onto rootstock.

Cultural practices (Experiment 2)

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees were fertilised in September and November with a complete fertiliser supplying 180 g N, 30 g P, 100 g K, and again in February with 250 g K per tree. Trees were trained to an open goblet system and they were moderately dormant-pruned (30% heading back of shoots) in 1991 and lightly pruned (10% heading back of shoots) in 1992.

Experiment 2

Experiment 2 was conducted at a commercial orchard at Palmwoods (Latitude 26°S). on a uniform block of four year old trees of the *Annona* spp. hybrid cv. African Pride. Trees were spaced 4 m in rows and 6 m between rows (416 trees ha^{-1}) on a sandy loam overlying a clay substratum.

The experimental design was a randomised block with eight treatments, applied in factorial combination, to one uniform lateral (about 30 cm in length) on each of 10 single-tree plots. Treatments were: ±Ca, ±B, ±paclobutrazol. One flower on each lateral was hand-pollinated (pollen cv. African Pride) on the 30 November 1993 to ensure adequate fruit set. Calcium as calcium nitrate and B as borax were foliarly applied to the selected laterals at rates of 2 g l^{-1} and 1 g l^{-1}, respectively, with 0.1 mL l^{-1} wetting agent (Agral 60®) added. Two sequential sprays of both nutrients were applied, the first on the date of hand-pollination and, the second, four weeks later. Fruitlets were thinned three weeks after fruit set to leave only one fruit per lateral. Paclobutrazol (Cultar®) at 10.0 g a.i. l^{-1} was applied on the same date as flowers were hand-pollination, to the terminal 4-5 nodes of new laterals which were about 30 cm long.

Cultural practices (Experiments 2)

Trees were irrigated using under-tree mini-sprinklers delivering 30 l h^{-1} to each tree. Water was applied weekly with the rate based on 80% class A pan evaporation. Each year, trees were fertilised in November with a complete fertiliser supplying 300 g N, 86 g P, 226 g K, and again in February with ,130 g N, 383 g K per tree. Trees were trained to an open vase system and were winter-pruned in early Spring (15 September).

Measurements (Experiment 1)

Tree growth

For both years of the Experiment, tree height, diameter (N - S, E - W), and girth (30 cm above ground level) were measured in August, when trees were dormant. Tree canopy volume was calculated from the formula for determining the volume of a semi-ellipsoid (V = 2/3 pr^{2}h; V = tree volume, r = tree radius, h = tree height). Shoot extension was recorded at about fortnightly intervals in both growing seasons on six uniform laterals (pruned to 30 cm) on each datum tree. Flowering intensity and pattern was determined by counting, at about fortnightly intervals, the number of flowers at anthesis in a m^3 quadrat placed at a median tree height in the N and S sectors of each tree.

Fruit growth

Six fruit, one per lateral (similar size as those used for shoot extension measurements) were selected and fruit length and diameter (two directions) was measured at about fortnightly intervals.

Fruit quality

Trees were harvested at the normal commercial stage of fruit maturity (change in ground colour from green to yellow) at intervals of seven days for yield and fruit quality assessment. All fruit quality assessments, with the exception of `brown pulp' ratings, were made at peak harvest (mid-May) on 30 fruit randomly sampled from each tree. For the 1991-92 season only, `brown pulp' rating was also carried out for early- (April) and late- (July) season harvested fruit. Fruit were sectioned into flesh, skin and seed before fresh weight determinations of pulp. The fresh weight of the pulp affected by `woodiness' and the % weight of pulp affected by `woodiness' was determined. Two observers, working independently, visually rated the % of a vertical cross-section of fruit which appeared off-white or brown (`brown pulp ' disorder). Fruit were also rated visually, on a scale of 1-5, for fruit symmetry (1=irregular, 5=regular shape) and skin type (1=lumpy, 5=smooth). For each fruit, skin thickness was measured at four points selected at the equator of the fruit. The number of days taken for fruit to ripen at ambient temperature (25°C) was also determined.

Leaf and fruit nutrient sampling and analyses

During the fruit development period (FDP), twenty recently-matured leaves (the 4th or 5th leaf from the growing point of fruiting laterals) and 20 average-size fruit were sampled at about monthly intervals for Ca and B nutrient analyses. Whole fruit including skin and seed were analysed.

Trees were also sampled in mid-March, the standard leaf sampling time for *Annona* spp. hybrids (George *et al*, 1989) so that comparisons between treatment effects and leaf nutrient standards set for *Annona* spp. hybrids (George *et al.*, 1997, unpublished data) could also be made. Twenty recently matured leaves were sampled from non-fruiting shoots on each datum tree for N, P, K, Ca, Mg, Fe, B, Cu, Zn and Mn analyses using analytical techniques previously described by George *et al.* (1989).

Measurements (Experiments 2)
Fruit quality

Fruit quality assessments and harvesting procedures were the same as for Experiment 1. In addition, pulp colour (Hunter L*a*b values) was also determined around the seed pocket which is the area normally most affected with `brown pulp', and for a median section of pulp, using the Minolta CR-210 chromameter.

Leaf and fruit nutrient sampling and analyses

At harvest (mid-May), all matured leaves on treated fruiting laterals and subtending fruit were sampled for Ca and B analyses. Analytical procedures were the same as for Experiment 1.

Results

Experiment 1

Vegetative growth and yield

Calcium or B, alone or together, did not significantly affect tree size, growth or yield. In contrast, sugar apple inter-stock was highly effective in dwarfing `African Pride' trees, significantly ($P<0.05$) reducing tree canopy volume by about 70% and shoot extension in 1991-92 and 1992-93 by 13.6% and 38.6%, respectively (Figure 1). Irrespective of treatment, moderate dormant pruning in 1991 resulted in strong compensatory regrowth (139.7 cm) in the subsequent growing season. In contrast, as a consequence of lighter dormant pruning in 1992, shoot extension was reduced by 42% (81.2 cm). Trees exhibited 2 peaks in vegetative flushing (Figure 1). Flowering and fruit growth patterns were similar for all treatments (data not presented). Tree yields were similar for both harvest seasons with 30% lower tree fruit weights on sugar apple inter-stock compared with trees on their own roots (15 vs. 213 kg).

Seasonal patterns in leaf and fruit nutrient concentrations

Seasonal changes in leaf and fruit Ca concentrations are presented in Figure 2. Leaf and fruit Ca concentrations were significantly reduced ($P<0.05$) for high vigour trees on their own roots compared with those on inter-stock. Leaf Ca concentrations were not significantly increased by soil Ca applications although the trend was towards higher leaf Ca concentrations particularly near harvest. This was reflected in significantly higher ($P<0.05$) fruit Ca concentration during the harvest period in 1992 only (Figure 2). B alone, or in combination, did not significantly affect either leaf or fruit Ca concentrations. At harvest, sugar apple inter-stock increased fruit Ca concentration by about double and total Ca content per fruit by 80%. The overall trend was for fruit Ca concentrations to decline throughout the growing season and for total fruit Ca content to increase. In the 1992-93 season, a mid-season plateau in both leaf and fruit Ca concentration and content was probably a reflection of reduced fruit growth during Stage II of fruit development. Leaf Ca concentrations, in January, three months prior to harvest, were moderately correlated with fruit Ca concentrations (Figure 3); this relationship was weaker at other sampling times. Fruit Ca concentrations were also moderately correlated with fruit B concentrations (Figure 4).

Seasonal changes in leaf and fruit B concentrations are presented in Figure 5. For the 1992-93 season only, sugar apple inter-stock increased leaf but not fruit B concentrations, at the later sampling times. Soil applied B more than doubled leaf B concentrations but fruit B concentrations were either not affected (1992-93) or only slightly (25%) increased (1991-92). For 1991-92 only, fruit and leaf B concentrations were moderately correlated in January ($r^2=0.41$, $P<0.05$) but less so at other sampling dates. The overall trend was for fruit B concentrations to decline throughout the growing season and for total fruit B content to increase. For both seasons a small mid-season peak or plateau in fruit B content was observed, similar to Ca and probably a reflection of reduced fruit growth during Stage II of fruit development.

Leaf nutrient standards (mid-March sampling)

Irrespective of treatment, sugar apple inter-stock significantly reduced leaf N, P, K, Mn, Cu, Zn concentrations but increased leaf Ca compared with trees on their own roots (Table I). Soil-applied Ca did not significantly raise leaf Ca concentration but overall leaf Ca concentrations were 25% higher in 1993 compared with 1992. Soil applied B more than doubled leaf B concentrations in 1992, and increased leaf B concentration in 1993 by 51%. Irrespective of treatment, leaf Ca concentrations were in the upper end of the leaf nutrient standard range set for *Annona* spp. hybrids in subtropical Australia; in contrast, leaf B concentrations for trees not receiving B were at the lower end of the standard range (George *et al.*, 1998, unpublished data).

Fruit quality

For 1992 and 1993, sugar apple inter-stock increased skin thickness by 28 and 42% respectively (Table II). For 1992 only, Ca reduced skin thickness by 37%. For 1992 only, Ca and sugar apple inter-stock, alone, increased pulp recovery by about 5%. Sugar apple inter-stock improved fruit smoothness, slightly (Table II). Treatments did not significantly affect fruit symmetry, days to ripen or seed number per 100g of flesh.

Internal disorders - effects of season and harvest date

Irrespective of treatment, the severity of internal disorders at peak harvest (mid-May) was 5-7 times greater in the 1993 season compared with 1992 (fresh weight of woodiness, 1992, 40.8g; 1993, 8.7g; % `brown pulp', 1992, 37.5%; 1993, 5.2%). For the 1992 harvest season, irrespective of treatment, early-season fruit had about 6 times the severity of `brown pulp' than late season fruit (Figure 6). In contrast, in 1993, harvest date did not significantly ($P>0.05$) affect % `brown pulp', presumably due to the low severity of the disorder.

Internal disorders- effects of tree vigour

For the 1992 and 1993 harvest seasons, sugar apple inter-stock reduced fresh weight of `woodiness' per fruit at peak harvest by 32 and 63%, respectively (Table II) and for the 1992 harvest season only, % `brown pulp' of early-, mid- and late-season fruit by 47, 71 and 40%, respectively (Figure 6). Fresh weight of `woodiness' per fruit increased near linearly with shoot extension, (Figure 7), shoot growth increment from budbreak until one month after budbreak ($r^2=0.49$, $P<0.05$) and fresh weight of shoot attending the fruit ($r^2=0.77$, $P<0.05$).

Internal disorders- effects of Ca

For 1992 only, Ca significantly reduced fresh weight of 'woodiness' per fruit at peak harvest by 17% (Table II) and % 'brown pulp' of early-, mid-and late-season fruit by 35, 20 and 18%, respectively (Figure 6). Irrespective of treatment, fresh weight of 'woodiness' increased with decreasing fruit Ca concentrations (<0.10%) in January, three months prior to harvest, but this relationship was weaker at other sampling times (Figure 8).

Internal disorders- effects of B

For 1992 only, B reduced 'brown pulp' of early-, mid- and late-season fruit by 50, 23 and 20%, respectively (Figure 6). For both harvest seasons B did not significantly reduce 'woodiness' and severity of the disorder was not correlated with either leaf or fruit B concentrations.

Relationship between 'woodiness' and % brown pulp'

For both harvest seasons, fresh weight of 'woodiness' per fruit was moderately correlated with the percentage of total flesh weight affected with 'woodiness' (r^2=0.73, P<0.05) and with % 'brown pulp' (r^2=0.59, P<0.05).

Experiment 2

Irrespective of treatment, the fresh weight of 'woodiness' per fruit was very low (<10 g) compared with the 1992 harvest in Experiment 1 (Table III). Foliar applied Ca, alone, reduced fresh weight of 'woodiness' and % 'brown pulp' per fruit by 31 and 55%, respectively and when applied in combination with B, by 55 and 63%, respectively. Paclobutrazol did not significantly reduce (P<0.05) 'woodiness' but severity was less for treated shoots. Paclobutrazol prevented shoot growth immediately after application (control, 1.2 m; paclobutrazol treated, 32 cm). Leaf Ca but not fruit Ca concentrations were increased on paclobutrazol-treated shoots. Fruit Ca concentrations at harvest were significantly increased by foliar sprays of Ca applied at fruit set and one month later. In contrast, foliar sprays of B did not affect either leaf or fruit B concentrations at harvest. Paclobutrazol significantly increased fruit fresh weight by 24% and pulp recovery by 10.8% (Table III). Skin type, fruit symmetry and seed number per 100 g of flesh were not affected by treatments.

Discussion

These Experiments have shown that excessive tree and shoot vigour increase severity of internal disorders 'woodiness' and 'brown pulp' but external fruit quality is only slightly or not affected by treatments. Both 'woodiness' and 'brown pulp' appear to be closely related disorders with similar causes. It appears that the developing fruitlet does not compete satisfactorily with the leaves and shoots for assimilates, in particular for Ca and B. Early-season fruit appear to be the worst affected presumably because they develop from the earliest set flowers which compete concomitantly with the first strong vegetative growth flush. The severity of the 'internal disorders was markedly greater in 1991-92 season compared with 1992-93. This may have been due to the younger age of trees but, more likely, to greater compensatory regrowth induced by severe dormant pruning. Severity of 'woodiness' is greater under warmer growing conditions particularly because the first vegetative flush is more vigorous than in cooler growing regions (George *et al.*, 1997, unpublished data).

In these studies Ca and B concentrations and content per fruit decreased as fruit size and age increased. The Ca response is similar to that reported for avocado (Witney *et al.,* 1990). The decrease in Ca concentration is primarily a result of the continuing Ca accumulation to counteract the rapid increase in fruit size. For a period of six weeks after fruit set, fruit Ca concentrations were negatively correlated with leaf Ca (data not shown) but at later stages of fruit development were positively correlated. The data indicates that in the early stages of fruit development, fruit sink strength for Ca is weaker than for other tissues, presumably developing leaves and shoots. Competition between sinks is intensified when Ca^{++} in xylem is low and transpiration high. Tissues with greater evapo-transpiration will generally accumulate more Ca (Bangerth, 1979; Witney *et al.,* 1990a,b). In addition, the greater the number of immature leaves (which typically exhibit greater transpiration loss per unit leaf area) would result in greater transpiration flow to vegetative organs in vigorous trees (Clarkson, 1984). The developing leaves would also have a higher demand for structural Ca.

The lack of leaf nutrient response to soil-applied Ca may have been due to the initial slow movement of this fertiliser through the soil profile and to the existing high Ca leaf levels. In contrast, the leaf concentration response to applied B was rapid but increased leaf B concentrations did not equate to higher fruit B

concentrations. However, this apparent lack of response may be due to the our inability to detect very low, concentration differences between treatments, particularly near harvest (<2 0g g^{-1}) and the variability in the data.

The data indicates that it is necessary to control overall tree vigour before responses to Ca or B are likely. Post-set foliar applications of Ca were partially successful in controlling `woodiness' and `brown pulp' disorders. Batten and Vimpany (1992) also found responses, in one year out of two, to foliar applications of Ca when applied in conjunction with B. In contrast, soil applied Ca raised leaf and fruit Ca only slightly. Fruit Ca concentrations need to be maintained at >0.15% and leaf Ca >1.6%. The current leaf nutrients standards for *Annona* spp. hybrids appear to be set too low.

Seasonal shoot extension growth be restricted to less than 60 cm to keep `woodiness' to an acceptable level of <10g per fruit. The critical period when growth needs to be reduced is during the first major vegetative growth flush. Current observations indicate that tipping all shoots on the tree reduces internal disorders and improves fruit size (George *et al.*, 1998, unpublished data). On a whole tree basis, control of shoot and tree vigour also can be achieved through the use of dwarfing inter-stocks of sugar apple and through the application of either foliar or trunk-injected paclobutrazol (George *et al.*, 1997, unpublished data). Paclobutrazol foliarly-applied post-fruit set, when new shoot were about 30 cm long, was shown to increase fruit size. In the long term, dwarfing rootstocks of cherimoya (*Annona cherimola*) may be the most efficient method of controlling `woodiness' and improving fruit quality. For other tree crops, vigour may also be controlled using regulated deficit irrigation, tip pruning and manipulating N status so as to reduce the strength of the summer vegetative flush. Further studies are needed to evaluate all these factors, either singly, or in combination.

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Table. ***Effects of inter-stock, Ca and B on fruit quality of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means for three trees per treatment.***

Treatment	Level	Fruit quality parameter: % pulp recovery		Skin thickness (mm)		Skin type[1]		Fresh weight of woodiness per fruit (g)		% 'brown pulp'	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Inter-stock	+	83.1	67.1	1.22	0.58	-	2.8	24.3	4.2	26.7	3.9
	-	78.8	65.9	0.95	0.41	-	2.5	35.5	11.3	43.3	7.5
Ca	+	82.3	66.1	0.84	0.51	-	2.7	27.1	8.1	28.8	6.6
	-	79.6	66.8	1.33	0.48	-	2.6	32.6	7.6	41.2	4.8
B	+	80.7	67.7	1.14	0.58	-	2.7	25.8	8.1	25.6	6.3
	-	81.1	65.3	1.04	0.41	-	2.6	34.0	7.4	44.4	5.1
LSD (P =0.05)											
Inter-stock		1.7	n.s.	0.21	0.09		n.s.	6.5	3.7	8.6	1.1
Ca		1.7	n.s.	0.21	n.s.		n.s.	6.5	n.s.	8.6	n.s.
B		n.s.	n.s.	n.s.	0.09		n.s.	n.s.	n.s.	8.6	n.s.
Inter-stock X Ca		n.s.	n.s.	0.30	n.s.		n.s.	n.s.	n.s.	n.s.	n.s.
Inter-stock X B		n.s.	n.s.	n.s.	0.12		0.34	n.s.	n.s.	n.s.	n.s.
Ca X B		2.4	n.s.	0.30	n.s.		0.34	n.s.	n.s.	n.s.	n.s.

[1] 1=lumpy, 5=smooth

Table ***Effects of foliar applied paclobutrazol, Ca and B on fruit quality variables of the Annona spp. hybrid cv. African Pride in subtropical Australia. Data are the means for 10 trees per treatment.***

Treatment	Level	Average fruit weight (g)	% pulp recovery	Skin thickness (mm)	Fresh weight of woodiness per fruit (g)	% 'brown pulp'	Leaf Ca (%)	Fruit Ca (%)	Leaf B (mg g^{-1})	Fruit B (mg g^{-1})
Paclobutrazol	+	494.2	66.6	1.19	7.17	15.3	1.51	0.08	146	9.1
	-	399.5	60.1	1.21	7.94	13.3	1.39	0.09	135	9.6
Ca	+	445.3	62.4	1.32	6.16	9.4	1.44	0.09	142	9.1
	-	448.5	64.3	1.07	8.95	19.2	1.46	0.07	139	9.6
B	+	409.0	62.7	1.14	7.14	12.3	1.43	0.09	149	10.7
	-	484.7	63.9	1.25	7.97	16.3	1.47	0.08	132	8.7
LSD (P =0.05)										
Paclobutrazol		80.5	5.1	n.s.	n.s.	n.s.	0.09	n.s.	n.s.	n.s.
Ca		n.s.	n.s.	0.16	2.1	7.9	n.s.	0.009	n.s.	n.s.
B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Paclobutrazol X Ca		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Paclobutrazol X B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca X B		n.s.	n.s.	n.s.	4.2	11.2	n.s.	n.s.	n.s.	n.s.

Captions for figures

Fig.ure 1 Effects of season and pruning severity on flushing patterns of the *Annona* spp. hybrid cv. African Pride at Nambour, Queensland. Pooled data for Ca and B treatments only.

Figure. 2 Seasonal changes in fruit and leaf Ca concentrations and fruit Ca content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means of 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure. 3 The relationship between leaf and fruit Ca concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for all treatments means for the 1992 and 1993 harvest seasons.

Figure. 4 The relationship between fruit Ca and B concentrations of the *Annona* spp. hybrid cv. African Pride in January, 3 months prior to harvest. Pooled data for the 1992 and 1993 harvest seasons.

Figure. 5 Seasonal changes in fruit and leaf B concentrations and fruit B content of the *Annona* spp. hybrid cv. African Pride over 2 seasons (1991-92, 1992-93). Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure. 6. Effects of harvest date on % 'brown pulp' of the *Annona* spp. hybrid cv. African Pride in the 1992 harvest season. Data are the means for 3 trees per treatment. Vertical bars represent LSDs (P=0.05).

Figure.7 The relationship between shoot extension recorded in March, 1 month prior to harvest, and fresh weight of 'woodiness'. Pooled data for 1991-92 and 1992-93 seasons.

Figure. 8 The relationship between fruit Ca concentration in January, 3 months prior to harvest, and fresh weight of 'woodiness' of the *Annona* spp. hybrid African Pride. Pooled data for the 1991-92 and 1992-93 seasons.

Table 1 ***Effects of tree vigour, Ca and B on leaf nutrient concentrations of the Annona spp. hybrid cultivar `African Pride' in subtropical Australia. Data are the means for three trees per treatment.***

	Major nutrients											Minor nutrients									
	Level	N (%)		P (%)		K (%)		Ca (%)		Mg (%)		Cu (mg g^{-1})		Zn (mg g^{-1})		B (mg g^{-1})		Fe (mg g^{-1})		Mn (mg g^{-1})	
		1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993	1992	1993
Inter-stock	+	2.18	1.19	0.15	0.11	1.84	1.64	1.63	2.16	0.25	0.27	10.1	6.8	19.8	34.4	98.3	103.1	72.4	63.8	281	335
	-	2.55	1.36	0.17	0.12	3.29	2.95	1.45	1.70	0.23	0.26	13.8	9.1	22.9	37.9	92.3	85.1	77.8	58.5	364	419
Ca	+	2.39	1.11	0.16	0.12	2.61	2.28	1.58	1.86	0.24	0.27	11.9	7.8	20.9	37.1	101.4	91.0	79.6	55.3	361	392
	-	2.34	1.16	0.16	0.12	2.52	2.32	1.50	2.00	0.23	0.28	11.9	8.1	21.8	35.2	89.1	97.9	70.7	66.9	283	363
B	+	2.39	1.28	0.15	0.11	2.67	2.56	1.53	1.84	0.23	0 .25	11.9	8.0	21.5	31.8	135.3	113.8	79.2	60.0	351	367
	-	2.34	1.27	0.16	0.12	2.46	2.04	1.55	2.03	0.24	0.29	11.9	7.9	21.2	40.5	55.3	75.2	71.1	62.2	294	386
LSD (P=0.05)																					
Inter-stock		0.13	0.11	0.006	n.s.	0.21	0.33	0.11	0.17	n.s.	n.s.	1.08	0.8	2.2	n.s.	n.s.	13.4	n.s.	n.s.	71	n.s.
Ca		n.s.	0.11	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
B		n.s.	n.s.	0.006	n.s.	0.21	0.33	n.s.	0.17	n.s.	n.s.	n.s.	n.s.	n.s.	4.9	24.4	13.4	n.s.	n.s	n.s.	n.s.
Inter-stock X Ca		n.s.	n.s.	n.s.	0.015	n.s.	n.s.	n.s.	0.24	n.s.	n.s.	1.5	n.s.	n.s.	n.s.	n.s.	18.9	n.s.	n.s.	n.s.	n.s.
Inter-stock X B		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	0.29	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	6.9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Ca X B		n.s.	n.s.	0.009	n.s.	0.30	0.46	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	13.8	n.s.	n.s.	n.s.

3.2 Post-harvest research

SEASONAL CHANGES AFFECT CHILLING SENSITIVITY IN ATEMOYA (ANNONA CHERIMOLA MILL.X A. SQUAMOSA L.)

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Abstract

Post-harvest chilling injuries resulting from 0, 0.6, 1, 2 and 3 days at 0, 4, 7, and 10 °C (chilling temperatures) were recorded throughout the three-month harvesting season of atemoya ('custard apple'). After subsequently ripening at 22°C, chilling injuries as skin blackening were quantified in relation to the temperature and harvest date. Fruit developed unacceptable chilling injury (>30% skin area blackened) if stored for longer than 15 hrs at 0 or 4°C, or 48 hours at 7°C. Skin blackening at 10°C was never more than 20%. Internal quality was unaffected. Skin blackening from identical treatments at the eight different harvest dates showed major variation, typically from 4-50% skin area blackened. Because of such variation, precise recommendations on short-term sub-optimal storage durations are difficult, but may possibly be predictable. Injury data over the season were correlated to field temperature, rainfall, and humidity at harvest. The intensity of chilling injury correlated best to relative humidity at harvest ($R^2 = 0.73$; $p = 0.01$).

Keywords: Chill injury, harvest date, refrigeration, skin blackening, atemoya, *Annona cherimola* African Pride, custard apple.

Introduction

Atemoya are highly perishable without refrigeration and even under good temperature management the market life is limited to 7-12 days as refrigerated storage below 10-13°C induces chilling injury (CI) (Brown and Scott, 1985), with chilling injury manifesting itself predominantly as skin blackening. CI develops within 1-4 days of exposure if fruit is re-warmed after chilling (Brown and Scott, 1984; Wills *et al*, 1984; Batten,1990). Atemoya are commonly transported and stored in cold rooms which are below the recommended 10°C storage temperature, usually 3-7°C, largely due to the unavailability of suitable coldrooms. While skin blackening can result from a wide range of other stresses such as mechanical injury (for example, from poor packaging), fruit immaturity, or fruit 'sweating' within plastic wraps, the effects of short term storage under sub-optimal refrigeration is unknown. The contribution of field factors is also unclear. We report here on CI in atemoya from each of eight harvests over three months of the one season following storage at a range of sub-optimal (chill-inducing) storage temperatures for different durations. Field temperature, rainfall and relative humidity data were subsequently recovered to correlate the observed variations in CI.

Materials and methods

Harvest and temperature treatments

Commencing with the earliest commercially mature fruit (mid April) and for eight consecutive harvests approximately one week apart, 100-120 atemoya cv African Pride (436 ±135g) were harvested from 10 yr old trees, at Nambour (27°S), transported the same day to the Hamilton laboratory (90 km south), weighed, and visually assessed for initial % skin blackening (blemish-free fruit = 0, completely black fruit =100). Care was taken at all stages to avoid any mechanical damage to the fruit. Eighty fruits of minimum initial skin blemish (typically 4-6% black) were selected at each harvest and four fruit randomly allocated into 20 time x temperature treatments (0, 4, 7, 10 and 22°C) for 15 hrs, 1, 2, and 3 days. Removed fruits were stored at 22°C (60-70%RH) until eating soft, and then visually assessed for skin blackening. Initially, all fruits were cut and examined for internal disorders, but after finding no internal chilling injury symptoms, only random fruits were cut for verification. Freshly harvested Atemoya normally show some natural skin blackening indistinguishable from CI. This incidence of natural skin blackening was recorded at harvest (approximately 3-6%) but subtracted from the subsequent recorded skin injury to give the % skin area attributable to CI.

Project jointly funded by HRDC (FR425) and RIRDC (DAQ- 167A), and Australian custard apple growers

3.2 Post-harvest research

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Project jointly funded by HRDC (FR425) and RIRDC (DAQ- 167A), and Australian custard apple growers

Statistical analysis

Regression coefficients were generated using SigmaPlot for Windows v 4 (SPSS Inc) and analyses of variance were determined using Genstat for Windows v 5: 3.2 (Lawes Agricultural Trust). Meteorological data was retrieved from the standard meteorological records (twice daily, 9 and 3 pm) within 100 m of the trees. Rainfall data was complete, but wet and dry bulb temperatures were not recorded on weekends or public holidays.

Results

Chilling injury development

Chilling injury commenced either at points of abrasion or as irregularly shaped areas on the epidermis as localised, small, intense black spots or patches. Any natural skin blemishes were exacerbated by the exposure to chill-inducing conditions and served as foci for development. With increased exposure to CI inducing conditions, the affected areas expanded and darkened until, in the severest cases, the complete skin became intense black with a resinous texture. We found that skin blackening is caused by secretion of an extra-cellular resin, which darkens and hardens with time rather than intra-cellular polyphenols, the more common for of browning in fruits and vegetables. (unpublished data). Two distinct types of chilling injury occurred: (i) spots or irregular patches of various intensity developed following exposure. Injury development usually intensified as the fruit ripened but in cases of the severest injury (100%) the resinous hardened skin never softened although the flesh did ripen; and (ii) occasionally, much of the skin surface could develop a dusty-looking superficial bronze hue (we term this injury "bronzing"). The bronzing didn't further develop with time, but changed after 2-3 days to the more commonly-observed black discolouration as the fruit ripened.

Variation of injury within season

During the eight week season fruit stored at 0, 4 and 7°C developed CI of widely variable severity with much lesser variations from 10 and 22°C. (Figures, 1(a) and 3). Possible climatic causes of the wide variation of CI at 0, 4 and 7°C, such as changes in rainfall, field temperature and humidity (Figs. 1 a,b,c.) do not consistently correlate to the CI recorded. (Relative humidity was calculated from the recorded wet and dry bulb temperatures; Wilhelm, 1976). However, relative humidity at the day of harvest was found to be significantly correlated ($p<0.01$) to the skin injury at 7°C. (Fig. 4; $R = 0.85$; Adj $R^2 = 0.62$; standard error of estimate = 6.69; $n = 8$).
Correlations between CI and either the field temperatures or rainfalls over the previous 12, 24 or 48 hours were not significant.
The CI data for 0, 4 and 7°C together showed similar but not matching patterns of injury variation over the season.
The average level of natural skin blackening in the hard green fruits at each harvest was 5-11% of the total skin area over the season.
In the control samples (without cool storage, ripened at 22°C), skin blackening at eating soft varied over the season from 6 to 25%.
Chilling injury was not significantly affected by fruit size ($p <0.01$)

Storage temperature and skin blackening

For fruits stored at 0 and 4°C skin-blackening intensity increased with storage time, until by three days storage, about 50% of the skin became black at ripe (Figure 2). Injury severity at 0°C and 4°C were not significantly different. At 4 and 7°C, injury did not significantly increase during one to two days exposure (ANOVA data not presented). Fruit could be acceptably stored 1- 1.8 days longer at 7 then at 0 or 4°C. At 10°C, injury never rose above 20% at ripe.

Discussion

While Atemoya (cv African Pride) were acceptably stored for up to 2-3 days at 0-4°C early in the season, these same conditions resulted in unacceptable injury. By comparison, ripe Cavendish banana will show chilling injury symptoms following 18-20 hours at 10°C (Marriott, 1980), a similar sensitivity to African Pride. Hence the commercial post-harvest temperature management of African

Pride should be similar to ripe bananas. Commercially bananas are commonly not refrigerated but cleared

The small difference, if any, in skin blackening following storage at 10°C (Fig. 3) compared to 22°C (Fig.1a) is consistent with the current industry recommendation (Anon, 1995) that 10°C is an acceptable marketing temperature. While consumer dissatisfaction with skin blackened fruit would depend on price and concomitant eating quality, consumers would accept 30% skin blackening as the limit of acceptability (Smith, unpublished data).

The two different types of injury (bronzing and blackening) is of interest as bronzing does not appear to have been previously reported. While bronzing disappears after 1-2 days to be replaced by the more common blackening, bronzing has been seen occasionally in wholesale markets, and its aetiology and significance are now better understood.

Atemoyas produced in tropical areas of Queensland are commonly held for 1-3 days at 10°C following harvest before packaging and transport under refrigeration. Transport conditions are commonly 12-24 hrs at 7°C, depending upon the destined market. Hence by the time the fruit arrive at the more distant market, the above data suggests they are already chilled to their acceptable limit, and further refrigeration would induce the latent injury to reach unacceptable levels.

The variation in skin blackening in the non-refrigerated control fruits (22°C) over the season (Fig. 1a) is most interesting, varying from a low of 6% to a high of 25% (and virtually paralleling the 10°C storage data). Furthermore, this high level of injury (25%) occurred in fruit that had been treated carefully (in our experiments). The injury from commercial handling practices is likely to be even higher. Hence, the African Pride variety has the potential to develop moderate-severe skin blackening from harvesting at different times of the season.

The variation of injury in fruit stored for 2 and 3 days at 0, 4 and 7°C (Figure 1a) shows a different pattern of variation (of injury severity with harvest date) compared to fruit at 10°C (Fig. 1a) and 22°C (Fig. 3). The injury in fruit stored at 10 and 22°C varies little from harvest to harvest, yet it does steadily increase to a peak and decline. The different patterns (between 0,4,7 and 10, 22°C) strongly suggest two different field-factor aetiologies of injury present. With respect to the 10, 22°C pattern, the decreasing field temperature (Fig. 1c) does suggest an inverse relationship to skin blackness. The injury increases as the temperature decreases, and subsequently, the injury decreases at harvest day 48 where there is a slight increase in temperature. This data is obviously tenuous but does suggest a link that requires further investigation.

With respect to the injury following 0, 4, or 7°C storage, the substantial seasonal variation confirms similar casual observations from two previous years. An inspection of the available temperature data (Fig 1c) does not suggest any relationship with temperature: While the data shows a major rainfall immediately preceding a substantial increase in skin injury on days 13-14 (Fig. 1 b), a decrease in injury occurred following a small fall on day 29, and an inexplicable increase of injury followed a prolonged dry (days 30-40). Furthermore, substantial rainfall (25mm) the day before the final harvest did not result in an increase in injury, but a decrease. Hence, any positive relationship between chilling sensitivity at 0, 4, 7°C and rainfall alone appears tenuous. More complex links may exist, perhaps including other parameters.

In contrast, the relative humidity may affect chilling sensitivity (Fig. 4). Relative humidity in the field is extremely variable. The relative humidity data used for the correlation are the recorded values from one specific time of the day (9.00am). However, a significant relationship was found, although it too is tenuous, with only eight datum points, one value for each harvest. More data is required to claim a definitive conclusion on the role of humidity, and the relationship presented here is an initial result. Interestingly, humidity has been linked to chilling sensitivity in bananas, but in this fruit chilling injury was *lessened* by high post-harvest humidity (Marriott, 1980).

In this review, a range of treatments to reduce chilling injury in bananas was reported including 100%RH and using safflower oil. In future atemoya research, controlled environmental conditions may be used, to better resolve the problem of changing sensitivity over a season and to point to ways of reducing the chilling sensitivity of this variety. Also, ameliorating agents such as safflower oil could be also investigated.

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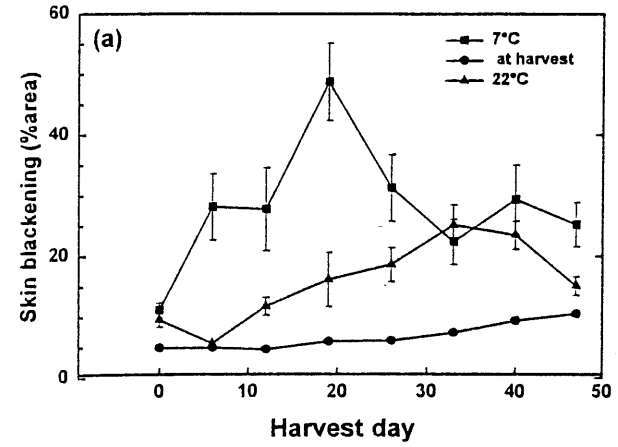

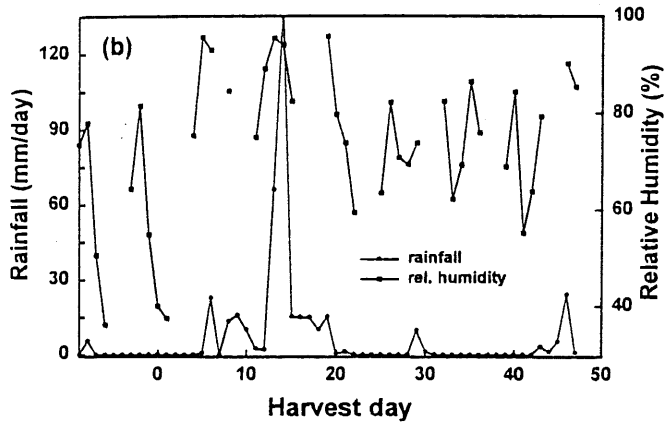

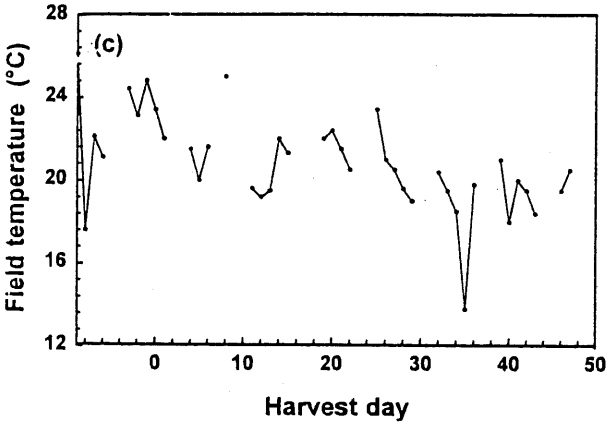

Figures 1 (a,b,c). The seasonal variation of skin blackening (0-100% skin area) of Queensland grown atemoya cv. African Pride at three postharvest stages, aligned with the corresponding daily rainfall and field humidity and the temperature spanning the harvest period. **(a)** Skin blackening shown for: unripe fruit at harvest; fruit stored 2.5 days at 7°C and then 22°C until eating soft; and control fruit, stored and ripened at 22°C. Humidity and temperature measurements recorded at 9.00am daily.

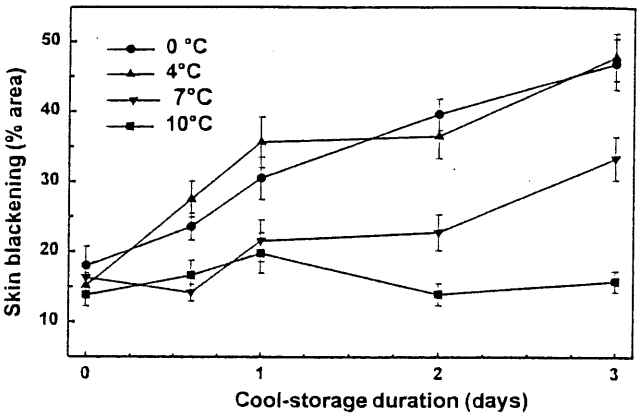

Figure 2. The effect of four cool storage temperatures (0, 4, 7, 10°C) for up to three days, on the severity of skin blackening in Queensland grown atemoya (cv. African Pride) averaged over eight harvests of the one season. Each point is the mean of 32 fruits, assessed at eating soft.

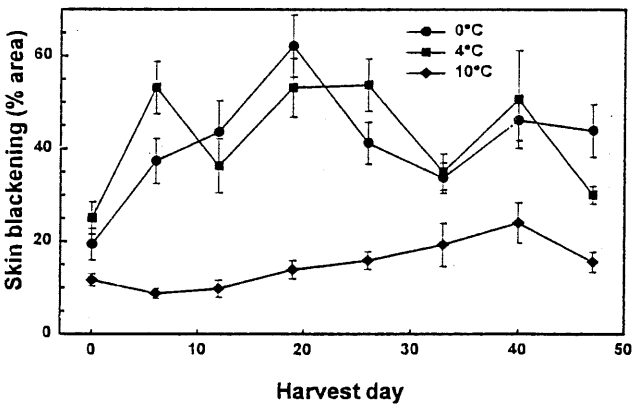

Figure 3. The variation of the skin blackening (0-100%) in Queensland grown atemoya occurring during one season in frut stored at 0, 4 or 10°C. Means of eight fruits stored two days and then removed to 22°C until eating soft.

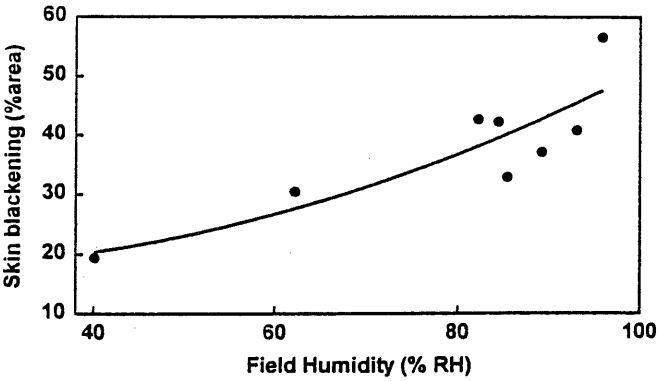

Figure 4. The relationship between skin blackening at 7°C and the field humidity at 9.00am on day of harvest in Queensland grown atemoya cv African Pride. Means of eight fruits stored two days and then removed to 22°C until eating soft.

Socks and tissues compared: a bigger picture is involved.

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Summary of results

The usefulness of styrofoam socks as carton packaging was compared to paper tissues as protection in fruit sent to Sydney June 1997, using both African Pride and Pinks Mammoth fruit.

- In terms of absolute % black, the difference between using socks or tissues was not great, about 1-2 % decrease results from using socks. In relative terms, for high quality near-unblemished fruit, the 2% black increase represents nearly a 100% increase in blemish which down grades the carton. The actual $ effect is complex and needs to be calculated of one or more seasons. The results are in contrast to earlier laboratory work where much more marked differences were shown, and the consequences are being considered within a much broader perspective. This is because the results are only a small part of the marketing scene (see 2. below) where a whole range of factors interact and impinge on each other. A collation of results is shown in Table 1.

- A whole raft of impinging issues are now seen to be involved, organisational as well as packaging and economics, and these issues cannot be resolved in a simple fashion. It's little use spending time and effort assessing individual factors as there are many involved and all inter-relate. The whole marketing system needs to be analysed and assessed as an interactive whole, rather than just a sum of individual components. As a direct consequence, a program of domestic market research has been developed and will commence in late 1998 involving wholesalers, retailers and consumers.

- It should be noted that, to properly compare different packaging procedures and materials, large numbers of fruit need to be examined over several trials, to enable an adequate comparison of all the many factors involved. These factors include the variability of initial blemish within the cartons, as well as the effect of different fruit sizes, and the fruit from different growers, and production areas and market destinations. Such an exercise would be highly labour intensive, costly, and exhausting for the staff involved as several hundreds of fruit would need to be individually closely assessed for damage, and repacked, all without too much disruption to the normal marketing process and price structuring. That exercise was beyond our resources so we chose a smaller trial involving three farms, each with quite different procedures and fruit quality, and using two varieties from two of the farms. From each farm we had three cartons of each styro-socks and tissue paper, and each carton with a different count size. Fruits of comparable blemish were packed in each treatment.

Project jointly funded by HRDC (FR425) and RIRDC (DAQ- 167A), and Australian custard apple growers

Table. ***Packaging Trial Sydney, Out-Turn Flemington Market, 5th June 1997***

Pinks Mammoth, using three different count size cartons:
Farm A

Packaging Treatment	**Absolute difference** (% black) compared to tissues	**Relative difference** (% of tissue value) ([diff % / tissue %] x 100)	**Average Out-turn % black**	Count-size per carton	Gross Weight with lid (kg)	Carton number
SOCKS	*0.5% black decrease*	*8 % relative decrease*	**4.6**	14	6.6	1
TISSUES			**5.1**	14	6.6	4
SOCKS	*0.6% black decrease*	*9% relative decrease*	**4.8**	11	6.5	2
TISSUES			**5.4**	11	7.0	5
SOCKS	*No difference*	*No difference*	**6.3**	9	7.3	3
TISSUES			**6.3**	9	6.9	6
Farm B						
SOCKS	*1.8% black decrease*	*95% relative decrease*	**1.9**	14		7
TISSUES			**3.7**	14		10
SOCKS	*1.5% black decrease*	*60% relative decrease*	**2.5**	11		8
TISSUES			**4.0**	12		11
SOCKS	*1.8% black decrease*	*60 % relative decrease*	**3.0**	9		9
TISSUES			**4.8**	9		12
Farm C						
SOCKS	*0.5% black decrease*	*7% relative decrease*	**8.6**	10	7.0	13
TISSUES			**8.1**	10	7.5	18
SOCKS	*0.3% black increase*	*No difference*	**9.1**	9	7.2	14
TISSUES			**8.8**	8	7.9	17
SOCKS	*0.6% black decrease*	*6% relative decrease*	**9.1**	7	8.3	15
TISSUES			**9.7**	6	8.4	16

African Pride, using three different count size cartons:
(Farm A only)

SOCKS	*No difference*	*No difference*	**4.3**	14	6.5	19
TISSUES			**4.2**	14	6.3	22
SOCKS	*No difference*	*No difference*	**4.4**	12	6.8	20
TISSUES			**4.9**	12	6.6	23
SOCKS	*0.5% decrease*	*7% relative decrease*	**4.8**	11	7.2	21
TISSUES			**5.5**	11	7.7	24

Acknowledgments

We thank Dick and Joan Austin, Lyn and Rick Bronson, and John Madden for their assistance with these trials.

3.3 Example of Sections from Agrilink Kit

The following key issues are dealt with in the Agrilink information kit.

KEY ISSUES

This section contains more detailed information on some of the important decision making areas and information needs for custard apples.. The information provided on each issue is not designed to be a complete coverage of the issue but instead lists the key points that need to be known and understood. Where additional information may be useful, we refer you to other parts of the kit. Symbols on the left of the page will help you make these links.

Where appropriate, decision flow charts are provided to help facilitate the best management decision. The flow chart is followed by information and recording tools to assist in the decision making process.

- Keys to making a profit
- Business management
- Markets
- Understanding the custard apple tree
- Selecting varieties
- Rootstocks
- Propagation
- Nutrition
- Irrigation
- Training and pruning
- Pest and disease management
- Pollination
- Post-harvest handling and storage
- Packaging

The first three sections of the Custard Apple Agrilink Information Kit follow. They are included as examples of the key issues section of the kit. Photographs and figures are not included.

Section 1. Keys to making a profit

For most growers, the primary aim of their farming business is to make a profit. The secondary aim is to maximise that profit. This section provides an overview of the key elements in achieving maximum profits.

- The simple profit equation
- Maximising returns
- Minimising costs
- The key to profit

The simple profit equation

In very simple terms, the profit from any enterprise can be expressed as:

Profit = Returns - costs

It follows then that maximum profits come from **maximising returns** and **minimising costs**. Let us now consider each of these and their potential impact on profit.

Maximising returns

The two factors that affect returns received from the custard apple enterprise are:

- price received for the product, and
- volume of product sold.

Price received

Three factors affect the price received for custard apples. These are:
- the quality of the fruit on arrival in the market
- the actual market that the fruit is sent to, and
- the long term reputation of the product.

Quality

Quality of custard apples in the marketplace is essentially determined by five factors:

- **Size.** The best prices are paid for large fruit of count 13 or larger per single layer tray pack.
- **Cleanliness and appearance.** The best prices are paid for fruit that is free from any marks or blemishes that affect appearance. Fruit must also appear to be characteristic of the variety when grown under normal conditions.
- **Flavour.** Sweeter flavoured fruit has a tendency to achieve higher prices and repeat sales.
- **Shape.** The best prices are paid for fruit that are well-shaped and typical of the variety (Figure 1).
- **Soundness and shelf life.** The best prices are paid for fruit that is sound (free from cuts and punctures) and stored properly in order to maximise shelf life.

Figure. ***Ideal market shape for custard apples (left: African Pride; right: Pinks Mammoth)***

These quality characteristics are influenced by a number of pre and post-harvest management practices, some more significantly than others. The impact of these management practices on quality is summarised in Table 1.

Table. ***Impact of pre and post harvest management practices on quality of custard apple fruit***

Management practice	**Impact on quality (5 = high impact; 1 = low impact; - = not applicable)**				
	Size	**Cleanliness**	**Flavour**	**Shape**	**Soundness**
Variety	5	3	5	5	-
Rootstock	3	1	-	1	-
Pre-harvest					
Nutrition	3	1	2	3	3
Irrigation	3	1	1	3	3
Pruning and training	5	5	-	1	1
Pest/disease management	2	5	-	1	5
Pollination	4	3	-	5	-
Post-harvest					
Storage	-	3	2	-	4
Packaging	-	5	-	-	-
Post-harvest handling	-	5	-	-	5
Transport	-	4	-	-	-

Market destination

Different markets have different price opportunities for the various product types. The key here is to make sure all market options are well researched in order to match the type of product you can produce (environment and management system) to the best market opportunity. This includes determining the potential competitors and when their product hits the market.

Reputation

A product often receives a higher price because of its past reputation. A product that has been consistent in quality and supply, year after year, is usually bought first and often at the highest price. The development of a good reputation is now very dependent on the implementation of quality management throughout your entire production and marketing system.

Volume sold

The other way of maximising returns is to maximise the volume of fruit produced. The main factors affecting the volume of fruit harvested and marketed are listed in Table 2.

Table. ***Impact of management factors on volume of fruit produced***

Management factor	Impact on volume of fruit produced (5 = high impact; 1 = low impact)
Variety x age	5
Rootstock	1
Pollination	4
Nutrition	2
Irrigation	2
Pruning and training	2
Pests and diseases	1

Obviously, variety by age has the biggest impact. For example, whereas Pinks Mammoth trees of 10 years and older on 12 x 12 m spacings, have been recorded producing up to 200 kg of fruit, they have also been known to produce little or no fruit at all. Typical average yields per tree are shown in Table 3.

Table. ***Average yield per tree (kg)***

Age	3	4	5	6	7	8	9	10
African Pride	10	35	60	70	70	80	80	80
Pinks Mammoth	-	4	15	25	50	70	80	100

Minimising costs

To minimise costs, it is first necessary to examine where the major costs occur. Typical costs are shown in Table 4.

Table. ***Costs of growing and marketing custard apples***

Cost area	Cost per tray ($)
Growing costs	
• fertiliser, chemicals, mulch, irrigation	1.20
• labour for growing and pruning	1.30
• hand pollination	1.10
Picking and packing costs	
• picking labour	1.10
• packing labour	1.40
• packaging (carton and liner etc)	3.25
Marketing costs	
• freight (domestic)	0.80
• levies, inspection and insurance	0.59
• commission	1.40
Total costs per tray	***12.14***

The figures show that 70% of the costs are involved in the picking, packing and marketing processes. As it is often difficult to significantly reduce these costs without affecting quality, cost minimisation often has little impact on overall profitability.

The key to profit

In summary, the key to maximising profitability appears to lie in maximising returns. And the most effective way of maximising returns appears to be improving the price obtained. This can be best demonstrated by the following analysis.

Take a typical mature custard apple orchard of 4 hectare of Pinks Mammoth trees and 4 hectare of African Pride trees planted at a density of 144 trees/hectare. Assume the Pinks Mammoth trees yield 13 trays/tree for a market price of $28/tray, and the African Pride trees yield 9 trays/tree for a market price of $16/tray. This produces a gross margin (income less variable costs) of $119 280 for the 8 hectare orchard. Let us now compare the impact on profitability of improving price compared to increasing production and minimising costs.

Scenario 1: Increase price	Say the price received is increased by $1/tray. Assuming an appropriate quality management system is in place, no additional outlay is required. The only loss is the extra commission on the additional sales – equivalent to $1267. The gross margin increases by $11 405 to $130 685 (an increase of 10%). **Comment**: reasonably achievable provided market quality and reputation credentials are well established.

Scenario 2: Increase productio n	Assume an additional $500/ha is spent in improving production. Increased production also incurs additional harvesting and marketing costs for the extra production - equivalent to $11.21/tray. To achieve a similar increase in gross margin to Scenario 1, production would need to be increased by well over 1 tray per tree. This means an overall extra outlay of approximately $18 000. **Comment**: increase of over 1 tray/tree difficult to achieve without better varieties and production technology. Also requires significant additional outlays to achieve.

Scenario 3: Minimise costs	To achieve a similar increase in gross margin to Scenario 1, costs would need to be reduced by close to $1/tray. **Comment**: reduction of $1/tray difficult to achieve because most of the costs are in harvesting and marketing and these costs are difficult to reduce because of their potential impact on quality. As growing costs make up a relatively small part of total production costs, a reduction of $1/tray would be difficult to find.

Section 2. Business management

Growing custard apples should be looked on as a business, not a lifestyle. So in effect, becoming a grower of custard apples is entering a new business, or at least adding a new enterprise to an existing business. Seeing the decision to enter a new industry as a *business* decision helps to keep the important issues in perspective. It means that thinking and planning about finance and marketing is elevated to more or less equal importance with thinking and planning about production. The obvious rationale behind this is that no matter how good the product, the business will only be successful if there are markets that can be profitably accessed.

Treating a custard apple enterprise as a business involves looking at the development of business and marketing plans, recording of farm information, financial management, marketing and control (implementation of quality management systems).

- Business and marketing plans
- Recording of farm information
- Financial management
- Marketing
- Control (quality management systems)
-

Business and market planning

All businesses need to have some type of plan in order to be successful. A plan helps to focus on what is the core business and what the business hopes to achieve. A business plan is generally drawn up for a 5 to 10 year period and is a living document. This means it must be reviewed and modified annually to ensure objectives are met.
A typical business plan includes the following sections:
1. Mission
2. Goals and objectives
3. Situation analysis – SWOT (Strengths, Weaknesses, Opportunities, Threats)
4. Action plan/implementation
5. Budget
6. Control plan

In addition to the business plan, marketing and financial plans may also need to be developed. A typical marketing plan includes the following sections:

1.0 Executive summary
2.0 Current marketing situation
  2.1 Domestic
  2.2 Export
  2.3 Competitive situation
3.0 Opportunity and issue analysis
  3.1 SWOT analysis (Strengths, Weaknesses, Opportunities, Threats
  3.2 Issue generation and prioritisation
4.0 Objectives
  4.1 Financial
  4.2 Marketing
5.0 Marketing strategy
  5.1 Pricing
  5.2 Product description and lines
  5.3 Positioning and segments
  5.4 Distribution strategy
  5.5 Sales
  5.6 Advertising and promotion strategy
  5.7 Research and development
6.0 Action program and control
7.0 Budget

Recording of farm information

Accurate and ordered recording of information on the farm is essential for good business management. Types of information that should be recorded include:

- pre-harvest factors (pest and disease monitoring records, spray program, labour inputs, pollination details, leaf and soil analysis, soil moisture monitoring, fertiliser and irrigation schedules);
- post-harvest factors (labour, picking, packouts, handling and storage logs),
- quality management records and financial details.

This information can be ideally recorded on a computer where information can be quickly accessed and compared, or it can be recorded in books or on forms and accurately filed in a filing cabinet. A lot of this information is used for the development of business and marketing plans and for checking to see if plan objectives have been met. This information is used to compare performance from year to year and in the establishment of best farm practice.

Besides their use in business and marketing plans, farm recording information has other significant benefits:

- Meet the needs of an approved supplier program and ICA protocols.
- Record of operations for Workplace Health and Safety audits.
- Record of operations for environmental audits that may be required in the future under Farmcare, Landcare and Catchment Management schemes.
-

Available options for developing farm block recording systems include:

- available proprietary farm recording software;
- recording systems captured in quality management manuals;
- your own recording system. Consultants and extension officers may be able to provide assistance in setting this up.

Examples of recording sheets are shown in Figure 2.

Figure. ***Examples of farm recording sheets***

Financial management

Accurate recording of financial inputs and outputs ensures that the true financial situation of the business is known at all times. This is important for decision making. Accurate recording of inputs and outputs means including all costs such as family labour, loan interest and depreciation.
There are many financial recording packages available on the market (mainly for computer use). Quicken® is probably the one most widely used by horticultural producers.

Economic analyses of custard apple enterprises

As a guide in setting up your own financial recording program, two different economic analyses are provided here.
The first is a study in the Mareeba-Dimbulah irrigation area on the Atherton Tableland, which analyses a model or hypothetical farm of five hectares of Pinks Mammoth. It provides the following details:

- variable costs at full production (includes growing, harvesting and marketing costs);
- fixed costs for a 5 hectare orchard (includes an allowance for permanent labour and the farmer's own labour, administration costs, electricity, depreciation);
- the capital costs for a 5 hectare orchard;
- an annual whole orchard profit and loss statement at orchard maturity. This includes a gross margin (the difference between the gross income and the variable or operating costs);
- a discounted cash flow analysis to determine the annual cost of production and profitability. This is a technique used widely to analyse profitability for long term tree crops where costs and benefits occur over a long period. The technique reduces the time stream of costs and benefits to an equivalent amount of today's dollars. That amount is known as the present value of the future stream of costs and benefits. The present values are calculated using compound interest and a specified discount rate (in this case 8%). The Net Present Value (NPV) is the difference between the present value of the benefits and the present value of the costs.

The second analysis is a study of a farm in the Sunshine Coast area growing both African Pride and Pinks Mammoth . It provides the following details:

- variable costs;
- fixed costs;
- capital costs;
- an annual whole orchard profit and loss statement for each year of the expected 20 year lifespan of the orchard. This includes a gross margin (the difference between the gross income and the variable or operating costs);
- a discounted cumulative net cash flow, shown on the profit and loss statement, which has been calculated using a discount rate of 4%. This shows the projected net cash flow in constant terms, taking into account the lost 'opportunity cost' of the money invested in the orchard

Economics of growing custard apples — Atherton Tableland

Information courtesy of Andrew Hinton, Economist, DPI, Mareeba.
Figures used in the analysis were current as of November 1996.

Assumptions

Here are the main assumptions used in this analysis:

- The hypothetical orchard consists of a 5 hectare, 720-tree custard apple farm (the 5 hectare includes room for buildings).
- Trees are planted with 8 m between rows and 8 m between trees (144 trees/hectare).
- The orchard is considered to be at steady state full production in the eighth year.
- Mature tree yields are considered to be 12 trays/tree. Fruit is marketed in Singapore (75%) and Brisbane (25%). Average prices are $40/tray in Singapore and $20/tray in Brisbane, giving a weighted average price of $35 per tray, less commission, freight, levies and insurance.
- Capital equipment is bought at the start of the operation and is purchased new, except for a tractor and utility which are bought second-hand.
- Machinery operation includes fuel and oil costs only.
- No permanent labour is used. Casual labour is employed for pruning, thinning, harvesting and packing to supplement family labour of the owners.
- The orchard is well managed.
- A project life of 20 years is used with a real discount rate of 8% to calculate the net present value (NPV).

Variable costs at full production

Item	No./yr	Unit	Units/hectare	$/unit	$/hectare
Machinery operation					
Applying defoliant	1	hour	1.5	12	18.00
Spreading fertiliser	4	hour	1	12	48.00
Pest/disease spraying	10	hour	1	12	120.00
Slashing	10	hour	2	8	160.00
Pruning and thinning					
Pruning	1	hour	54	11	594.00
Fertiliser					
Urea	1	kg	352.8	0.54	190.51
Muriate of potash	1	kg	237.6	0.45	106.92
Superphosphate	1	kg	24.48	0.38	9.30
Dolomite (spread)	0.5	kg	1200	0.10	60.00
Defoliant (urea and Ethrel)	1	L	1440	0.17	244.80
Weed control and mulching					
Glyphosate	3	L	0.576	9.75	16.85
Paraquat	2	L	0.72	9.57	13.78
Mulch (barley straw)	1	bale	144	8.00	1152.00
Mulching labour	1	hr	36	11.00	396.00
Irrigation					
Water costs and pumping	–	ML	7	47.68	333.76
Pest/disease control					
Endosulfan	3	L	1.008	7.65	23.13
Kocide	3	L	1.44	6.33	27.35
Dimethoate	1	L	0.432	8.20	3.54
Lorsban - yeast solution	5	L	14.4	0.38	27.36
Lorsban - butt drench	1	L	2.59	17.82	46.19
Hand pollination					
Labour	1	hr	144	11.00	1 584
Harvesting and marketing					
Labour (picking, grading, cleaning and packing)	1	tray	1728	3.21	5546.88
Packaging	1	tray	1728	3.25	5616.00
Freight: Brisbane	1	tray	432	3.75	1620.00
Freight: Singapore (inc. Road freight to Cairns)	1	tray	1296	7.25	9396.00
Levies	1	tray	1728	0.59	1019.52
Agent's commission (12%)	1	tray	1728	1.38	2384.64
TOTAL VARIABLE COSTS					**30758.53**

Fixed costs for the 5 hectare orchard

Item	Amount ($/year)
Allowance for family labour	25 000
Fuel and oil for utility and farm motorbike	1 000
Electricity for equipment, lighting and cold room	1 000
Repairs and maintenance	5 000
Administration	5 000
Depreciation	22 233
TOTAL FIXED COSTS	**59 233**

Capital costs for the 5 hectare orchard

Item	Year/s of purchase	Cost ($)
Tractor (45 kW)*	0	30 000
Utility*	0,5	10 000
Slasher	0	3 500
Trailer	0	2 500
Fertiliser spreader	0	3 500
Air blast sprayer	0	10 000
Spray outfit for weeds (PTO)	0	1 000
Knapsack sprayers	0	2 000
Irrigation equipment & water allocation	0	14 300
Harvesting & pruning equipment	2/3/6	1 080
Cold room	2	25 000
Machinery shed & packing shed	0	25 000
Shed machinery	0	5 000
Grading equipment	2	5 000
Land ($8 000/hectare) - includes 2 hectare for infrastructure and buffer zones	0	56 000
Land preparation & planting	0	3996
Trees (grafted) including freight	0	7200
TOTAL CAPITAL COSTS		**205 076**

- - purchased second-hand

Profit and loss statement for the 5 hectare orchard (NPV)

Item	$/farm/yr	$/tray
GROSS INCOME	**181 259**	**35.00**
Variable costs		
Machinery operation	1 582	0.31
Pruning and training	2 530	0.49
Fertiliser, defoliation and mulch	8 032	1.55
Insect & disease control	523	0.10
Irrigation	1 458	0.28
Weed control	146	0.03
Hand pollination	6 481	1.25
Harvesting and marketing	76 638	14.80
TOTAL VARIABLE COSTS	**97 390**	**18.81**
Fixed costs		
Allowance — family labour	26 273	5.07
Administration	5 000	0.97
Repairs and maintenance	5 000	0.97
Fuel and oil	1 000	0.19
Electricity	1 000	0.19
Capital costs	22 233	4.29
TOTAL FIXED COSTS	**60 506**	**11.68**
TOTAL COSTS	**157 896**	**30.49**
Return to management	**23 363**	**4.51***
GROSS MARGIN	**83 869**	
GROSS MARGIN/hectare	**16 774**	
GROSS MARGIN/tray		**16.19**

* Based on a discounted yield of 5179 trays for the orchard

Discounted cash flow analysis for the 5hectare orchard

Year	Yield (trays per year)	Receipts	Operating costs	Fixed costs	Capital costs	Annual cash flow	Discounted annual cash flow	Discounted accumulative cash flow
0				12500	174296	-186796	-186796	-186796
1	0	0	3640	37000	0	-40640	-37630	-224426
2	0	0	7415	37000	5220	-49635	-42555	-266980
3	720	25200	28789	37000	25520	-66109	-52480	-319461
4	1440	50400	42589	37000	120	-29301	-21544	-341004
5	2880	100800	65386	37000	8000	-9586	-6525	-347529
6	5760	201600	108399	37000	160	56041	35314	-312215
7	6480	226800	120881	37000	0	68919	40213	-272002
8	8640	302400	153730	37000	640	111030	59986	-212015
9	8640	302400	153730	37000	0	111670	55863	-156152
10	8640	302400	153730	37000	56910	54760	25365	-130788
11	8640	302400	153730	37000	0	111670	47894	-82894
12	8640	302400	153730	37000	4720	106950	42471	-40423
13	8640	302400	153730	37000	520	111150	40870	447
14	8640	302400	153730	37000	160	111510	37965	38412
15	8640	302400	153730	37000	8000	103670	32681	71093
16	8640	302400	153730	37000	120	111550	32560	103654
17	8640	302400	153730	37000	0	111670	30181	133835
18	8640	302400	153730	37000	680	110990	27775	161610
19	8640	302400	153730	37000	0	111670	25875	187485
20	8640	302400	153730	37000	-83550	195220	41884	229370
NPV	50847	1779632	956200	375772	218291	229369		
Av/ farm/ year	5179	181259	97390	38273	22233	23363		
Av/ tray		35.00	18.81	7.39	4.29	4.51		

The analysis shows a peak overdraft of $347 529 which occurs in the fifth year and annual expenses exceed annual income until the sixth year. The payback period, or the time required for accumulated income to exceed accumulated expenses, is thirteen years. Put another way, it would take thirteen years to recover the initial project outlay.

Reference for further reading and research: *Growing custard apples in the Mareeba–Dimbulah Irrigation Area — an economic perspective* by Andrew Hinton, *in Custard Apple — Choices Seminar* (1994), Department of Primary Industries, Mareeba.

Economics of growing custard apples - Sunshine Coast
Information courtesy of Julie Miller, Economist, QDPI Nambour.
Figures used in the analysis were current as of July 1998.

Assumptions:

- 10 hectare of land purchased at a cost of $100,000;
- 4 hectare planted to Hilary White variety, and 4 hectare to African Pride variety;
- mature tree yield of Hilary White is expected to be 12.85 trays per tree, with 58% being sold on the export market and 42% on the domestic market at an average price of $28.13 per tray;
- mature tree yield of African Pride is expected to be 9.15 trays per tree, with 3% being sold on the export market and 97% on the domestic market at an average price of $16.06 per tray;
- discount rate of 4% used (this is the 1998 bank rate less the inflation rate);
- machinery costs include fuel, oil and maintenance;
- all assets were sold at the end of the 20 year period;
- payback period represents a discounted payback period;
- trees planted at a density of 144 trees per hectare, with a life of 20 years;
- steady state production by year 9;
- casual labour required to help with thinning, picking, packing, and hand pollination;

- allowance for family labour of $25,000 annually;
- capital equipment is purchased throughout the period, and all is bought new, except for the utility which is purchased second-hand;
- the orchard is well managed.

Variable costs at full production (year 9)

Item	$/unit	$/hectare/yr
Machinery and operations		
Grass/weed spraying		46.35
Pest/disease spraying		78.82
Slashing/mowing		82.46
Trailer		26
Miscellaneous tractor operations		9.02
Fertiliser spreader		15.2
Dipping machine		3.13
workshop equipment		5.38
Equipment shed		3.13
Packing shed		27.81
Coolroom		40.35
Pneumatic secateurs		0.5
Pruning equipment		1.72
Utility		18.75
Pruning and thinning		
Pruning		0
Thinning		266
Fertiliser		
Urea	0.54	190.512
Muriate of potash	0.46	109.296
Superphosphate (every 2nd year)	0.38	9.3024
Defoliant (urea and Ethrel)	0.17	244.8
Weed control and mulching		
Roundup	23.5	11.75
Paraquat	12.78	25.56
Mulch (round bales)	8	1152
Tests		
Soil tests	90	90
Leaf tests	78	78
Irrigation		
Water costs and pumping		200
Pest/disease control		
Endosulfan	18	54.36
Kocide	7.2	103.68
Dimethoate	11	4.73
Lorsban	5	38.9
yeast	9.12	393.984
Hand pollination		

Item	$/unit	$/hectare/yr
Labour (casual)		577
Harvesting and marketing		
Labour (picking, grading, cleaning and packing)	2.87	4546.08
Dipping chemicals	0.0004	0.6336
Packaging	3.25	5148
Freight and commission	4.5	7128
Levies	0.59	934.56
TOTAL VARIABLE COSTS		**21665.768**

Fixed costs for the 8 hectare orchard

Item	Amount ($/year)
Allowance for family labour	25000
Repairs and maintenance	1030
Administration	5170
TOTAL FIXED COSTS	**31200**

Capital costs for the 8 hectare orchard

Item	Year/s of purchase	Cost ($/orchard)
Tractor (45 kw)	0	45000
Utility	0,5,10,15	10000
Slasher/mower	0	3500
Trailer	0	2500
Air blast sprayer	0	10000
Spray outfit for weeds	0	1000
Fertiliser spreader	0	3500
Irrigation equipment	0	18000
Picking bags	0	810
Pneumatic secateurs	1,6,11,16	400
Stackable tubs	3	6000
Pruning equipment	0,5,10,15	1100
Cold room	2	20000
Packing shed	2	25000
Equipment shed	0	10000
Shed machinery	0	4000
Land ($100,000 for 10hectare without house)	0	100000
Land preparation, planting	0	10216
Trees (grafted) including freight	0	15552
Roads	0	500
Boundary fencing	0	3600
Benches	2	500
Hole digger	0	1700
Dipping machine	2	5000
TOTAL CAPITAL COSTS		**297878**

The analysis shows that the peak overdraft, $511 768, occurs in the fifth year and annual expenses exceed annual income until the sixth year. The payback period, or the time required for accumulated income to exceed accumulated expenses, is 16 years. Put another way , it would take 16 years to recover the initial project outlay.

Marketing

Involvement in marketing will probably make the biggest difference to your success as a grower. Understanding what marketing is all about provides you with a base on which to plan how the product will be produced.

Marketing is not:

- selling
- waving your product goodbye at the farm gate in the belief that someone else will look after your best interests.

Marketing is:

- putting yourself in the consumer's shoes and profitably meeting their needs within the limitations of your resources.

Successful marketing therefore implies knowing who and where your consumers are, and what they want. It also implies knowing at what level of return you are making a profit. Sadly, Australian horticulture provides many examples of growers who have no idea of how or if their product is meeting consumers' needs. In addition, the financial performance of many horticultural businesses indicates that there is also a lack of understanding about how cost of production is linked to marketing success. Many growers blame this state of affairs on the 'marketing system', but this is virtually admitting that growers are somehow outside the marketing system. Nothing could be further from the truth.
Here are some ideas as to how a grower of custard apples can get onto the 'inside' of marketing.

Think as if you were a consumer

What does a consumer of custard apples look for? Is it price, quality, size, colour, firmness, or a combination of these factors? If a grower cannot make even a reasonable guess at the answer to this question, how can they set targets for production? For example, there is a decision to be made about growing large fruit at a lower overall yield but a higher individual price, or smaller fruit with higher overall yield and lower individual prices. There is also a decision about how hard to grade out blemished fruit. Grading too hard means fewer trays of very high quality; grading too lightly means more trays of lower quality.

Another question - at what point are market returns the best? How can a grower make these management decisions in the absence of information about what consumers want and how much they are prepared to pay?

Important sources of knowledge and information about what the market wants are:

- Market research studies. These are generally conducted by industry and research organisations and are published in special reports. Grower organisations, the Australian Horticultural Corporation (AHC) and the Horticultural Research & Development Corporation (HRDC) are sources of this information.

- Marketers who are in close contact with buyers and consumers. For the domestic market, specialist custard apple wholesalers in the major metropolitan markets are an invaluable source of detailed market knowledge. Market authorities in each of the major markets can provide some advice on custard apple wholesalers. For the export market, custard apple exporters are an equivalent source of expert market knowledge.

Know the marketing chain for your fruit

This means identifying all the steps and all the people that link your fruit at the farm gate to particular groups of consumers. One chain might include a transport company, an unloading company, a

wholesale merchant, a supermarket buyer, a grocery section manager and consumers from a particular region of a city. Knowing how the chain works is important because you actually choose some of its players, and each of the players in the chain make decisions about your product that collectively influence its marketing performance.

Visit the markets in which your fruit is wholesaled and retailed

There is no substitute for actually seeing how your fruit is performing in its markets. But just looking at the fruit is not enough. You should not only be monitoring the fruit's physical and financial performance, but also assessing the performance of the people in whose hands you have placed these marketing functions. Remember that they are in essence working for you, but they will happily ignore this fact if you are not interested in them.

Actively seek market information

Not only visit the market but actively seek information about each consignment of fruit. Ask your agent to send you a report to indicate if the fruit is acceptable. No news is not necessarily good news. Often feedback does not get back to growers unless they set up a system to receive this information. This can be easily done through the use of fax machines or electronic mail. Out turn inspections by independent assessors is also a useful way to get information about your product.

Join a marketing collective (where available)

Small growers on their own not only have little clout in the market, but also miss out on sharing information with other growers. If you're considering marketing on your own so that you can closely guard information that you don't want others to have, think again. Chances are that while you're busily guarding this information, the rest of the industry will pass you by because no one will want to share their information with you. Joining a group of like-minded growers for the purpose of marketing is a very positive step towards overcoming the dual problem of lack of marketing clout and lack of information. The 'Jadefruit' custard apple marketing group is an excellent example of collective marketing where growers take responsibility for their marketing outcomes.

Control (quality management)

All business and marketing plans need a control process in order to be monitored, evaluated and modified. Quality management systems fulfil this role of control as they are a method of developing a flow chart of the business with a series of checks for critical operations to ensure that they are carried out and done correctly.

Quality is built into every aspect of management

Quality is a term used to describe the fitness for purpose of a product. It implies a predictable degree of uniformity and dependability. Some people view quality management as the planning and control of all the activities that influence product quality. This means that managers are constantly engaged in quality management, perhaps even without being totally aware of it.
In the past, the suitability of the product for its intended market was determined by what is called 'end point inspection' - inspection at the market level. This system has a number of important flaws:

- It is expensive to reject product at this late point in its cycle.
- It is difficult to predict product performance during the rest of the marketing process when its past history is unknown.
- It is often driven more by tradition than by the real needs of consumers.

Modern quality management aims to build quality right through the production and marketing process so that there is minimal need for rejections late in the marketing chain. This system also provides consumers with documented evidence that the product they are buying will meet their needs. Quality management, therefore, may be seen as a marketing tool to achieve better prices and repeat sales, as well as a productivity improvement tool to identify problem areas, prevent mistakes and reduce wastage. It also helps access markets with quarantine and other barriers to normal entry and promotes greater trust and cooperation between growers.

There are five core principles of quality management.

- The customer defines quality, not the grower.
- Decisions are based on facts, not feelings.
- Problems are identified at the earliest possible point, not at the end point.
- Quality management has to be planned, organised and managed - it does not happen by itself.
- Everyone in the business, including the workers, is responsible for quality management, not just the managers or owners of the business.

In the future, every grower will be engaged with quality management. Rather than waiting until formal quality management systems are mandatory in horticultural production systems, there is a broad process you can follow to get started now.

Implementing a quality management system

- Learn about quality management. Read as much as you can about it and attend training courses where these are available. The Australian Horticultural Corporation has some excellent information and training resources on the subject.
- Develop a plan that sets out the standards you want to achieve.
- Share your plan with any staff (managers, pickers, packers) and ask for feedback. Involve staff at all stages from here on.
- Critically analyse your current system for its strengths and weaknesses in meeting the standards. This may involve preparing a flow chart of operations, a hazard analysis and an organisational chart.
- Develop new or modified operations to provide the quality standards you are seeking. These could involve field operations such as selection of varieties, management of nutrition, watering, pest and disease control, picking etc., as well as packing, handling and refrigeration operations after harvest. Document this in a quality management manual.
- Train your staff in the quality management system and display your quality standards on posters for all to see.
- Set up a recording system to carefully record and document all field operations so you can see what you have done should problems arise.
- Appoint a quality auditor (or be that person yourself) to audit your quality management system and make sure it is working. Randomly select a sample of each grade of each consignment for inspection. Inspect about one carton in every 25 cartons. Check this sample of fruit for all facets of quality. Record these objective assessments. Keep a sample of fruit aside in the cool room so you can check its marketing characteristics in a few days time when your consignment will be in the hands of the retailer and consumer. Ask your wholesaler to provide feedback on the quality of your fruit.

Remember that it is not easy to put a quality management system together. You will need commitment, good planning, staff involvement, and simple and effective procedures including well-defined and objective quality standards.

Formal quality management systems remove the guesswork and are recommended.

Formal quality management systems

Quality management systems formalise the knowledge, experience and methods developed previously into a simple documented process. Several quality management systems exist and they vary in complexity and purpose. Here are the main ones relevant to horticulture.

- **ISO 9002** - This is an internationally recognised system and is the one on which most others are based. It consists of 20 elements covering all aspects of producing products and servicing customers. It is expensive to establish, costing $5 000 to $20 000 to implement and about $3 000 to $5 000 in annual auditing and registration fees.

- **HACCP 9000** (Hazard Analysis and Critical Control Point) - This is a relatively new food industry system combining elements of risk management and quality management. It involves a process of identifying risks or hazards and applying specific control measures, primarily to prevent food from being unsafe to eat. It adds about 20% to the cost of the ISO 9002.

- **SQF 2000** (Safe Quality Food) - This system was developed by Agriculture Western Australia for small businesses in the food industry. It consists of six elements incorporating aspects of ISO 9002 and includes the HACCP system. It is recognised in Australia, but not internationally at this stage. It costs upwards of about $2 500 to implement and about $500 in annual auditing costs.

- **AHQ** (Australian Horticultural Quality) - This is an accredited training package but not an auditable quality management system. It is generally used as a foundation for growers to upgrade to SQF 2000 or ISO 9002.

- **Woolworths Vendor Quality Management Standard** - This is a HACCP-based food safety and quality requirement for Woolworths suppliers who do not have SQF 2000 or ISO 9002. The company is first targeting its major direct suppliers but intends to eventually demand it as a minimum standard for all suppliers.

- **AQIS Certification Assurance (CA)** - This is a scheme established by AQIS as an alternative to end point inspection. It is a voluntary arrangement between AQIS and exporting businesses to replace the inspection function with set procedures and regular audits.

- **Interstate Certification Assurance (ICA)** - This system has been developed by state departments as an alternative to inspection of procedures for fruit fly disinfestation and other pest and disease problems before interstate shipment. It consists of set procedures and annual audits.

Recent trends in quality management

The demand for quality management systems at the farm and packhouse levels has grown significantly in the last year. The major catalyst for this has been the growing demand from consumers and retailers for safety standards for all food, including fruit. These standards include minimal chemical residues, lack of food contamination organisms, freedom from foreign matter and so on. This builds on top of the demand for other quality parameters such as good shelf life, colour, flavour and so on. In addition, retailers are moving towards demanding individual produce labels containing PLU's (product look up numbers).

At present, all major retailers are putting in place systems where produce will only be purchased from suppliers that can guarantee food safety standards under a HACCP based food safety quality management system. These systems are likely to come into operation for fresh produce during 1999. As most fruit is currently supplied to retailers through produce wholesalers (agents and merchants in the major metropolitan produce markets), these wholesalers will have to meet the HACCP requirements. In turn, growers that supply them will be required to meet certain food safety standards and become approved suppliers. It is likely that in time, other quality issues and PLU's will also be required as conditions of approved supplier status. Without approved supplier status, growers will be left to supply the non-supermarket sector of the market that is now minor and decreasing year by year. Note that growers who wish to supply major retailers direct, will need to implement an on-farm HACCP based quality management system such as SQF 2000.

Section 3. Selecting varieties

Success in commercial custard apple production depends to a large extent on the correct selection of varieties. This is not always easy as there are a number of varieties to choose from and many differing opinions on which varieties are best. This section will help you understand the different varieties and their advantages and disadvantages. Here is what you need to know.

- The custard apple family
- Current varieties and their main characteristics
- Selecting varieties
- New variety development

The custard apple family

The Annonaceae family, of which custard apple is a member, includes 120 genera containing over 2000 species. One of these genera, Annona, includes the atemoya, cherimoya, sweetsop, ilama; soursop, bullocks heart and pond (or sugar) apple. Species of another genus, Rollinia, are of minor importance.

In Australia, the atemoya is commonly known under the general name 'custard apple'. The common atemoya varieties grown in Australia are thought to be crosses or hybrids between two species, the cherimoya (*Annona cherimola*) and the sweetsop (*Annona squamosa*). As such, atemoya is not a true species. Varieties grown commercially are sometimes referred to as cultivars, to distinguish them from non-commercial varieties. Recent evaluation by the Australian industry of both overseas and domestic markets has shown high consumer acceptability of atemoya, and several varieties are gaining greater prominence in world markets.

Current varieties and their main characteristics

Atemoya hybrids (hybrids between *Annona cherimola* and *Annona squamosa)*

Pinks Mammoth
History: The first commercial variety grown in Queensland. Introduced into Queensland from Guyana in 1899. Quickly became a highly desired fruit in the Brisbane markets. Now largely superseded because of production problems.
Major benefits: Excellent flavour, regarded by many as the Australian industry standard.
Major problems*: Shy and irregular bearing behaviour. Poor natural fruit shape from poor pollination – makes fruit difficult to pack. Low yields. Soft and fragile when fully ripe, with a short shelf life.*

Hillary White
History: Originated as a bud sport (mutated shoot) on a Pinks Mammoth tree at Hillary White's orchard in the Redland Bay district of Queensland in the mid 1980's. Has superseded Pinks Mammoth as the most important variety grown in Queensland.
Major benefits: More precocious and consistent bearer than Pinks Mammoth. Fruit more attractive, smoother in appearance and of reasonable shape, making them easier to pack than Pinks Mammoth. Good flavour.
Major problems: Soft and fragile when ripe, with a relatively short shelf life. Will require some hand-pollination in most seasons.

African Pride
History: Selected in South Africa in the early 1950's and introduced into Australia in about 1959. Today still the leading variety grown in Australia, but being rapidly replaced by Hillary White and other newer selections.
Major benefits: Precocious and regular bearer, which does not require hand pollination. Yields in excess of 25 t/ha possible. Remains firm fleshed when fully ripe, with good shelf life.
Major problems: Can be very seedy with a marginal flesh:seed ratio. Sometimes poor flavour. Fruit often small unless thinned.

Palethorpe

History: Seedling of African Pride, selected in the early 1980's at Glasshouse Mountains, Queensland. Initially appeared promising but was not accepted by industry due to its high susceptibility to fruit fly and long juvenile period. However, needs revaluation and may prove to be suitable if top-worked to mature trees, thus reducing the juvenile period. Worthy of limited trial.
Major benefits: Excellent external fruit quality.
Major problems: Marginal flesh to seed ratio. Very susceptible to fruit fly. Long juvenile period before production commences.

Gefner

History: The leading cultivar grown in semi-tropical regions of the world. Selected in Israel in the 1960's. In semi-tropical regions, has produced fruit of reasonable quality.
Major benefits: Precocious and heavy bearing.
Major problems: In the subtropics, fruit are too small, exhibit poor flesh-seed ratios and are susceptible to splitting during periods of low temperatures.

Martin

History: Promising variety which was produced from a cross between Bullock's Heart (a local atemoya cultivar, not to be confused with the species *A. reticulata* which is also sometimes called Bullock's Heart) and Hillary White. Was the only selection made from 600 atemoya crosses grown at Bob Martin's orchard at Glasshouse Mountains, Queensland. Worthy of limited trial.
Major benefits: Vigorous tree which flowers profusely. Exhibits a higher level of natural set than Hillary White.
Major problems: In subtropical Queensland, if not hand-pollinated, trees produce 40% large, highly symmetrically shaped fruit and about 60% small, poorly shaped fruit. For this reason, it is recommended that growers undertake some hand-pollination to ensure adequate set of the larger size fruit. Smaller, deformed fruit should be removed at the completion of the fruit set period, normally January in south-east Queensland. Under wet summer conditions, fruit are susceptible to Diplodia fruit rot.

Maroochy Gold

History: Selection made at the Maroochy Horticultural Research Station at Nambour in 1995. Cross between the red-skinned sugar apple (*Annona squamosa*) and Hillary White. Worthy of limited trial
Main benefits: Limited testing to date indicates that this variety can set good crops naturally without the need for hand pollination. Fruit are highly symmetrical in shape with very smooth skin. Flesh to seed ratio is moderate, but better than African Pride. Very good flavour and texture.
Major problems: None to date.

Maroochy Red

History: Cross between the red-skinned sugar apple (*Annona squamosa*) and Hillary White. Has a dark red skin and a slight pinkish tinge in the flesh. Worthy of limited trial.
Major benefits: Limited testing to date indicates that this variety can set good crops naturally without the need for hand pollination. Fruit are moderately symmetrical in shape, slighted pointed with very smooth skin. Flesh to seed ratio is moderate, but better than African Pride. Excellent flavour and texture.
Major problems: None to date.

Maroochy No 2

History: Selection made at the Maroochy Horticultural Research Station at Nambour in 1995. Cross between the red-skinned sugar apple (*Annona squamosa*) and Hillary White. Worthy of limited trial.
Major benefits: Limited testing to date indicates that this variety can set good crops naturally without the need for hand pollination. Fruit are highly symmetrical in shape with very smooth skin. Flesh to seed ratio is moderate, but better than African Pride. Very good flavour and texture. Very similar to Maroochy Gold.

Cherimoya - *Annona cherimola* (originates from the cool dry highlands of Ecuador and Peru)

Fino de Jete

***History and description*:** A Spanish variety with fingerprint, U-shaped depressions on the skin. Best growth occurs in a temperature range between 7 to 18°C mean minimum and 15 to 28°C mean maximum. The tree grows up to 10 m high with typically round leaves which have a velvety lower surface. The fruit is heart shaped and flavour is more acid than the atemoya. Because it has a lower temperature requirement for growth than atemoya, it breaks dormancy earlier in the spring and fruit may mature as early as February in south east Queensland

Fruit quality characteristics

A summary of the fruit quality characteristics of the important commercial varieties is shown in Table 6.

Table. ***Fruit quality characteristics of the most important Annona spp. hybrid varieties in subtropical Australia***

Variety	Average weight (g)	Seed no per 100 g of flesh	Fruit symmetry *	Skin type*	Flavour *	Text ure*
Pink's Mammoth	520	4.7	5	T	9	7
Hillary White	440	7.2	3	T	9	8
African Pride	380	10.1	2	I	7	7
Martin	480	7	2	T	8	8
Marooch y Gold	420	8.5	1	S	8	8
Palethorp e	420	10.9	2	T	8	7
Gefner	350	14.5	1	T	6	5

***Codes:**

- Fruit symmetry: 1 = highly symmetrical, 5 = poorly symmetrical
- Skin type: T = tuberculate (lumpy/lobed), I = impressa (indented), S = smooth
- Flavour and texture are rated on a hedonic scale, where 1 = dislike extremely, and 9 = highly acceptable

Selecting varieties

The selection of varieties is based on two main factors:

- climatic conditions
- target market.

Each variety has a set of climatic conditions for which it is best suited, and fruit with characteristics sought after by particular markets.

Climate

Figure. Decision flow chart for selecting varieties for different climatic conditions

Target market

Both varieties have vocal supporters but different preferences have developed in different markets in response to varying local factors.

The Asian export market has a preference for Pinks Mammoth because of its slightly sweeter flavour. Where fruit of Pinks Mammoth are in short supply, small amounts of African Pride have been exported to Asian markets. Asian consumers appear to clearly distinguish African Pride from Pinks Mammoth and align it more with their locally grown sugar apple. Although it has a similar appearance, it is larger in size, less seedy and has a better flavour. Nonetheless, price may suffer as a result. African Pride may better suit western tastes and needs investigation in European and Canadian markets.

New variety breeding program

The custard apple industry in Australia is currently based on three main atemoya varieties only - African Pride, Pinks Mammoth and Hillary White. In Florida and Hawaii, the variety Gefner is the only one grown commercially.
All currently grown commercial varieties have limitations. However, breeding and selection programs in Australia and Florida are starting to yield promising results. In Australia, two new varieties have been named in recent years and more will follow. Some of these will replace existing varieties.
In the breeding programs, characteristics being sought in new varieties are summarised in Table 7.

Table. ***Characteristics sought in selection of superior atemoya varieties***

Characteristic	Desired type
Tree morphology	
• Degree of apical dominance	low
• Number of fruit bearing laterals	high
Yield capacity	
• Percentage of flowers set	3-5%
• Precocity of bearing	2-3 years after planting
• Max. yield at full maturity	>60 kg
Fruit quality	
Number of seeds per 100 g of flesh	<10
Fruit size range	300-600 g
Skin thickness	moderate to resist bruising
Skin colour	attractive - green, yellow, red
Fruit shape	round, highly symmetrical
Skin type	smooth or mildly tuberculate or impressa
Skin russetting	none
Flavour	sweet, highly acceptable
Flesh texture	smooth, creamy
Flesh colour	creamy white to pinkish tinge
Post harvest	
Storage life	>10 days
Storage characteristics	little or no skin discolouration