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Water and Nutrient Relations of Parasitic Quandong and Acacia Host Species.

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Foreword

Quandong (*Santalum acuminatum*) and acacia seed are two of the most important native food crops currently being developed in Australia. This project was designed to quantify water and nutrient relations, and leaf gas-exchange in quandong growing on a range of acacia host species. The aim was to provide producers with important information that will aid in the selection of suitable hosts and the development of efficient irrigation and fertilisation strategies for quandong production in arid and semi-arid environments, including regions with salinity problems. The information obtained will also be useful to acacia-seed producers. The report provides information on the best hosts to use in quandong production systems based on information obtained about parasite and host water-use strategies, nutrient dynamics, and parasite growth and fruiting.

This project was funded from RIRDC Core Funds which are provided by the Australian Government.

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Peter O'Brien
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Ben Lethbridge provided considerable assistance with collection of field data, subsequent data analysis and writing up of the report.

David Hollingworth also contributed significantly to the collection of field data.

Abbreviations

AALBG	Australian Arid Lands Botanic Garden
ANOVA	Analysis of Variance
AQIA	Australian Quandong Industry Association
A. arg	*Acacia argyrophylla*
A. bru	*Acacia brumalis*
A. cal	*Acacia calamifolia*
A. hak	*Acacia hakeoides*
A. hem	*Acacia hemiteles*
A. mur	*Acacia murrayana*
A. riv	*Acacia rivalis*
A. vic	*Acacia victoriae*
Fv/Fm	Dark adapted photosynthetic efficiency
MPa	Mega Pascals (units for water potential)
ψ	Plant water potential

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Executive Summary

What the report is about and who the report is targeted at

This project quantified water and nutrient relations in the parasitic tree, quandong (*Santalum acuminatum*), growing on a range of acacia host species in a semi-arid region at Port Augusta in South Australia. The information collected will aid quandong producers in the selection of suitable hosts and the development of efficient irrigation and fertilisation strategies for quandong production in arid and semi-arid environments, including regions with salinity problems. We also gathered data on the host species, to ensure that our results will also be useful to acacia-seed producers.

Aims and Objectives

Specific objectives were:

1. To quantify water potential gradients between *S. acuminatum* and a range of acacia host species.
2. To characterise the water relations of *S. acuminatum* and acacia hosts in response to seasonal changes in water availability.
3. To measure rates of growth and fruit production in *S. acuminatum* on a range of acacia hosts.
4. To determine chemical composition of host and parasite foliage.

Methods

The research was conducted at the Australian Arid Lands Botanic Garden (AALBG) at Port Augusta, South Australia in an established acacia/quandong plot. The plot consists of eight acacia species (*Acacia murrayana, A. victoriae, A. rivalis, A. brumalis, A. calamifolia, A. hakeoides, A. hemiteles* and *A. argyrophylla*), which have been growing in combination with *S. acuminatum* (quandong) since April 2001. Growth (stem diameter & tree height) and fruiting were measured for parasites on eight acacia hosts in both 2005 and 2006. Water potential and photosynthetic efficiency of *A. victoriae, A. argyrophylla, A. hemiteles* and *A. hakeoides* and their attached quandongs (5 replicate pairs) were measured in winter 2005 and summer 2006. The results of this work were analysed and outlined in this report.

Results and Recommendations

Despite having the highest water potentials and the greatest proportion of parasites with fruit, *A. victoriae* is not an ideal host for sustained parasite growth and fruit production because the parasite has such a negative impact on host growth. In the plot we used, many *A. victoriae* with parasites had died, and presumably the parasites had subsequently attached to other hosts in the vicinity. One recommendation from this study would be that *A. victoriae,* under the present management regime, is only a good host in the first couple of years of parasite establishment, and that growers would be advised to interplant with other more resilient hosts to sustain parasite growth and fruit production in the long term. The best hosts for this purpose, based on our data, would be *A. calamifolia*, *A. hemiteles* and *A. argyophylla*, but not necessarily in that order. Although *A. hakeoides* was least affected by the parasites, it was also the least suitable host in terms of both parasite growth and fruit production. Thus, we would not recommend this particular host. In addition to our recommendations, host choice will depend on other factors such as water availability, soil types, salinity and climate. Growers could select the most suitable host from the list of those we recommend on the basis of their particular soil and climate.

Introduction

Quandong (*Santalum acuminatum*) and acacia seed are two of the most important native food crops currently being developed in Australia (Graham & Hart, 1997). The fruit of quandong is used to produce preserves (e.g. jams & chutneys) and also has potential for wine and liqueur production (G. Herde pers comm.). Until recently, most quandong was collected from wild trees. This source of fruit is unsuitable for a number of reasons. First, the quality and quantity of fruit is unpredictable. Second, pickers may have to travel long distances to source trees. And, finally, the quandong is a protected plant and collection of fruit could have an adverse impact on wild populations of the tree as well as other organisms that depend on it. For these reasons, quandong is increasingly being cultivated in commercial orchards rather than being sourced from the 'wild'.

The commercial cultivation of quandong is still in its infancy and while advances have been made in propagation and cultivation, much is still unknown. One of the most pressing issues is that of host selection. Quandong is a parasitic plant that attaches to the roots of its hosts from which it draws water and nutrients. The range of possible hosts is apparently quite wide, however, there is evidence that some hosts are better than others (Loveys & Tyerman, 2002; Lethbridge, 2003). There are at least three major factors to be considered when selecting suitable hosts for quandong production. First, does the host supply the parasite with sufficient water and nutrients for good growth? Second, is the association stable over time? That is, can the host support growth of the parasite without itself being adversely affected? And third, is the association suitable for the specific climatic and soil conditions in which the orchard has been established? We investigated these questions using eight different acacia hosts on which quandongs had been established.

Previous research (Lethbridge, 2003) found significant differences in growth of quandongs on different acacia host species, with acacias from drier regions being better hosts than those from wetter sites. This suggests that acacias from drier habitats not only provide sufficient water and nutrients to support quandong growth, but also may be more tolerant of the water stress imposed by the parasite. By examining the water relations and photosynthetic characteristics of both hosts and parasites across seasons, we obtained useful insights into host selection and irrigation management for improved quandong production in dryland regions. In addition, chemical analysis of host and parasite tissues provided information on potential transfer rates of nutritive or toxic compounds from host to parasite. This will significantly aid in the sustainable agronomic management of integrated quandong-acacia orchards in arid and semi-arid regions.

Methods

Site Description & Plant Material

The research was conducted at the Australian Arid Lands Botanic Garden (AALBG) at Port Augusta, South Australia. Natural vegetation in this region consists of chenopod-dominated heath growing on alkaline (pH 9.5) loams. Average annual rainfall is 300mm and mean maximum and minimum temperatures are 24^{o}C and 12^{o}C, respectively. The garden contains an established acacia/quandong plot. The plot consists of eight acacia species (*Acacia murrayana, A. victoriae, A. rivalis, A. brumalis, A. calamifolia, A. hakeoides, A. hemiteles* and *A. argyrophylla*), which have been growing in combination with *S. acuminatum* since April 2001.

Experimental Design & Methods

Water potential and photosynthetic efficiency of *A. victoriae, A. argyrophylla, A. hemiteles* and *A. hakeoides* and their attached quandongs (5 replicate pairs) were measured in winter 2005 and summer 2006. Time and resources did not permit an investigation of these traits in all eight species. Instead we selected four hosts that represented a range of responses to infection by *S. acuminatum*, based on previous data (Lethbridge, 2003). However, growth (stem diameter & tree height) and fruiting were measured for parasites on all eight acacia hosts in both 2005 and 2006.

Pre-dawn and midday shoot water potential measurements of both hosts and parasites were made using a Scholander pressure bomb. Pre-dawn photosynthetic efficiency was measured using chlorophyll fluorescence (Mini-PAM, Walz, Germany). Leaf material was collected from both parasites and hosts on each field trip, dried at 60 ^{o}C and then analysed by Inductively Coupled Plasma-Atomic Emission Spectrometry and Gas Chromatography at the Waite Analytical unit, University of Adelaide.

Water potential data provides evidence of the magnitude of the water potential gradient that exists between different hosts and the parasite and can indicate how this gradient is affected by water availability across seasons. This gradient must be favourable for the parasite or transfer of water and nutrients from the host will not occur. Any water or nutrient stress should impact on the photosynthetic efficiency of both the parasite and the acacia hosts, and can be accurately assessed using the chlorophyll fluorescence parameter Fv/Fm. Comparison of these parameters with the data on quandong growth indicates whether they are useful predictors of good potential hosts for quandong cultivation. By comparing these characteristics across a range of host:parasite pairs, important information can also be gained on the suitability of different associations for commercial cultivation in arid and semi-arid regions.

Data analysis

All data were analysed by standard statistical methods using SPSS software with results presented graphically and in tables, as appropriate. A value of α of 0.05 or less was used to indicate a statistically significant difference in tests.

Results

Water relations

Water potentials of parasites were always lower than those of hosts, regardless of season or time of day (Figures 1 & 2). This confirmed that quandongs maintain a water potential gradient that favours transfer of water and nutrients from host to parasite, and that they can successfully maintain this favourable gradient with all four hosts that were investigated. *A. victoriae* had higher water potentials, both midday and pre-dawn, during the summer when water stress is highest, than the other 3 hosts. On the basis of this result one might predict that *A. victoriae* would be a good host for *S. acuminatum* because it requires less effort for the parasite to maintain a water potential gradient when host water potential is high. Initial analysis of growth data (Lethbridge 2003) supported the notion that *A.victoriae* was a good host. However, the subsequent growth data presented in this report did not support this hypothesis.

Water potentials for *A. victoriae* were always above –3.5 MPa, regardless of time of day or season (Figures 1 & 2). However, water potentials of the other 3 acacia species went below –4.0 at midday in summer, suggesting that they were more water stressed under these conditions than *A. victoriae*. These hosts would also have required the quandongs to maintain lower water potentials than those growing with *A. victoriae*, which is confirmed by the results we obtained (Figures 1 & 2).

Photosynthetic efficiency

Predawn photosynthetic efficiencies of both hosts and parasite were always >0.7 (Figure 3). This suggests that neither hosts nor parasites were suffering long-term photoinhibition, which is an indicator of plant stress. In general, parasites had lower photosynthetic efficiencies than hosts. This is a pattern that has been observed in other host/parasite systems such as with mistletoes and their hosts.

Foliar nutrients

Analysis of the elemental composition of parasite and host leaf material provided some interesting results. Apart from sodium (Na), iron (Fe) and aluminium (Al), *A. victoriae* had higher concentrations of all analysed elements than any of the other acacia species (Figs 4, 5 & 6). Relative to hosts, parasites accumulated higher concentrations of molybdenum (except for *A. hemiteles*), nickel, sodium, potassium, phosphorus, and sulphur. In contrast, parasites appeared to exclude iron, manganese, boron, copper, zinc (only in *A. victoriae*), calcium (except in *A. argyrophylla* and *A. hakeoides*), and aluminium (except in *A. victoriae* and *A. hemiteles*). These data suggest that movement of nutrients from host to parasite is not simply a passive process, and that *S. acuminatum* can accumulate certain elements and exclude others. It is likely that processing of nutrients from the host's xylem sap occurs at the haustorial interface between host and parasite.

The sodium levels in the quandong leaf can contribute significantly to the osmotic potential of the plant, influencing water uptake from the host. This may help explain the low values of sodium for quandongs growing with *A. victoriae* hosts.The relatively high water potentials of *A. victoriae* , when compared with the other hosts, would require less effort for the parasite to maintain a water potential gradient.

A. argyrophylla, *A. hakeoides* and *A hemiteles* all had higher foliar nitrogen concentrations than the quandongs attached to them (Figure 7). Unfortunately, *A. victoriae* samples were lost before nitrogen analysis was completed and we only have data for *S. acuminatum* attached to *A. victoriae* (Figure7).

Growth and fruiting of *S. acuminatum*

Figure 8 shows the stem diameters (at 10 cm.) and heights of quandongs associated with selected acacia species. The 2005-2006 measurements cover the period of interest in this report. Note that the growth rates of quandongs over this period do not match the projected growth from previous years (0 to 4 years), probably due to the declining health of the acacia host plant with relative increasing size of the quandong. (See Figure 10).

Figure 9 shows a good positive correlation between stem diameters (at 10 cms., April 2006) and percentage of fruiting trees for each quandong/acacia species combination. Clearly, quandong/host combinations that allow faster overall growth rates (Figure 8) will lead to earlier tree maturation and fruiting character. We also found a good, negative correlation between stem growth of quandongs and the concentration of sodium in their leaves (Figure 9b).

Impact of *S. acuminatum* on host health

Figure 10 shows the effect of the semi parasitic quandongs on the health of the acacia host. These results are consistent with the notion that improved quandong growth rates will lead to greater stress on the host plant measured as percentage leaf cover or in extreme cases death of the host. The previous report (Lethbridge 2003) noted this effect with the *A. victoriae* / quandong combination. This combination showed the best growth rate for quandongs, stress effects on the acacia were noticeable at this early stage. It is now apparent that after 5 years the quandongs with moderately good growth rates in association with Acacia species are succumbing to the higher stress levels that larger quandongs impose on their hosts. It is currently unknown how the quandong/acacia combinations will perform under different management regimes.

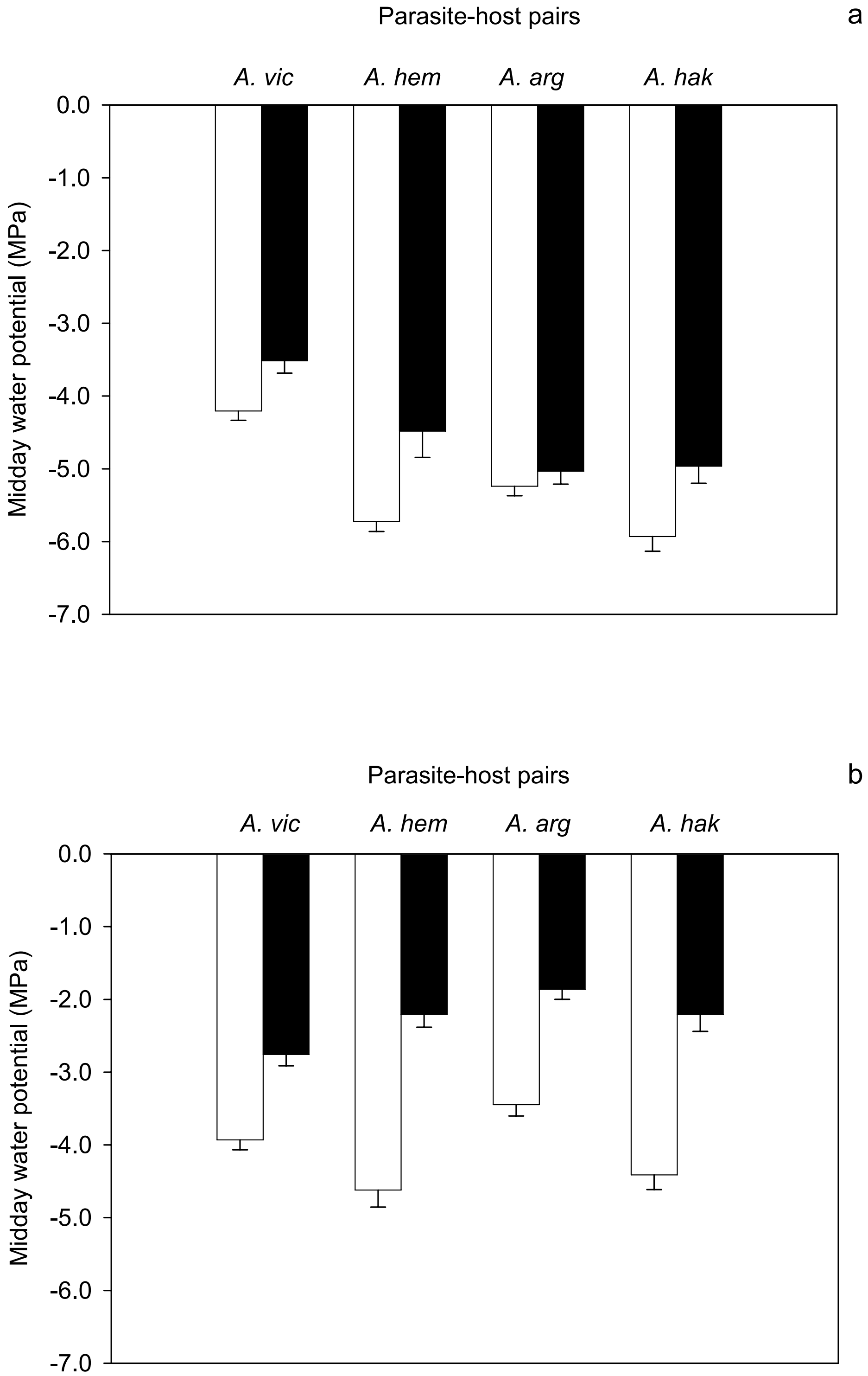
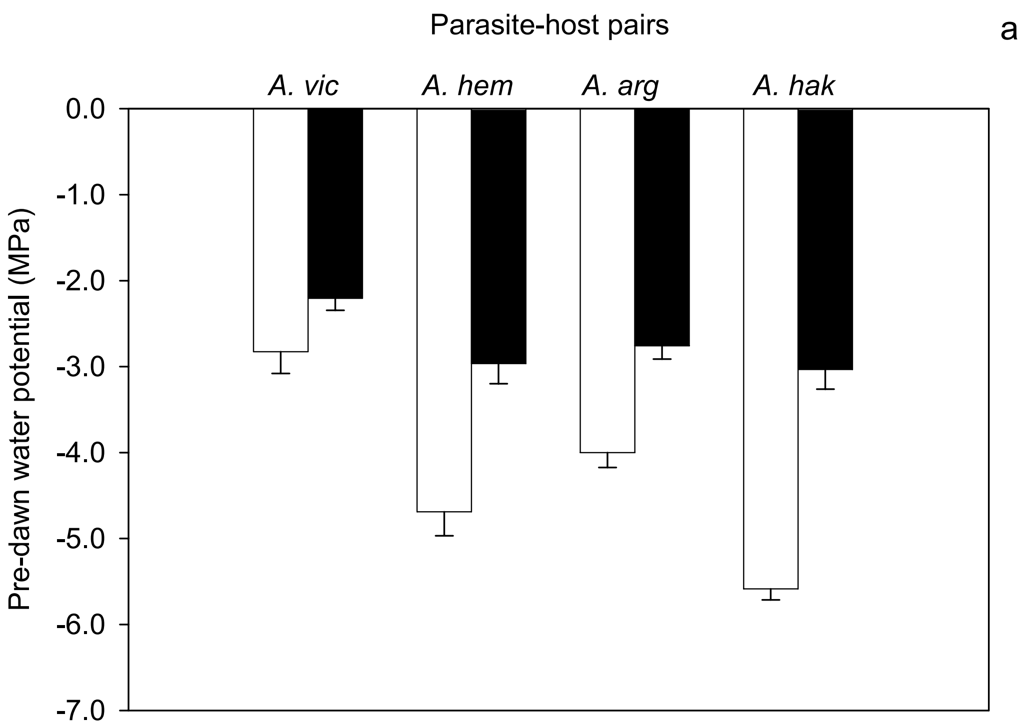


Figure 1. Midday water potentials (MPa) for *S. acuminatum* (open bars) and four acacia hosts (closed bars) in a) summer 2006, and b) winter 2005, at the AALBG, Port Augusta. Values are means ± se, n=5.



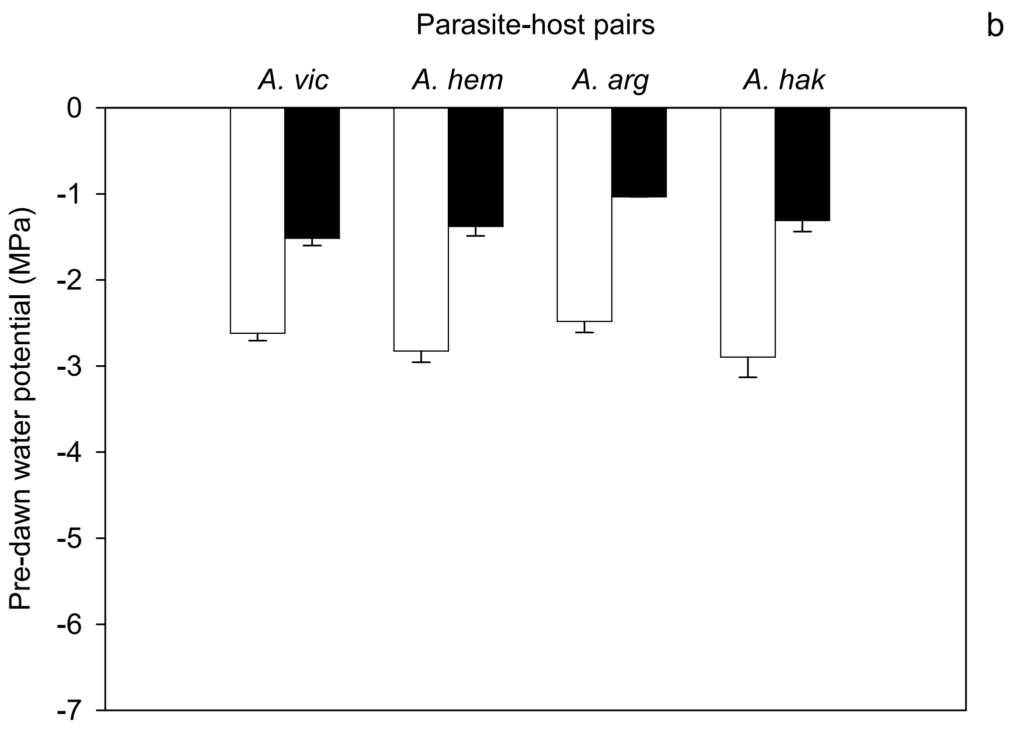


Figure 2. Pre-dawn water potentials (MPa) for *S. acuminatum* (open bars) and four acacia hosts (closed bars) in a) summer 2006, and b) winter 2005, at the AALBG, Port Augusta. Values are means ± se, n=5.

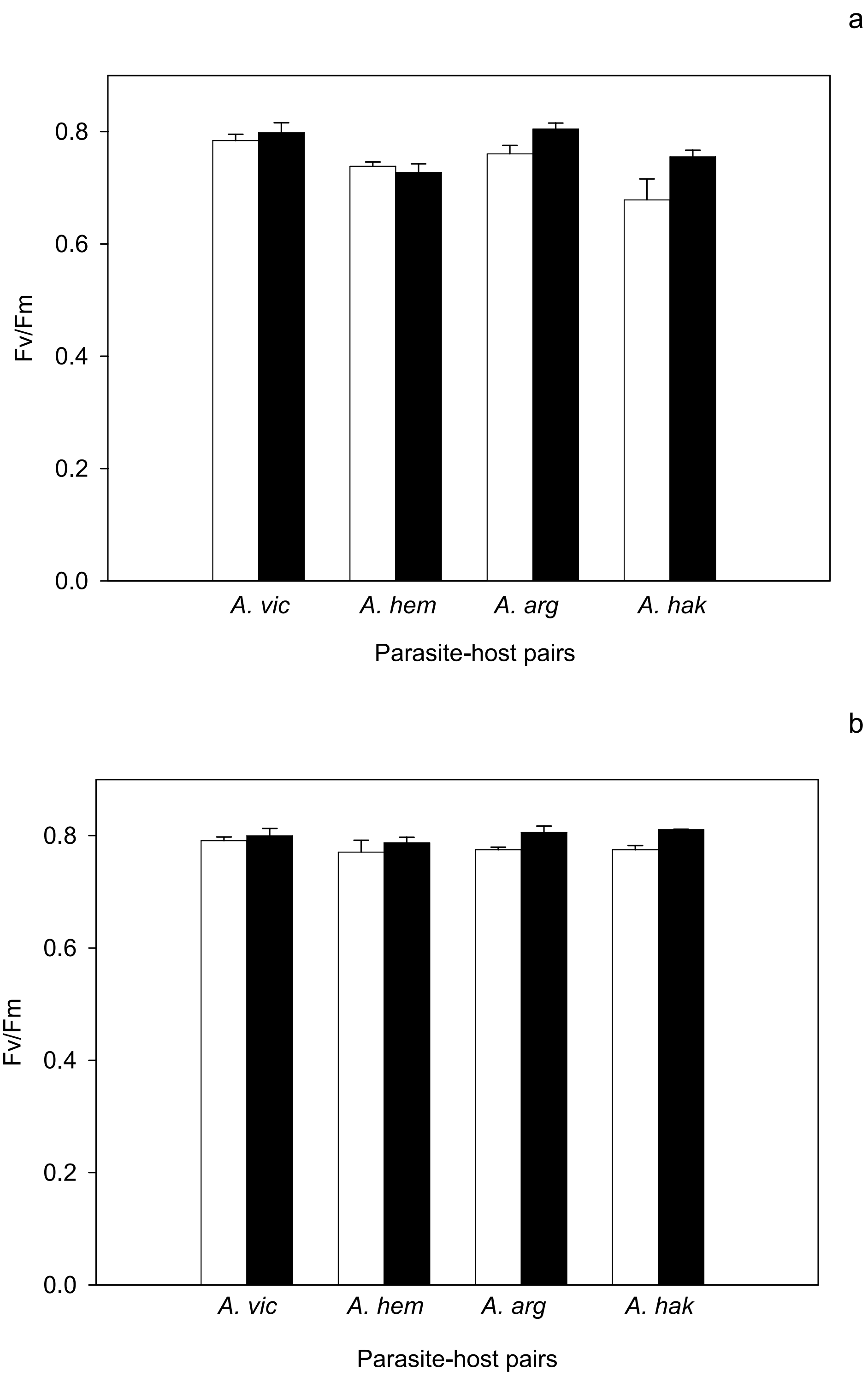


Figure 3. Pre-dawn Fv/Fm (photosynthetic efficiency-relative units) for *S. acuminatum* (open bars) and four acacia hosts (closed bars) in a) summer 2006, and b) winter 2005, at the AALBG, Port Augusta. Values are means $\pm$ se, n=5.

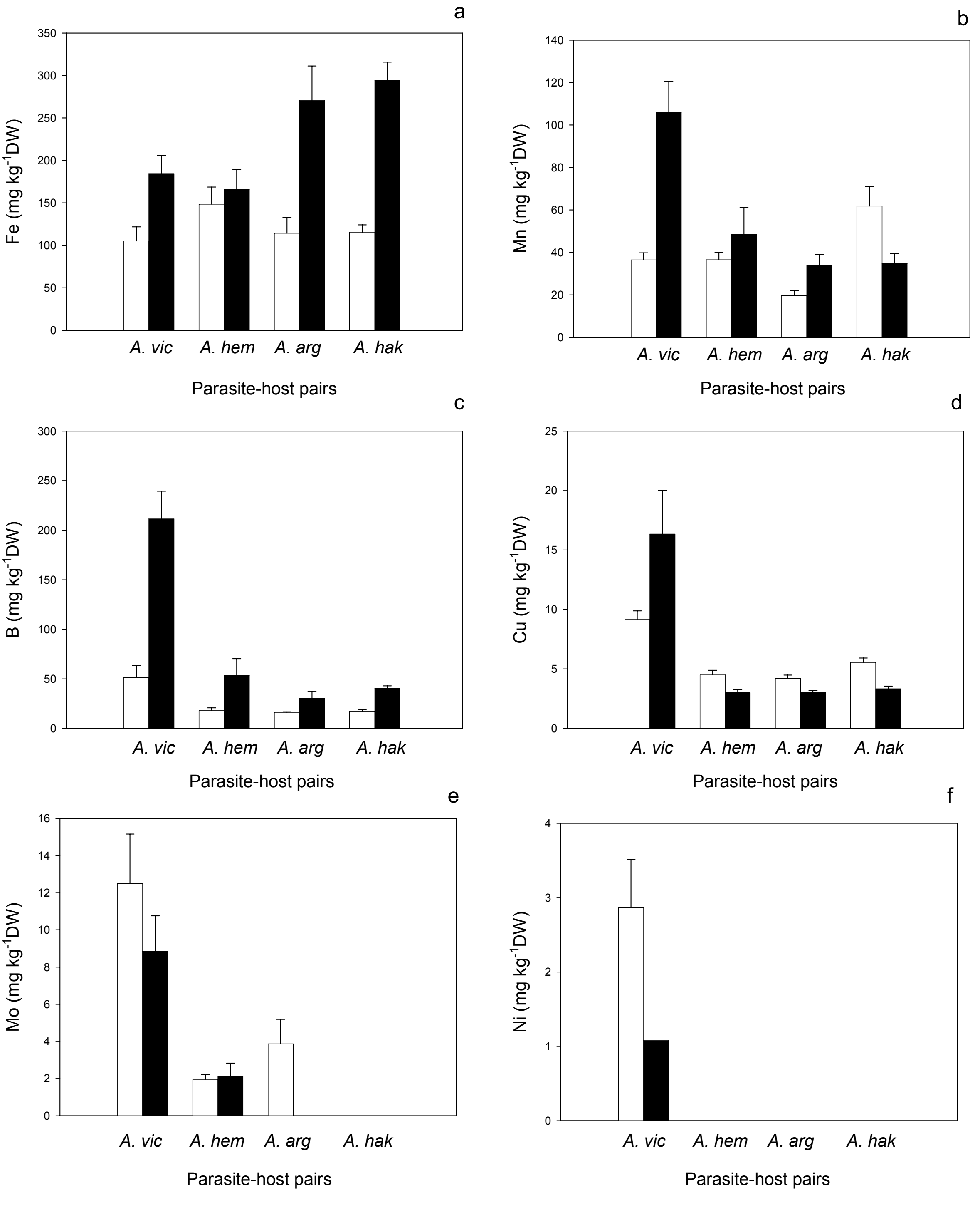


Figure 4. Leaf elemental concentrations (mg kg^{-1} dry weight) of a) iron (Fe), b) manganese (Mn), c) boron (B), d) copper (Cu), e) molybdenum (Mo) and f) nickel (Ni) in *S. acuminatum* (open bars) and four acacia hosts (closed bars) from the AALBG, Port Augusta. Values are means $\pm$ se, n=5.

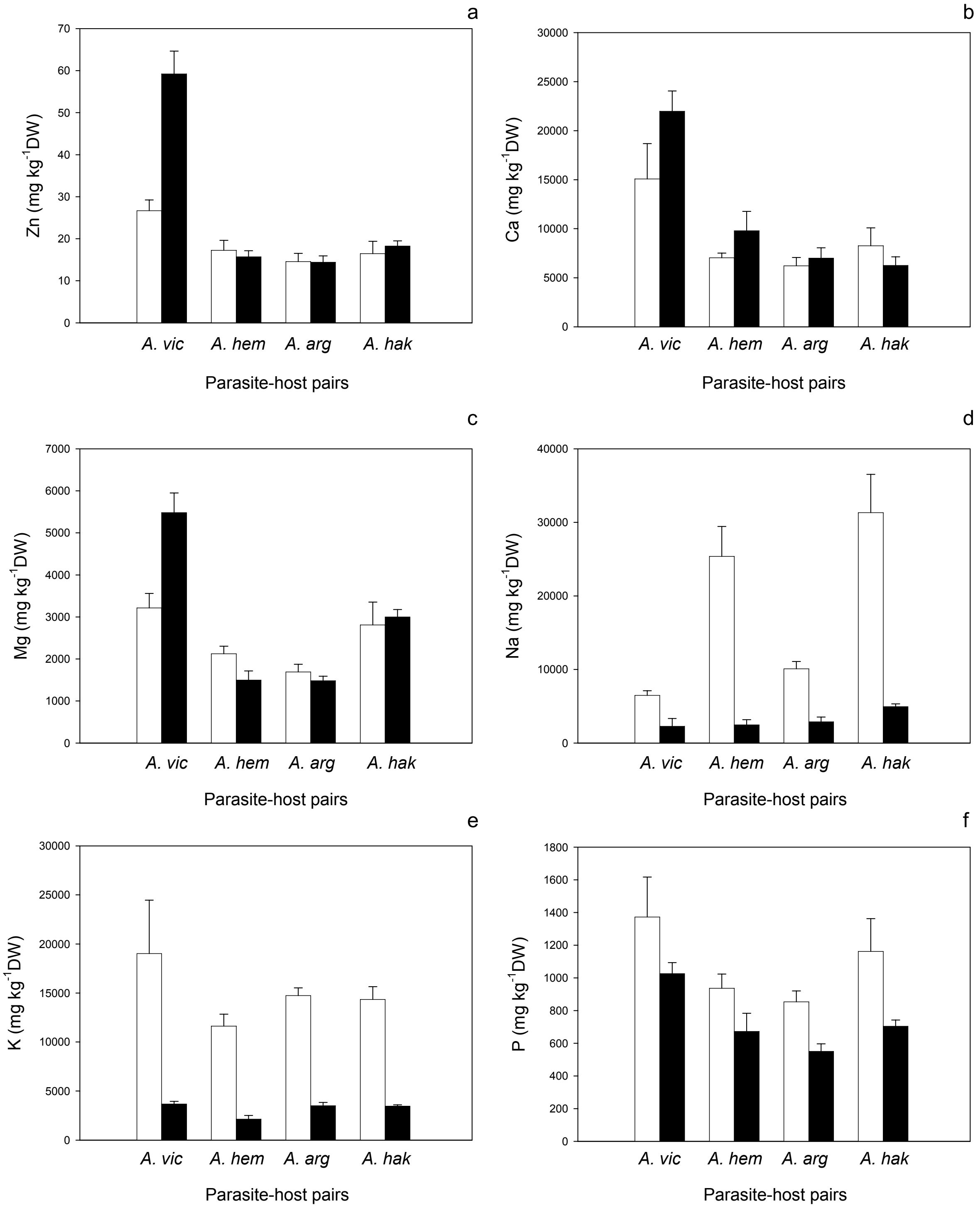


Figure 5. Leaf elemental concentrations (mg kg^{-1} dry weight) of a) zinc (Zn), b) calcium (Ca), c) magnesium (Mg), d) sodium (Na), e) potassium (K) and f) phosphorus (P) in *S. acuminatum* (open bars) and four acacia hosts (closed bars) from the AALBG, Port Augusta. Values are means ± se, n=5.

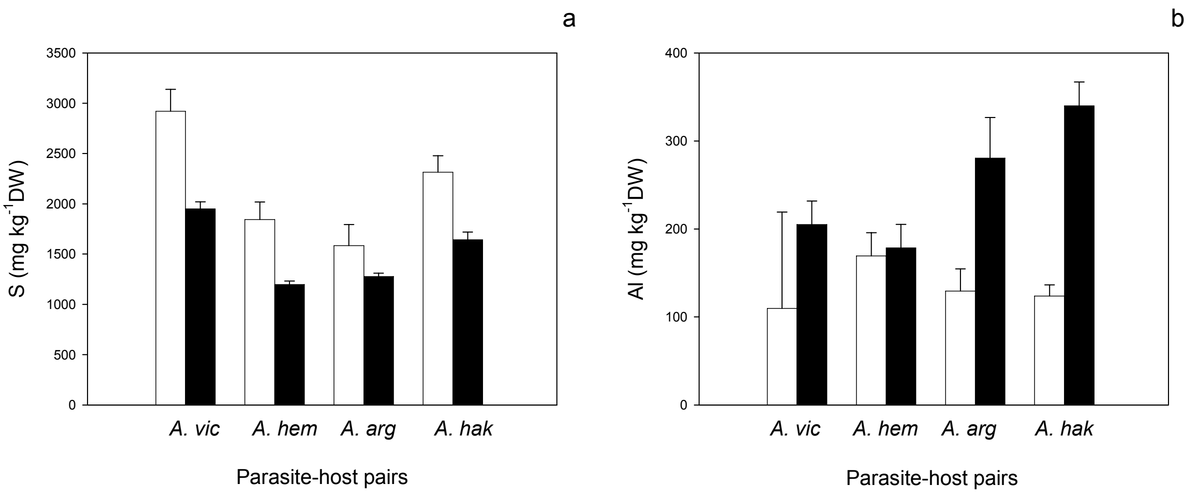


Figure 6. Leaf elemental concentrations (mg kg^{-1} dry weight) of a) sulphur (S), and b) aluminium (Al), in *S. acuminatum* (open bars) and four acacia hosts (closed bars) from the AALBG, Port Augusta. Values are means ± se, n=5.

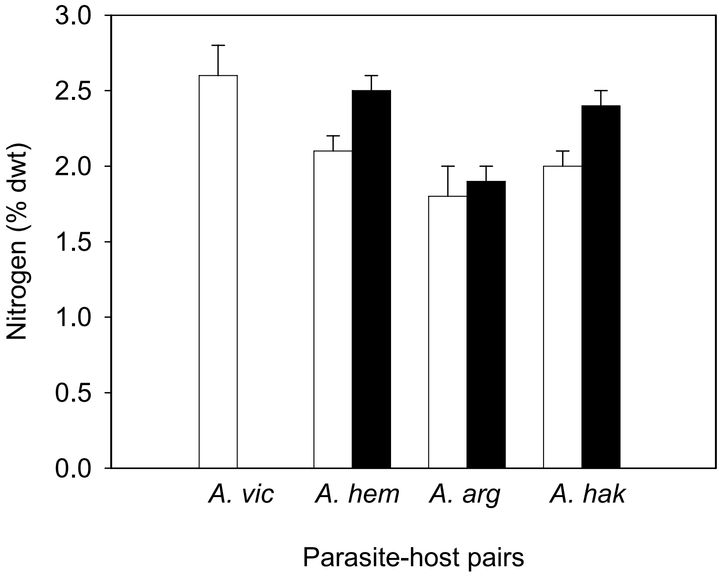


Figure 7. Leaf nitrogen concentrations (% dry weight) in *S. acuminatum* (open bars) and three acacia hosts (closed bars) from the AALBG, Port Augusta. Values are means ± se, n=5. Note that *A. victoriae* samples were lost prior to analysis and thus no data are presented for this species.

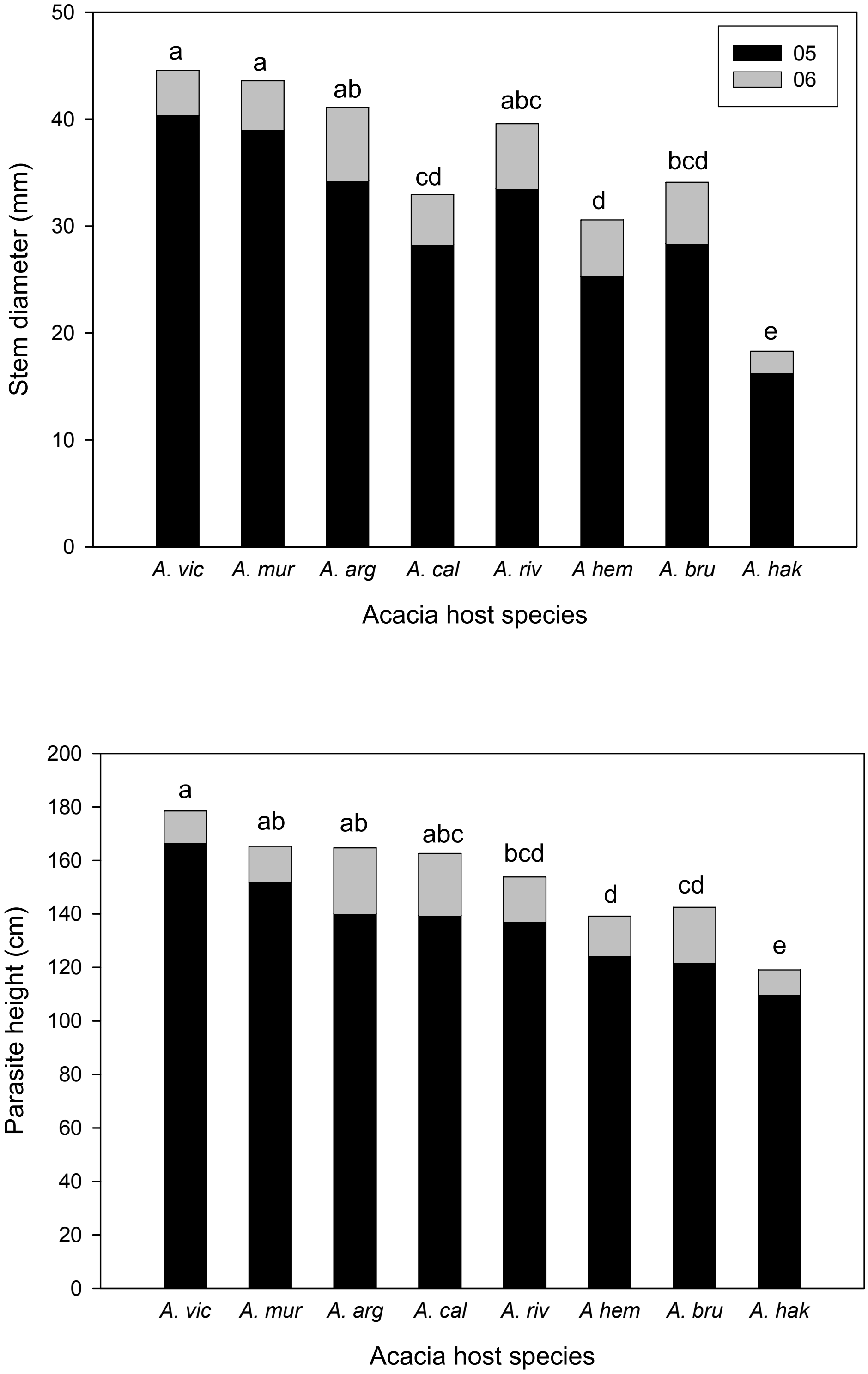
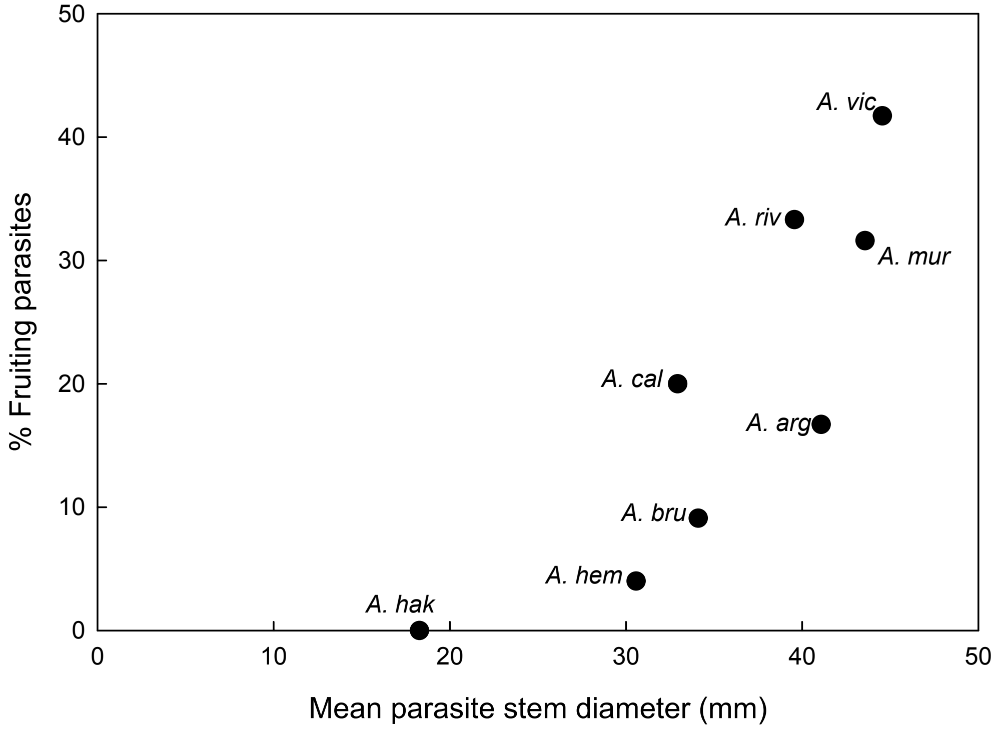


Figure 8. Stem diameter (mm) and tree height (cm) for *S. acuminatum* on eight different acacia hosts measured in 2005 and 2006 at the AALBG, Port Augusta. Values are means, different letters above a column indicate where significant differences exist by LSD.



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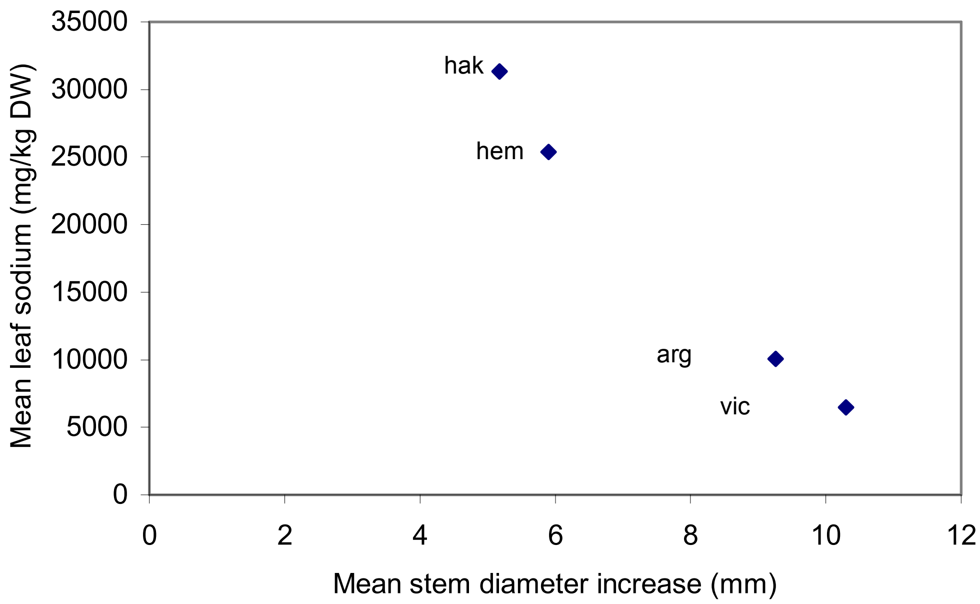

Figure 9. The relationship between a) mean stem diameter (mm) and the percentage of fruiting trees, and b) stem growth and foliar sodium concentration for *S. acuminatum* at the AALBG, Port Augusta in 2006. The host is indicated in each case.(n=5)

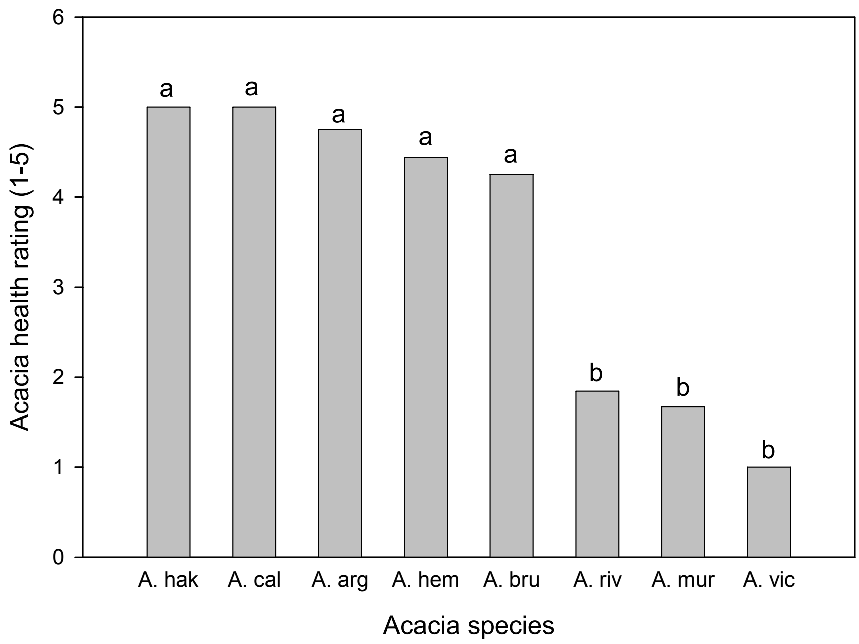

Figure 10. Mean relative health rating (scale of 1-5, with 1 being dead, and 5 being 100% canopy intact), for eight acacia host species with *S. acuminatum* parasites, at the AALBG, Port Augusta. . Values are means, different letters above a column indicate where significant differences exist by LSD.

Discussion

This project was set up to further analyse the interaction between quandongs and various selected native food/seed Acacia species as there is limited practical knowledge on the subject (Lethbridge 2004). The hemi-parasitic nature of the quandong is clearly a complex one, the nutritional and water use studies will help to further define fertilizer and irrigation designs to remove some of the guess work that is involved in this unique horticultural crop. This new data will complement nutritional information obtained from other quandong orchard trees (Koop 2000).

It is of special interest to note the negative correlation between foliar sodium levels and overall growth rates of quandongs associated with the four acacia species selected for further study, as it is known that quandong is categorized as a salt tolerant species (Walker1989). Radomiljac *et al* (1999) argues that for *S. album,* high leaf sodium contents may be contributing to the osmotic gradients, coupled with high transpiration rates this would ensure efficient water capture from the host. Leaf sodium levels in wild quandongs at Middleback SA were always appreciably higher in the quandong than the closest neighbour, and could contribute to the osmotic potential of the quandong (Loveys 2003). High sodium levels are of particular interest in saline/sodic areas. (See Marcar and Crawford 2003)

Acacia host health is a topic that was initially covered in the previous report (Lethbridge 2003). From the current results it is clear that host health can significantly influence the growth rate of the quandong and there is a fine balancing act between parasitism and competition for available nutrients and water. These findings have been noted by other researchers on the related species *S. spicatum* (Brand 2001)

Quandong growth rates are not only important in attaining mature fruiting trees quickly but also in improving success rates in field grafting (Lethbridge 2005), this and direct seeding (Lethbridge 2003, 2004) becomes an important alternative to nursery propagation, often a limiting step in new horticultural industry development.

A more detailed discussion of these results will be available in a scientific publication in the near future.

Implications and Recommendations

The results presented indicate that quandong /acacia host associations are finely balanced and highly regulated. Quandongs can be grown effectively without much intervention in the process provided the host plant is maintained in a healthy state. It is difficult to predict which acacia species will make good hosts based solely on data derived from the acacia species alone, hence our results for both host and parasite performance are of great value to growers.

One recommendation from this study would be that *A. victoriae,* under the present management regime, is only a good host in the first couple of years of parasite establishment, and that growers would be advised to interplant with other more resilient hosts to sustain parasite growth and fruit production in the long term. The best hosts for this purpose, based on our data, would be *A. calamifolia*, *A. hemiteles* and *A. argyophylla*, but not necessarily in that order. Although *A. hakeoides* was least affected by the parasites, it was also the least suitable host in terms of both parasite growth and fruit production. Thus, we would not recommend this particular host. In addition to our recommendations, host choice will depend on other factors such as water availability, soil types and salinity, and climate. Growers could select the most suitable host from the list of those we recommend on the basis of their particular soil and climate.

We also recommend that the quandong/acacia association be studied further with a focus on the role of sodium movement in host and quandong in saline environments. This could involve measuring the growth of salt tolerant acacia species and quandong in revegetation programs for salinity remediation.

For horticulturalists, the challenge is to define nutritional, irrigation and spacing regimes that make best use of the acacia/quandong association for best and most efficient production of quandong fruit. These experiments and this report will hopefully help in this quest.

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