

Photosynthetic Responses of Cotton to Spider Mite Damage and Water Stress

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Summary

It is necessary to research multiple stresses on cotton as plants are generally exposed to many stresses in the field, and interactions between them are largely unpredictable. We studied the effects of spider mite damage and water stress on cotton and determined whether cotton plants could compensate for these stresses. Dryland cotton was more resilient to mite stress than irrigated cotton. Neither dryland nor irrigated plants compensated for mite damage, except under severe mite stress when lower undamaged leaves were able to increase photosynthesis relative to uninfested / healthy plants due to faster senescence in upper leaves and consequent increased light levels.

Introduction

We investigated the combined effects of water stress and two spotted spider mite damage on photosynthesis of field grown cotton at the leaf level, to find out if mites affect dryland and irrigated cotton similarly. In a companion paper, Sadras et al.(1998a)(in this proceedings) present research on the interaction between mites and water stress at the crop level. We had two key objectives:

- To explore interactions between water deficits and mites.
- To assess the importance of compensatory photosynthesis in mite-infested plants.

Earlier research has mainly covered single stresses, i.e. mites or water deficit, but plants in the field are frequently exposed to multiple stresses. Research into combined stresses is required because interactions are largely unpredictable. Only a few studies have considered the interactions between mites and crop water regime (Leigh *et al.*, 1970; Smitley and Peterson, 1996; Youngman and Barnes, 1986), but none have measured physiological responses of cotton to the combined effects of mites and water stress at the plant or leaf level. Studies of how leaves or plants are affected by stresses are necessary for understanding what has occurred at the crop level.

Sadras and Wilson (1997) proposed that cotton appears to be able to compensate for the damage caused by low levels of mites. If this is the case then low levels of mite damage may have a minimal effect on cotton physiological processes and hence little effect on plant growth. We were therefore interested to see if we could measure any compensation for mite

damage at the plant or leaf level and to see if dryland and irrigated cotton are able to compensate in the same way. This paper presents results of field experiments designed to address these questions. To better understand these experiments, however, it is necessary to briefly revise key physiological mechanisms related to cotton photosynthesis, and its responses to mites and water deficits.

How do mites reduce photosynthesis?

Crop yield is obviously dependent upon photosynthesis, the process by which atmospheric carbon dioxide (CO₂) is converted to organic carbon which gives plants the energy and carbon structures required for growth. Past research has found that mites can reduce photosynthesis and do so in two ways:

1. Spider mites penetrate the underside of cotton leaves to feed on the inner leaf cell layers where photosynthesis occurs, thus preventing the conversion of CO₂ to sugars.
2. During the process of feeding on the inner cells indirect damage occurs to the outer leaf surface through dehydration of the inner cells. The outer, epidermal cells consequently dehydrate, this also includes guard cells which surround the stomata. Stomata are tiny pores on the outside of the leaves which allow gas exchange into and out of the leaf. The dehydration of the guard cells causes them to close over the stomatal pores in the leaves preventing gas exchange. Thus CO₂ can't be conducted into the inner leaf cells for conversion to sugar via the photosynthetic process.

How does water stress reduce photosynthesis?

Cotton is adapted to limited water supply and is often grown in areas of erratic rainfall or limited irrigation. Nevertheless, water deficits can influence cotton photosynthesis and ultimately yield (Turner *et al.*, 1986). Water stress affects the photosynthetic process similarly to mites. Many plants respond to acute water deficits by closing their stomata (Hopkins, 1995). However, closure of the stomata cuts off access of the inner cells to the atmospheric supply of CO₂, necessary for photosynthesis. Stomatal closure also prevents transpiration of water from the leaf which allows it to keep cool and maintain an optimum temperature for photosynthesis, causing further photosynthetic reductions (Sadras *et al.*, 1998b). Furthermore, water stressed plants may have low leaf water potential, in other words the leaf cells are no longer turgid due to reduced water content. Reduced turgidity in the cells which carry out photosynthesis results in a decrease in efficiency of chloroplasts, the photosynthetic machinery within cells.

We are trying to find out whether the effects of mites and water stress described above are additive or whether there is an interaction between the stresses, i.e. the combined effect is greater than or less than the two stresses added together.

How can plants compensate for mite herbivory?

Compensatory photosynthesis is an increase in the photosynthetic rates of foliage on partially defoliated or damaged plants relative to foliage of the *same age* on healthy plants (Nowak and Caldwell, 1984). In this way, to a degree, the overall photosynthetic rate of a mite damaged plant is able to be maintained at the same level as an undamaged plant. It is possible that compensation can occur within a leaf, i.e. photosynthesis increases in the undamaged portion of the leaf compensating for the reduction in photosynthesis of the damaged leaf portion (Trumble *et al.*, 1993). Compensation may also occur within a plant, i.e. undamaged leaves make up for reduced photosynthesis in damaged leaves (Trumble *et al.*, 1993). We investigated the possibility of *within plant* compensation by measuring photosynthesis of leaves damaged by mites (L1 where there is a high mite density) and by measuring photosynthesis of leaves undamaged by mites (L2, L3 where there are low spider mite densities) on mite infested plants (+Mites) (Figure 1). We compared these measurements to plants without mites (-Mites) to see if photosynthesis of undamaged areas were higher in + Mite plants. As well, we investigated the possibility of *within leaf* compensation by measuring photosynthesis of undamaged portions of mite damaged leaves (at the nodes shown on Figure 1) and compared the photosynthetic rates to the same area of leaves without damage on uninfested plants (Figure 2).

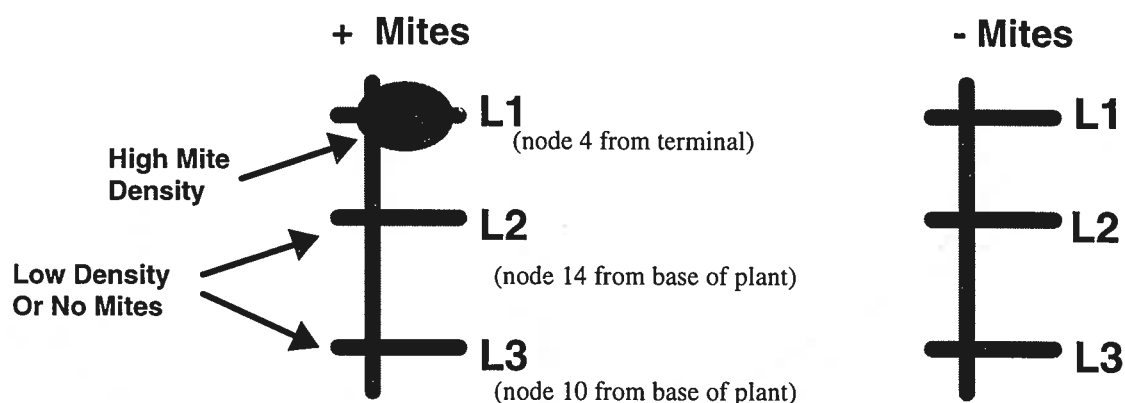


Figure 1: Positions on cotton plants where photosynthesis was measured to assess within plant compensation.

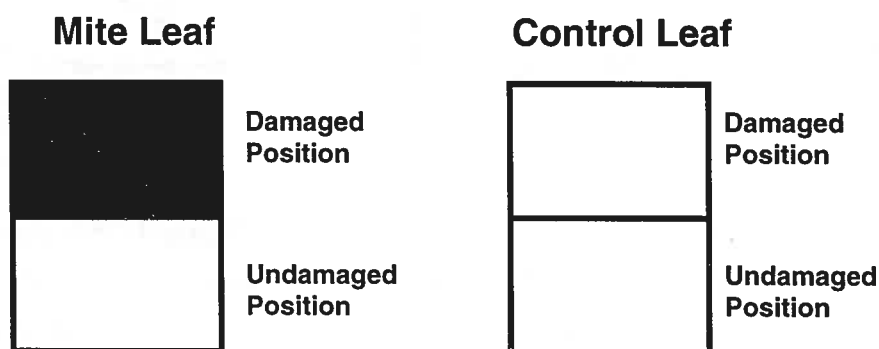


Figure 2: Positions on cotton leaves where photosynthesis was measured to assess within leaf compensation.

Methods

A field trial was set up, at the Australian Cotton Research Institute, Narrabri, as a split plot design with plots divided into two mite treatments (i) no mites (-M) or (ii) plants artificially infested with mites (+M) using NuCotn 37 cotton. These were combined with two water treatments (+W, -W). Six central rows of the +M subplots were artificially infested with mites using glasshouse grown, mite infested cotton seedlings, according to Wilson (1993). +W treatments were irrigated each time a soil water deficit of 50-60mm was reached and -W received no irrigation after sowing. Leaf photosynthesis was measured using an LI-6400 portable photosynthesis system.

Results

Effects of water stress and spider mite damage on leaf photosynthesis

Photosynthesis of irrigated cotton (+W+M) was reduced to a greater extent by spider mite damage than that of dryland cotton (-W+M) (Figure 3). The greater reduction in photosynthesis of the irrigated (+W) plots occurred despite no significant difference in mite populations between the two water treatments (Figure 4). The enhanced resilience of water stressed cotton to mites, compared to irrigated cotton is partially explained by the thicker, tougher leaves of water stressed plants which resulted in less intensive mite damage (Sadras *et al.*, 1998b).

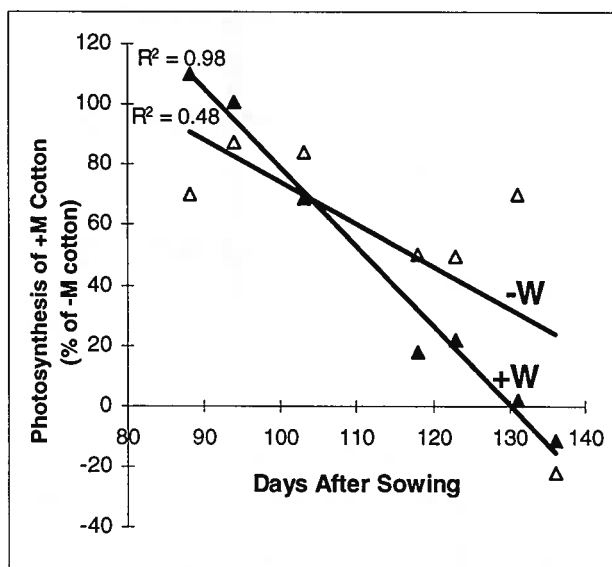


Figure 3: Reductions in photosynthesis of +M cotton compared to -M cotton as a result of mite feeding damage

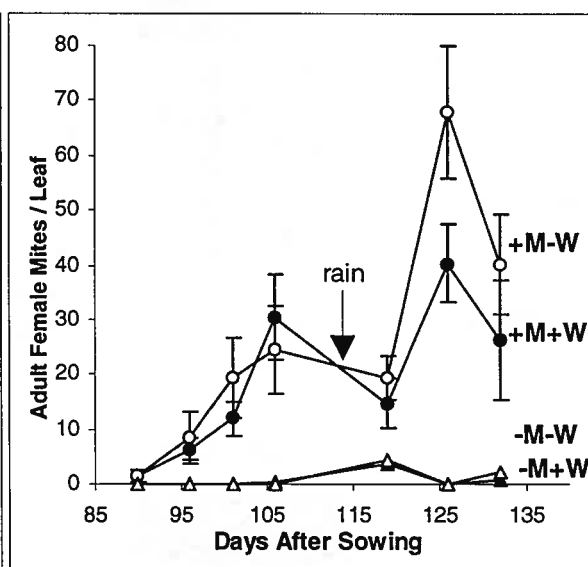


Figure 4: Mite population of all treatments represented by the no. of adult female mites.

Compensation of Cotton Leaves

Within Leaf Compensation

The photosynthetic rate of *damaged* portions of mite infested leaves decreased with increasing mite damage in relation to -M (control) leaves (Figure 5). *Undamaged* portions of mite infested leaves maintained similar photosynthesis levels to control (-M) leaves at low mite densities, i.e.: < 20 adult female mites / leaf (Figure 5). However as the mite density increased, > 20 adult female mites / leaf, photosynthesis also decreased in the apparently undamaged portions of mite infested leaves. Thus overall photosynthesis of both irrigated and dryland mite infested leaves decreases with increasing mite density. However, at low mite densities there is little damage and in areas surrounding this damage, photosynthesis is able to be maintained. These results are consistent with measurements of other physiological processes in cotton that showed no responses to mite densities below 20 adult females per leaf (Sadras and Wilson, 1997).

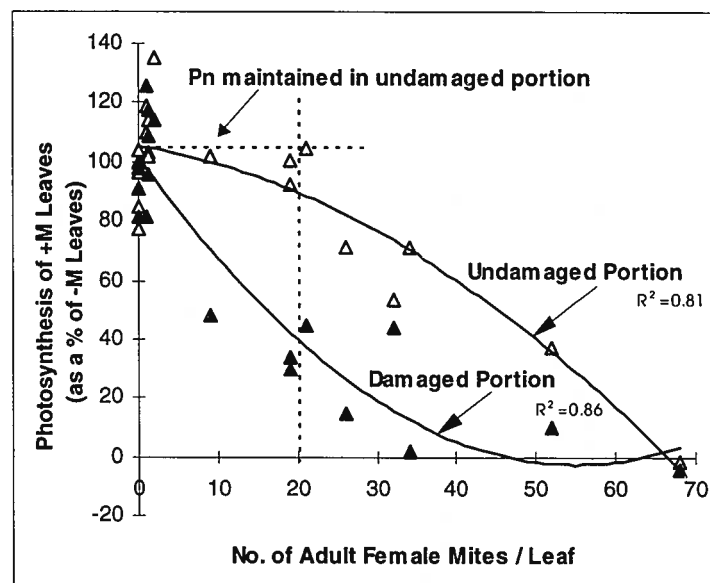


Figure 5: Photosynthesis of damaged and undamaged portions of mite infested leaves

Within Plant Compensation

No evidence for within plant compensation was apparent in undamaged portions of L1 (area of highest mite density) or L2 (leaves directly below high mite density) of either irrigated or dryland cotton. Photosynthesis was consistently lower in +M leaves than in leaves of -M plants of the same location, especially for L1 leaves (Figure 6). However, undamaged portions of lower leaves (L3) showed increased photosynthesis on comparison with leaves from -M plants (Figure 7). This was observed in both irrigated and dryland plants. These results, which provide evidence of *within plant* compensation, occurred due to faster senescence of upper leaves in the +M plants, and the increased light penetration to lower leaves in the canopy resulted in increased photosynthesis in these leaves. Seventy five

percent of the variation in the rate of photosynthesis of bottom leaves in +M and -M plants can be explained by variation in light. However, compensation in the L3 leaves was too little, too late as the plants were already severely damaged by mites. In any case, lower/older leaves of cotton photosynthesise at a low rate even in a healthy state (see -M, Figure 7) and would not have been able to make up for the amount of damage caused to the upper leaves.

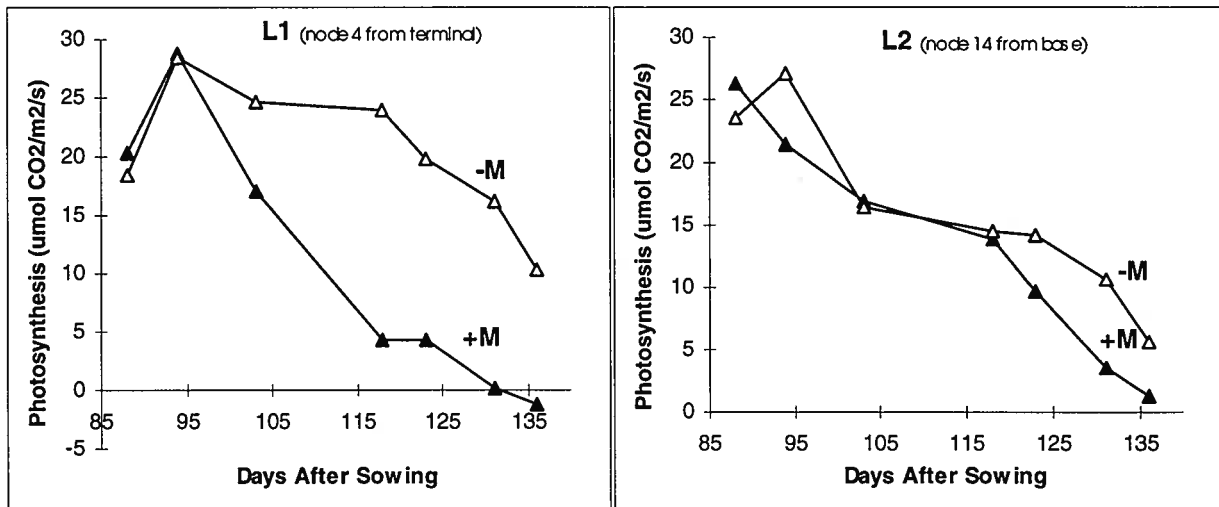


Figure 6: Photosynthesis of leaves from +M and -M irrigated plants at L1- high area of mite density and L2 - area directly below high mite density.

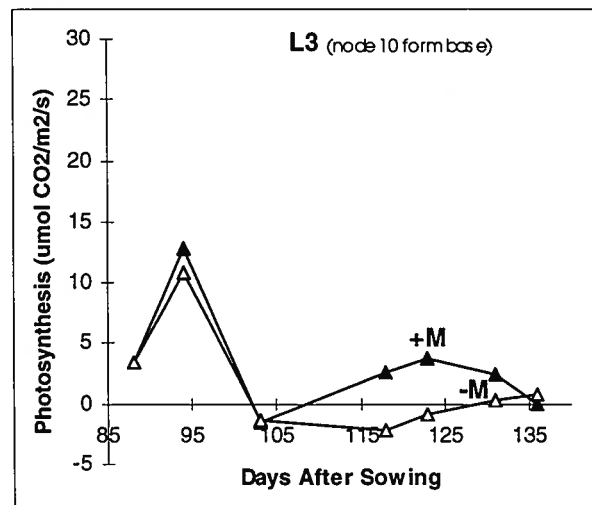


Figure 7: Photosynthesis of leaves from +M and -M irrigated plants at L3 - lower leaves of plant, well below high mite density.

The results therefore suggest that the compensation reported by Sadras and Wilson (1997) is not due to within plant or within leaf increases in photosynthesis in undamaged areas. Instead it is likely that at low levels of mite damage a relatively small proportion of leaves are affected - hence reduction in photosynthesis, though large on the leaves affected, is small when viewed at the crop level.

Conclusions

Mite Damage and Water Stress

Both mite infestation and water deficit had detrimental effects on cotton leaf photosynthesis. There was a significant interaction between the stresses i.e. the mites caused more damage to well-watered plants compared to the water-stressed plants, as shown by greater reductions in plant photosynthesis and more intensive feeding damage. The mechanism by which plants adjusted to water stress may have increased cotton resistance to mites, via increased leaf hardness.

Compensation

Mite infested plants were unable to compensate for mite damage at the leaf level, regardless of irrigation status. However, lower leaves of both irrigated and dryland plants showed *within plant* compensation. This was not compensation *per se* (as traditionally defined) but as a result of premature senescence of mite infested leaves in areas of high mite density.

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