



Assessing Effects of Canopy Nitrogen and Light Distribution on Radiation Use Efficiency of Cotton

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ABSTRACT

As a surrogate for photosynthesis, biomass accumulation at the crop level can be estimated from the product of the amount of radiation intercepted and the amount of dry matter produced per unit of radiation intercepted (radiation use efficiency, RUE). The cotton crop simulation model CERCOT uses this approach and modulates RUE in response to canopy nitrogen status. However, the response of RUE of cotton to its nitrogen status is uncertain. Using a previously reported approach to scale from leaf photosynthesis to canopy RUE, we explored the significance of developmental changes in the vertical distribution of canopy N and canopy light interception characteristics on the response of RUE to nitrogen status. Tested against a field experiment, the framework performed reasonably well for high observed RUEs but over-estimated low RUEs. A number of avenues are being explored to improve its performance. A sensitivity analysis with the framework suggested that RUE in cotton was not effected by developmental changes in the vertical distribution of canopy N or light interception characteristics, but this needs to be tested in cotton crops with larger canopies where these effects are likely to be more important.

Introduction

The cotton crop simulation model CERCOT has been developed for use in research and to assist in tactical and strategic decision making. In CERCOT, biomass accumulation by the crop is estimated from the product of the amount of radiation intercepted each day and radiation use efficiency (RUE, the amount of dry matter produced per unit of radiation intercepted). RUE for a given day is modulated according to the canopy nitrogen status. However, changes in either light interception properties or the vertical distribution of N within the canopy can effect RUE for a given canopy N status (Hirose and Werger, 1987; Pons *et al.*, 1989). Developmental changes in both these factors have been observed in cotton (Sadras, 1996; Milroy *et al.*, 1998) and could effect the relationship between the canopy nitrogen status and RUE over the development of the crop. This would have implications for models which use RUE to simulate biomass production.

To explore the importance of these developmental changes for RUE in cotton, we used a simple framework developed by Hammer and Wright (1994) that scales from leaf photosynthesis to RUE which accounts for, amongst other factors, both the vertical distribution of N and the light interception characteristics of the canopy. The framework estimates the photosynthesis of sunlit and shaded leaves at each of the specified layers in the canopy as a function of their light receipt and N status. The photosynthesis of leaves in all the layers are totaled and adjusted for respiration to calculate a whole canopy photosynthesis. In this paper we aim (1) to test the suitability of the framework of Hammer and Wright (1994) for estimating RUE of field grown cotton crops and (2) use

it to explore the predicted effects on RUE of average canopy N, the vertical distribution of N and the canopy light interception characteristics.

Materials and Methods

A field experiment was conducted at the Australian Cotton Research Institute Narrabri (30°S 150°E), a semi-arid environment in north-western New South Wales, Australia. The soil was a grey-clay. Cultivar Sicala V-2i was sown on 14 October with two nitrogen treatments; nil and 150 kg ha⁻¹ of N applied as anhydrous ammonia. The crop was grown using full irrigation and commercial insect control methods. A completely randomized design was used with four replicates. Plots were 75m by four rows spaced at 1m. Incident solar radiation was measured throughout the experimental period at a meteorological station 3 km from the site.

From about the time of first square, 1 m² destructive plant samples were taken each fortnight. On each occasion, the canopy was cut in four successive strata of equal vertical thickness. For each layer, the leaf area (hence LAI) was measured using a planimeter and the leaf material dried and weighed. The total dry matter (TDM) in the sample was also measured. Leaf N concentration (g N/g DM) was determined using a near infrared refractometer or a Leco high temperature combustion system, both calibrated against the Kjeldahl method. The stratified cuts continued until boll growth was completed and the crop was approaching maturity, giving five samplings. Two additional samples were taken, one before the first and one after the last stratified cut, for TDM and N only. The proportion of photosynthetically active radiation

(PAR) intercepted by the crop was measured using a ceptometer at approximately weekly intervals. Readings were taken above and below the canopy in each plot at around noon under clear conditions.

Instantaneous canopy light extinction coefficients (k), vertical specific leaf nitrogen (SLN, g N/m² of leaf) gradients within the canopy (henceforth referred to as SLN gradient) and average canopy SLN were calculated for each harvest date. The coefficient k was based on total global radiation and calculated from the light intensity above (I_0) and below (I) the canopy and LAI using the equation: $k = \ln(I/I_0)/-LAI$. The SLN gradients were calculated from the regression of SLN in a given layer against cumulative LAI (LAI_{cum}) from the top of the canopy to the mid-point of that layer.

RUE was calculated for each date when a stratified harvest was taken by using data from three consecutive sampling dates centred on the date of interest. For each date RUE was calculated from the linear regression of accumulated biomass on cumulative intercepted PAR over the three dates. The proportion of light intercepted by the crop canopy over the day (Q) was estimated from the proportion of interception measured around noon (Q_n) using the equation of Charles Edwards and Lawn (1984): $Q = 2.Q_n/(1+Q_n)$. In calculating biomass, the high synthesis cost of cotton fruit relative to vegetative growth was taken into account by adjusting the reproductive biomass by the ratio of the biosynthetic production costs (g glucose per g dry matter) of reproductive and vegetative tissues using the conversion factors of Wall *et al.* (1994). That is, the RUE is equivalent to that for the production of vegetative tissue.

The performance of the framework was tested by comparing the derived RUE's to those measured for each sampling date. For this purpose, the LAI for each layer, actual incident radiation, average canopy SLN, canopy SLN gradients and k as measured at each sampling date were used as inputs to the framework. A limitation was the lack of a field based response of leaf photosynthesis (P_n) to SLN. The response equation used was based on that of Hammer and Wright (1994) but with a maximum P_n of 1.5 mg CO₂ m⁻² s⁻¹ at high SLN based on Australian cultivars grown in the field at Narrabri (Warwick Stiller CSIRO, unpublished data).

Results and Discussion

In the field experiment, RUE varied between 0.6 and 2.1 g MJ⁻¹. These values compare well to published data for the production of vegetative tissue by cotton which range between 1.2 and 2.1 g MJ⁻¹ (Rosenthal and Gerik, 1991; Sadras 1996). Significant relationships were found between SLN in a layer and cumulative LAI from the top of the canopy ($P < 0.05$). The negative slope of the relationship (i.e.: the SLN gradient) varied between the sampling dates and between nitrogen regimes ($P < 0.05$, Fig. 1). Average canopy SLN also varied between treatments and

sampling dates ($P < 0.05$, Table 1), but k only varied significantly between sampling dates ($P < 0.05$, Table 1). The k values in Table 1 appear low relative to previously published values for cotton (e.g. Constable, 1986; Sadras, 1996) because they are based on total global radiation not PAR. On a PAR basis, the observations ranged from 0.51 to 0.81

The RUEs calculated for the field experiment using the framework were plotted against the observed values (Fig 2a). The calculated RUEs were approximately correct for the higher observed values but were over estimated at moderate to low observed values, particularly for the nil N treatment. Part of the reason for the lack of response to low N supply is most likely due to the function used for the response of P_n to SLN. The function had been derived for peanut but was modified for cotton by changing the asymptotic maximum P_n rate. Although

Reddy *et al.* (1979) have developed a relationship of this kind for cotton, it only used a limited range of SLN and was developed in a controlled environment. Significantly higher rates of P_n than the maxima reported by Reddy *et al.* (1979) or Constable and Rawson (1980) have been observed in the field (Warwick Stiller CSIRO, unpublished data). Leaf age may have also contributed to the over-estimation of RUE for the nil N treatment late in the season. The nil N treatment cut out earlier than the high N treatment and thus from this point onward the leaves at the top of the nil N canopy were older than those in the high N treatment. Thus, although they had only a slightly lower SLN (Fig. 1) they would have had significantly lower P_n rates (Constable and Rawson, 1980). Work is continuing to explore the response of P_n to SLN in the field and the interaction of leaf age and also light acclimation with this relationship. Non-linear canopy gradients (Hirose and Werger, 1987) may also have contributed to the scatter of the calculated RUEs. Research is continuing to quantify the importance of these aspects to the performance of the framework for cotton.

To assess the significance of the observed developmental variation in k on the calculated RUE, we substituted a k derived across all dates and treatments in place of the actual k for each date. This had only a limited effect on the estimated RUE (Fig 2b). This was surprising given that a sensitivity analysis showed that the calculated RUE from the framework varied by 15% over the range of k values observed in the field trial (with SLN gradient = 0.61 and average SLN = 3.0). The small effect on the calculated RUEs for the field trial was presumably because, while there was statistical variation between the observed k values ($P < 0.05$), most of the values lay near the overall value of 0.46. Thus only a few of the calculated RUE's were altered by using a common k . When we tested the significance of the observed variation in SLN gradient by substituting an overall gradient in place of those specific for each date, it had

even less effect than using a common k (Fig 2c). This was at least partially due to the low LAIs developed in the experimental crop. The analysis of Hirose and Werger (1987) indicated that canopy photosynthesis responded more strongly to SLN gradient at higher LAI; at an LAI of 2.12 the response was negligible. The highest LAI recorded in these crops was only 2.6 even though a yield of 2100kg ha⁻¹ was obtained in the high N treatment.

The stability of the predicted RUE with changes in either k or canopy SLN gradient over the range observed in this study is promising for the development of a response of RUE to SLN which could apply through out the development of the crop. However, higher SLN gradients are likely with higher LAI (Sadras *et al.*, 1993) and also the consequences of variation in k or SLN gradient are greater with higher LAI (Hirose and Werger, 1987). Therefore, it will be necessary to assess their importance in cotton crops which develop larger canopies than those in this study. This is the focus of ongoing experimentation.

Conclusions

The calculated RUE derived from the framework needs to be improved. This may be achieved through developing an appropriate field based response function for Pn versus SLN. Other aspects of the framework will also be examined to reduce the variability of the estimated RUE. The importance of developmental changes in SLN gradient and k for RUE in cotton needs to be quantified in crops with higher LAI than observed here.

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Table 1. Observed values for the canopy light extinction coefficient, SLN gradient, total LAI and average canopy SLN for cotton crops grown under nil (LN) and high (HN) nitrogen for different sampling dates (DAS = days after sowing) and used as inputs to the framework.

DAS	Extinction		SLN Gradient		Total LAI		Average SLN	
	Coefficient (k)						(g N/m ²)	
	HN	LN	HN	LN	HN	LN	HN	LN
64	0.50	0.57	0.72	0.58	0.57	0.36	3.05	2.11
77	0.36	0.44	0.72	0.58	1.65	0.75	2.46	1.73
94	0.47	0.47	0.82	1.17	2.33	0.91	2.31	1.46
113	0.42	0.47	0.31	1.03	2.64	1.01	1.90	1.29
128	0.51	0.51	0.59	1.60	2.41	0.96	1.67	1.71

Figure 1. Examples of the relationship between SLN and cumulative LAI for (a) the high N treatment and (b) the nil N treatment. Open symbols and broken lines are for 77 days after sowing (DAS), closed symbols and solid lines are 128 DAS.

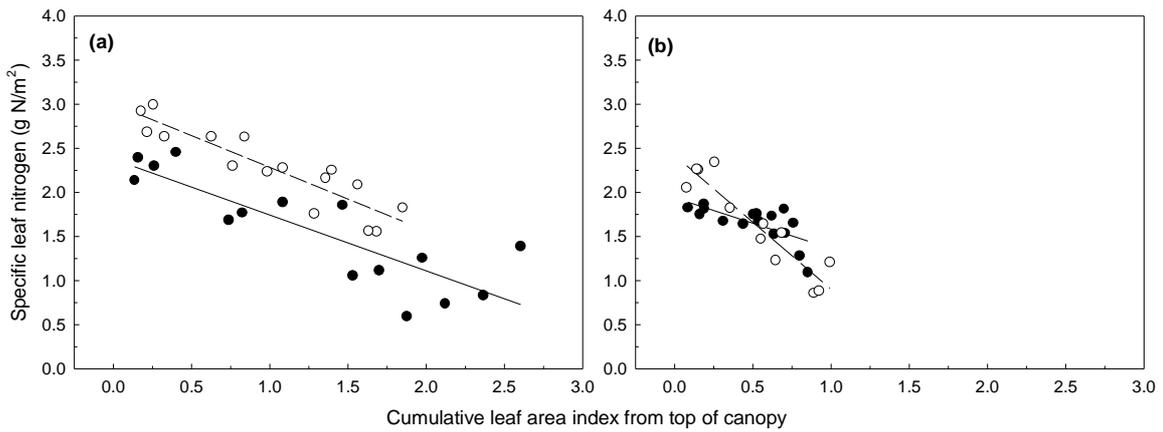


Figure 2. Derived versus observed RUE for the different dates in the field experiment using: (a) k and SLN gradient as measured for each date, (b) measured SLN and a common k calculated by pooling all the data and (c) measured k and a common SLN gradient.

