Canopy architecture and nitrogen utilisation for biomass production: the contrast between maize and sunflower

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Abstract

Canopy architecture has been reported to influence the nitrogen distribution within canopy. Above ground biomass (biomass), leaf area index (LAI), specific leaf nitrogen (SLN), nitrogen (N) uptake, light interception (LI), extinction coefficient (*k*) and radiation use efficiency (RUE) of maize and sunflower were compared in field experiment at different N levels. Biomass, LAI, SLN, N uptake, LI, *k* and RUE differed significantly between species. Sunflower and maize had non-uniform N distributions in the canopy. However, maize had more uniform distribution of nitrogen than sunflower. Differences in biomass between maize and sunflower and among N levels could be attributed to a different photosynthetic pathway and canopy architecture which determine light distribution and consequently N distribution.

Key words

Nitrogen, SLN, canopy architecture, maize, sunflower.

Introduction

Nitrogen (N) supply is a major constraint to productivity and profitability in most cropping systems of both the developed and developing world. In the former, N output from agriculture can be a major pollutant beyond the farm (12). Nitrogen is a constituent of the proteins, nucleic acids and nucleotides that are essential to the metabolic function of a plant. The amount of element N per unit leaf area, (specific leaf nitrogen, SLN (g/m^2)) provides a measure of concentration of these metabolites within the leaf tissues and reflects the metabolic activity of the leaf (3). A strong correlation has been demonstrated between N or SLN and net photosynthetic rate for maize (15) and sunflower (2, 4). SLN also influences radiation use efficiency (RUE) in sunflower (2) and maize (15), apparently through the direct effect of SLN on leaf photosynthesis (15).

Variation in vertical N or SLN distribution has been clearly shown. However, the relationship between SLN and cumulative LAI differed among species. SLN decreased exponentially (1, 5, 10, 11) or linearly (2, 6, 16) as a function of the relative cumulative LAI from the top of the leaf canopy.

Canopy characteristics can be expected to affect patterns of N distribution as well as the photosynthetic benefits as a result of N redistribution (1). Structural characteristics of canopy, such as the LAI and *k*, determine the light distribution, and it plays an important role in N distribution in the canopy (10). Species with more horizontally orientated leaves produce stands with high *k* values resulting in a more attenuated light climate, and will therefore be expected to reallocate more N towards the top of the canopy in order to enhance their photosynthetic performance (1).

The objective of this study was to document the effects of canopy architecture and N distribution on biomass production in two species, maize and sunflower, that differ in canopy architecture and photosynthetic pathway, under three different levels of N availability.

MATERIAL AND METHODS

A field experiment was sown on 19 Feb 1999 at Gatton, southeast Queensland. A split plot design with three replications was used. Main plots consisted of three N levels: 0 kg N/ha (N1), 50 kg N/ha (N2) and 150 kg N/ha (N3); with residual soil nitrate measured at 31 kg/ha. Subplots consisted of two species: maize (Hycorn 53) and sunflower (Hysun 36). Frequent quadrant harvests were made to measure above ground biomass, LAI, and N uptake. However, only results around anthesis (60 day after sowing) are shown here. Harvest samples were divided into height layers (0 to 50 cm; 50 to 100 cm; 100 to 150 cm and greater than 150 cm) to gather data on the vertical distribution of biomass and N. Light interception (PAR) at noon was recorded by canopy layer throughout the experiment. Extinction coefficient (*k*) was derived from the exponential regression of light interception versus LAI:

$$LI = 1 - e^{-kLAI}$$

Specific leaf nitrogen (SLN) was calculated as the quotient of leaf nitrogen content (LNC) and specific leaf area (SLA). RUE (g/MJ) was derived from the slope of the linear regression of accumulated biomass against cumulative intercepted total solar radiation.

Results

N and species had a significant effect on biomass but the interaction was not significant. Biomass was higher in maize than in sunflower (Table 1). In both crops, dry matter production was increased by applying 50 kg N/ha (from N1 to N2), but there was no significant difference between N2 and N3. RUE was significantly lower in sunflower than in maize, but did not differ significantly among N treatments, although it was slightly increased by higher N levels (Table 1).

Table 1. Above ground biomass, leaf area index (LAI), specific leaf nitrogen (SLN), light interception, total nitrogen uptake, extinction coefficient (*k*) and radiation use efficiency (RUE) for sunflower and maize for different N levels at 60 days after sowing.

Species	N levels	Biomass	RUE	LAI	Total nitrogen Uptake	Light interception	k	SLN
		(g/m2)	(g/MJ)	(m^2/m^2)	(g/m^2)			(g/m^2)
Sunflower	1	441	1.35	2.38	5.76	0.949	1.12	1.38
Sunflower	2	579	1.65	3.45	10.24	0.973	1.04	1.58
Sunflower	3	655	1.85	4.31	15.40	0.980	0.98	1.81
Maize	1	530	1.97	2.50	5.26	0.763	0.50	0.98
Maize	2	671	2.22	3.12	8.69	0.890	0.54	1.49
Maize	3	725	2.43	3.60	12.49	0.934	0.54	1.75
LSD*		118		0.67	2.28	0.24		0.19

LSD**	124	0.75	1.67	0.25	0.12

(*) LSD for comparing N level in the same species.

(**) LSD for comparing species at same N level.

Total LAI did not differ significantly between species but differed significantly among N levels (Table 1). LAI was increased by N level. In maize there was no significant difference for LAI between N2 and N3 but both treatments differed significantly from N1. In sunflower, there were significant differences among all treatments for LAI. Fig. 1a and b shows the distribution of cumulative LAI for maize and sunflower at all N levels within the canopy. Although plant height and cumulative LAI were different among N levels, the relative distribution of cumulative LAI was similar within both species at different N levels.

N uptake was significantly higher in sunflower than in maize. In both species, total N uptake increased with N level (Table 1).

Sunflower intercepted more radiation than maize. Light interception did not differ significantly among N treatments, although LI tended to increase with N level (Table 1).*k* was significantly *less* in maize than in sunflower. Across all N-levels, *k* was 0.53 for maize and 1.05 for sunflower. *k* was not significantly affected by N treatment (Table 1).

There were significant species x nitrogen interactions for SLN based on the whole canopy (Table 1). SLN was significantly less in maize than in sunflower, but increased more in maize with increasing N level. At the bottom of canopy, there were no significant differences in SLN between species, but differences were significant at the top of the canopy, with sunflower having higher values than maize. As a result, maize had more uniform N distribution than sunflower (Fig. 1c and d). In both crops, SLN was increased by N availability (from N1 to N3). The SLN per leaf strata was linearly related to I/Io (after transformation with natural logarithm) (Fig. 2a and b). The slope of regression did not change significantly with species and N availability.

Discussion

Differences in biomass at 60 DAS between irrigated maize and sunflower could be attributed largely to RUE rather than light interception. RUE of maize was higher than sunflower. Differences in biomass among N levels could be attributed to differences in both RUE and light interception (LAI). RUE increases with hyperbolical increases of leaf N (16). Consequently, the reduction in biomass production was associated with much larger reduction in RUE than in radiation interception (14).

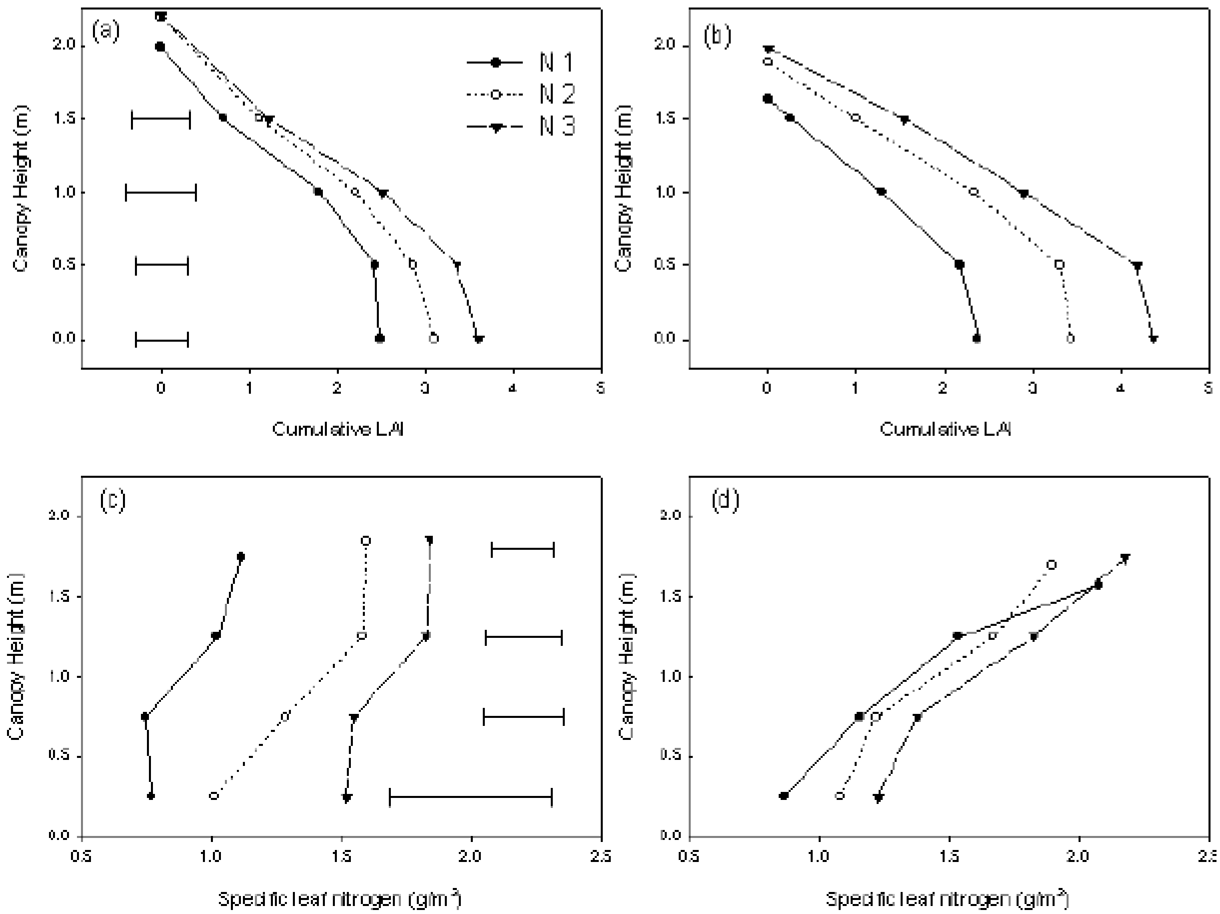

Figure 1. Canopy distribution of cumulative LAI from top to bottom (a, and b) and SLN (c and d) for maize (a and c) and sunflower (b and d) at all N levels. Horizontal bars are LSD for comparing N levels for the same species.

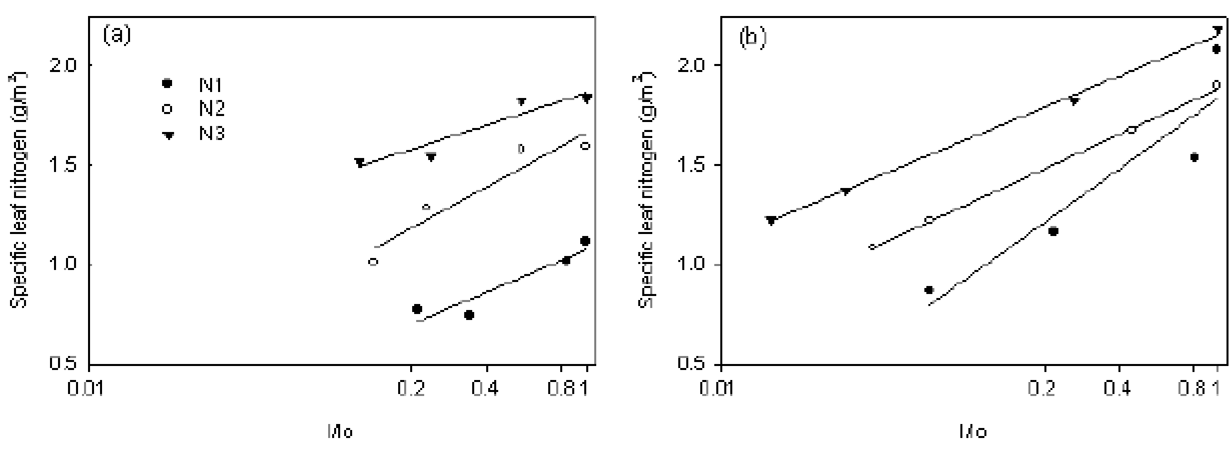

Figure 2. Specific leaf nitrogen (SLN) as a function of proportion of PAR absorbed (I/Io) for maize (a) and sunflower (b) at all N levels.

Nitrogen levels affect leaf area and SLN. Both species reduced LAI and SLN in response to N limitations. However, sunflower reduced LAI relatively more than maize. Consequently, sunflower favours the maintenance SLN more than maize (Fig. 1a, b). Leaf area reduction under N-stress was largely a result of reduced leaf size (data not shown), although reductions in leaf number may occur under extreme condition (4).

The values of *k* established here for sunflower (*k*=1.05) and maize (*k*=0.53) were similar to those established in other studies (2, 8, 9). *k* was slightly higher at low than at high N for sunflower (Table 1). This may be because at low nitrogen, leaves were smaller but appeared more horizontal than at higher N level. Similar results were found by Dreccer (6) in wheat. While Gimenez et al. (9) found no effect of N supply or crop age on *k* in sunflower.

Sunflower and maize had non-uniform N distribution throughout the canopy as found elsewhere for sunflower (2) and for maize (7). The N distribution in the dicot was less uniform than in the monocot stands. In other work, there were no significant differences in the patterns of N distribution between C_4 (sorghum and amarantus) and C_3 (rice and soybean) species of the same architectural type (1). The light distribution within the canopy has been suggested as a determinant of leaf N distribution in the canopy (5). The differences in canopy architecture between maize and sunflower caused differences in light distribution, and associated N distribution. There is a clear relationship between canopy architecture and vertical N distribution, although it is confounded here by the difference in C pathway. The non-uniformity of the N distribution in maize and sunflower increased with *k*. A similar result was found by Anten et al. (1). The sunflower canopy had higher proportion of light intercepted at the top of canopy as result of higher *k* values. Consequently, sunflower reallocated more nitrogen towards the top of canopy and this would have enhanced photosynthetic production. On the other hand, maize had canopy architecture with low *k* values and light penetrated deeper in the canopy. Maize canopy tends to have more uniform vertical N distribution than sunflower, because the distribution of light in the maize canopy was more uniform. Anten et al. (1) suggested that the pattern of N distribution is mainly determined by *k* and the total amount of free nitrogen in the canopy. Patterns of N distribution can also be associated with differences in leaf photosynthetic nitrogen use efficiency (PNUE), as PNUE determines the photosynthetic rate of a leaf with given SLN for a given photon flux density (1).

Conclusion

Sunflower and maize had non-uniform N distribution throughout the canopy, particularly in sunflower with higher extinction coefficient. Therefore, there is a clear relationship between canopy architecture and vertical N distribution.

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