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Light Absorption and Competition in Mixed Sorghum-Pigweed Communities

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ABSTRACT

Plant productivity in a community is governed in part by its ability to absorb and utilize photosynthetically active radiation (PAR). Studies on weed competition with a crop for light are limited. The effect of pigweed (*Amaranthus hybridus* L. and *A. palmeri* S. Wats) competition on leaf area development, light absorption, and dry matter production of fully developed grain sorghum [*Sorghum bicolor* (L.) Moench] was evaluated in a field experiment on Pullman clay loam (a fine, mixed, thermic Torrertic Paleustoll) at Bushland, TX, in 1984. Profile measurements (0–0.3, 0.3–0.6, 0.6–0.9, and >0.9 m above ground) of absorbed PAR (APAR) and leaf area index (LAI) by species were taken at four densities of pigweed (0, 1, 4, and 12 plants m^{-2}). APAR calculated for sorghum in mixed communities of 1, 4, and 12 pigweed plants m^{-2} was 79, 77, and 49% of the APAR in weed-free sorghum. Sorghum LAI was reduced to 81, 65, and 37% of the LAI of weed-free sorghum in canopies with 1, 4, and 12 pigweed plants m^{-2}. Sorghum LAI was concentrated in the 0.3- to 0.6-m layer, while the taller pigweed plants had the greatest leaf area concentration above 0.6 m. By absorbing light in the upper canopy, pigweed reduced light penetrating into sorghum. Leaf measurements of photosynthesis and transpiration rates, leaf temperature, and stomatal resistance indicated a relatively minor degree of water stress under full canopy and high potential evaporation conditions; the level of water stress measured was not adequate to explain sorghum dry matter reduction in plots with 1, 4, and 12 pigweed plants m^{-2} to 78, 56, and 28% of that in weed-free sorghum.

***Additional Index Words:* *Amaranthus palmeri*, *Amaranthus hybridus*, *Sorghum bicolor*, Leaf area index, Photosynthetically active radiation, Light competition.**

THE PRODUCTIVITY of plant communities is governed in part by their ability to absorb and utilize photosynthetically active radiation (PAR). Leaves are the primary tools for light absorption by crop plants, particularly during the canopy development phase. Numerous studies (Clegg et al., 1974; Loomis et al., 1968: Arkin et al., 1978) with various crops have shown an exponential relationship between leaf area index (LAI) and transmitted light in a canopy. While Rosenthal et al. (1985) showed that absorption of PAR by panicles and stalks of sorghum is important, especially after the onset of senescence, they also reported that absorbed PAR (APAR) for sorghum increased exponentially with LAI throughout the growing season until maximum LAI was reached.

Adams et al. (1976) indicated that soil shading or plant cover was a better indicator of light transmission than LAI in row spacing studies of sorghum. Steiner (1987) also reported that planting geometry can affect the transmission of light to the soil surface at a given LAI. However, for studies conducted under agronomically common geometries, the absorption of light is well related to LAI, and leaf area measurements are more easily analyzed in a three-dimensional study than is plant cover. Arkin et al. (1978) and Clegg et al. (1974) considered planting geometry or row spacing effects in the mathematical description of light transmission through a canopy as a function of leaf area.

Loomis et al. (1968) found that the structure of the upper canopy of corn (*Zea mays* L.) was critical in determining light penetration into the canopy. Clegg et al. (1974) reported similar findings for sorghum, showing that the upper half of the canopy, containing 38% of the leaf area, intercepted 70 to 80% of the incoming PAR. Sakamoto and Shaw (1967) also found that the light intercepted by a soybean [*Glycine max* (L.) Merr.] canopy was concentrated at the top and periphery of the canopy and was affected by lodging.

In mixed crop-weed communities, competition for light is a major factor affecting crop yield. Weed density and morphology affect distribution of light in the canopy and absorption of PAR by the crop. Models have been developed recently to describe competition for light in mixed communities based on the vertical distribution of leaf area of each species in layers. Rimmington (1984) predicted growth of mixed populations using a layered canopy and utilizing the optical properties of each species when grown in monoculture. Spitters and Aerts (1983) simulated competition between species based on the shares of light and water absorbed by each species, again based on a vertically layered plant canopy. However, few studies reported in the literature describe the penetration of light into mixed-species communities or the vertical distribution of leaves in mixed canopies.

Pigweed species are the most common broadleaf weeds in sorghum fields in the Great Plains (Wiese, 1981), inflicting serious yield losses to the crop (Shipley and Wiese, 1969). Chandler (1981) has estimated that weed competition costs sorghum producers in the United States almost $250 million per year in yield reductions. However, field studies quantifying the effect of weed competition on sorghum growth have been limited. The purpose of this study was to describe the distribution of leaves in a sorghum-pigweed mixed canopy and to quantify the effects of pigweed competition on the absorption of light in a fully developed grain sorghum canopy.

MATERIALS AND METHODS

The study was conducted in 1984 at the USDA-ARS Conservation and Production Research Laboratory in Bushland, TX, on a Pullman clay loam in level basin plots. Grain sorghum 'Funk 1711' was planted on 4 June in 6- by 40-m plots at 12 plants m^{-2} with 1-m row spacing. The area was heavily infested with pigweed seed, because weeds had been allowed to mature and set seed for 2 yr prior to conducting the study. A natural stand of pigweed, a mixture of smooth pigweed and Palmer amaranth, emerged at the same time as the sorghum and was thinned on 6 and 7 July to 0, 1, 4,

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and 12 plants m^{-2} intrarow with sorghum. Plots were checked weekly after the original thinning to maintain the desired population levels of pigweed.

Water and fertility were managed for high sorghum yields. The soil water holding capacity of plant available water is 0.2 m in a 1.5-m soil profile (Unger and Pringle, 1981). Soil water was maintained at greater than 50% of plant available water through the season. Two 100-mm irrigations were applied on 30 May and 8 August, and 310 mm of rainfall was received during the growing season. Fertilizer (18-46-0) was applied at a rate of 735 kg ha^{-1} (130 kg N ha^{-1} and 150 kg P ha^{-1}).

Transmission and reflection of light within the canopy was measured at a single site in each plot at 0, 0.3, 0.6, and 0.9 m above the soil surface using the top of the beds as a zero reference point. Profile stands to hold the instrumentation were constructed with crossbars at 0.3-m intervals from ground level to 1.5 m above the ground. Two stands were positioned directly opposite each other in adjacent rows parallel to and as close to the plant stalks as possible. Two Li-Cor[1] (Li-Cor, Inc., Lincoln, NE) 191SB Line quantum sensors (0.0127- by 1.0-m sensing surface) were placed perpendicular to the rows at each of four levels. One bar faced upright for reception of transmitted PAR, the other was inverted for reception of reflected PAR. Instruments were staggered to avoid mutual shading. Two Li-Cor 190SB quantum sensors (sensing surface 100 mm^2) were placed above the canopy to monitor incoming and reflected PAR. Readings were taken from the field plots in succession. The 10 sensors were connected to a Polycorder[1] data logger (Omnidata International, Inc., Logan, UT), and a set of 10 scans was initiated. For each scan, each sensor was sequentially read for 100 ms. A plot reading took about 25 s, after which the quantum sensors were moved to the next field plot. Measurement of the entire experiment took about 30 min per set of readings. APAR for each layer and for the entire profile was calculated as follows:

$$APAR_n = [(I_u - Refl_u) - (Trans_l - Refl_l)]/Io \times 100 ,$$

where $APAR_n$ = absorbed PAR (%) for layer n, I_u = incoming PAR at the top of layer n, $Refl_u$ = reflected PAR at the top of layer n, $Trans_l$ = transmitted PAR at the bottom of layer n, $Refl_l$ = reflected PAR at the bottom of layer n, and Io = incoming PAR at the top of the canopy. Five sets of readings were taken between 15 and 20 August [sorghum growth stage 6 (Vanderlip and Reeves, 1972)] during cloudless periods near solar noon. All quantum sensors were intercalibrated prior to the experiment.

Leaf photosynthesis and transpiration rates were measured using a Li-Cor[1] LI-6000 photosynthesis system in conjunction with light profile measurements. The LI-6000 is a closed circulation system that monitors changes in CO_2 and relative humidity within the sampling chamber during the measurement period. Each 30-s measurement consisted of 10 30-s scans, the mean value of which was used for statistical analysis. Stomatal resistance and leaf temperature were also monitored with the LI-6000. Three fully expanded, sunlit leaves were sampled on each plot, with 1520 mm^2 of leaf area exposed within the chamber, giving a total of nine measurements per treatment. Measurements were made on randomly selected flag leaves or penultimate leaves. To collect a set of readings from all plots in the experiment required less than 1 hr. Five sets of readings were taken near solar noon between 15 and 21 August in conjunction with the light interception measurements. Because the experiment was designed with complete blocks, a diurnal trend in photosynthesis could have been removed as a block effect, but there was no significant effect of blocks on any set of readings.

Plants were cut by layer from within the profile stands on 21 August. LAI, dry matter, and head weight (when present) were determined for each species by layer and for the entire profile.

The experimental design was a randomized block with three replications. Data were analyzed by analysis of variance, and means compared by the Student-Newman-Keuls test at a significance level of 5%.

RESULTS AND DISCUSSION

Three main sources of competition among plants are those for nutrients, water, and light. Allelopathic effects of pigweed residues have also been reported (Connick et al., 1986); however, all plots were exposed to uniform weed levels during the germination and establishment of sorghum, which is the period when most plants show the greatest sensitivity to allelopathic effects. Partitioning of yield reduction due to water, nutrient, and light competition is not possible in our study; however, both nutrients and water were managed so as not to be limiting to a weed-free sorghum crop. Spitters and Aerts (1983) suggested that these conditions would result in the greatest competition for light in mixed-species canopies. No significant difference in seasonal water use from thinning to maturity was observed among treatments (230, 255, 230, and 195 mm for 0, 1, 4, and 12 pigweed plants m^{-2}, respectively), indicating that each sorghum and pigweed plant in the weedy plots would have utilized less water than plants in the weed-free plots.

The distribution of PAR absorption in the canopy by height is shown in Fig. 1. Total APAR was 12 and 16% higher with pigweed populations of 4 and 12, plant m^{-2}, respectively, compared to weed-free sorghum (Fig. 1). In weed-free sorghum, over 50% of the total leaf area occurred in the 0.3- to 0.6-m layer, with high penetration of light into that region. In mixed populations, pigweed was generally taller than sorghum, with plant heights of over 1.4 m observed. For mixed canopies, relative to weed-free sorghum, light absorption was decreased between 0.3 and 0.6 m, which was a region dominated by sorghum, and increased significantly above 0.9 m where pigweed leaf area dominated.

As weed populations increased, the distribution of leaf area became more uniform by height throughout the profile, and light was increasingly absorbed in the upper layers of the profile by pigweed leaves. Combined total LAI of both species (CLAI) did not differ significantly among treatments (Fig. 1). An approximation of the light absorbed by each species was obtained by multiplying the percent of CLAI within a layer represented by each species by the APAR for that layer. Above 0.9 m, 13 and 41% of total incoming PAR was absorbed by pigweed populations of 4 and 12 plants m^{-2}, respectively. Estimated total APAR by sorghum in mixed populations was 79, 77, and 49% of total APAR in weed-free sorghum for weed populations of 1, 4, and 12 plants m^{-2}. These results are consistent with those of earlier studies by Loomis et

[1] Trade and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product listed by the USDA or by the Texas Agricultural Experiment Station, nor do they imply registration under FIFRA as amended.

al. (1968) and Clegg et al. (1974), which found that the structure of the upper canopy affected light penetration into the canopy. Sorghum total LAI decreased with increasing number of pigweed (Table 1).

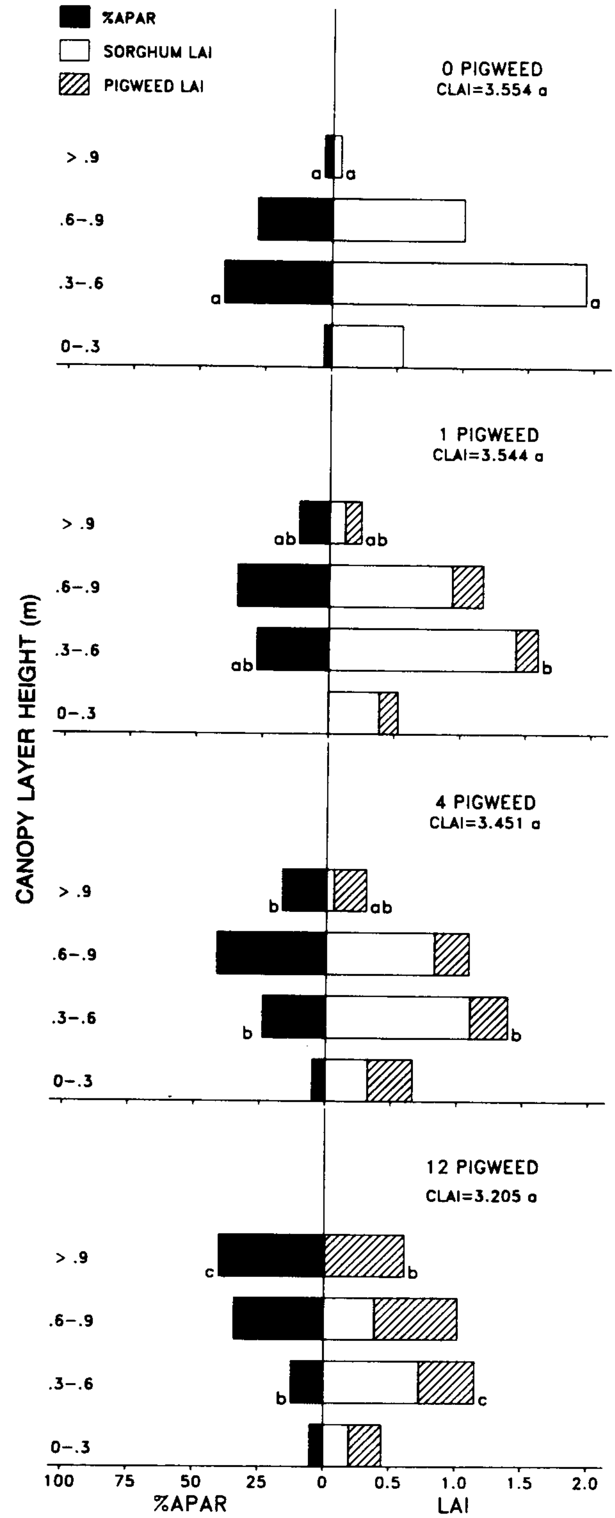

Fig. 1. Light absorption and LAI as affected by height (m) within the canopy. Letters following bars indicate significant differences ($P<0.05$) between treatments by layer for CLAI (sorghum LAI + pigweed LAI) and APAR, determined by Student-Neuman-Keuls multiple range test.

Maximum sorghum leaf area occurred between 0.3 and 0.6 m above the ground for all treatments. The greatest reductions in sorghum LAI also occurred between 0.3 and 0.6 m, with reductions of 26, 43, and 62% for populations of 1, 4, and 12 pigweed plants m^{-2}, respectively.

Sorghum photosynthesis rates decreased significantly in weedy treatments, compared to weed-free treatments (Table 2). Previous work (Steiner, 1987) has showed that these measurements can be used to detect water stress. There was no significant difference in initial CO_2 levels among treatments, indicating CO_2 in the ambient canopy had not been depleted by increasing pigweed numbers or by reduced mixing within the canopy. Incoming light levels at the chamber at the time of the readings did not differ among treatments (data not shown). Leaf temperatures increased slightly with pigweed number, and the highest stomatal resistance of sorghum was measured in pigweed populations of 12 plants m^{-2}, which also had the lowest transpiration rate. The ratio of photosynthesis to transpiration was significantly reduced by all levels of pigweed, indicating that pigweed competition reduced the photosynthetic efficiency (milligrams CO_2 assimilated/H_2O lost through transpiration) of sorghum.

Overall, the leaf photosynthesis/transpiration ratio measurements indicated a slight water stress under full-canopy, midday conditions in the sorghum plants subjected to pigweed competition. Because the measurements were made under conditions when the evapotranspiration rate was near its seasonal maximum (full cover, high radiation, high temperature), near maximum competition for water should have been observed. However, the level of water stress measured in this experiment was not sufficient to account for the drastic reductions in sorghum growth that were

Table 1. Sorghum and pigweed leaf area index (LAI), dry matter (DM), and sorghum head weight (HW) on 21 August.

		Sorghum			Pigweed	
Canopy height	Pigweed density	LAI	DM	HW	LAI	DM
m	plants m^{-2}		g m^{-2}			g m^{-2}
0-0.3	0	0.55a†	188a	--	--	--
	1	0.39a	142b	--	0.14a†	52a
	4	0.33a	99c	--	0.34b	110b
	12	0.20a	57d	--	0.25ab	124b
0.3-0.6	0	1.94a	189a	3a	--	--
	1	1.43b	137b	0a	0.17a	38a
	4	1.10c	111c	1a	0.29b	64b
	12	0.73d	58d	1a	0.42c	100c
0.6-0.9	0	1.01a	116a	51a	--	--
	1	0.94a	99a	38a	0.24a	42a
	4	0.83a	67b	20b	0.26a	68a
	12	0.39b	30c	9b	0.63b	114b
>0.9	0	0.07a	20a	17a	--	--
	1	0.12a	23a	14a	0.13a	40a
	4	0.06a	10b	3b	0.25ab	74a
	12	0.01a	1b	1b	0.61b	159b
Total	0	3.55a	513a	72a	--	--
	1	2.87b	401b	52b	0.68a	173a
	4	2.31c	287c	25c	1.14a	322b
	12	1.30d	147d	12c	1.90b	296c

† Means within each layer followed by the same letter are not significantly different ($P < 0.05$) as determined by Student-Newman-Keuls Multiple Range Test.

Table 2. Effect of pigweed competition on sorghum leaf temperature, stomatal resistance, transpiration, photosynthesis, and photosynthesis/transpiration ratio of upper sunlit leaves.

Pigweed density	Leaf temperature	Stomatal resistance	Transpiration	Photosynthesis	Photosynthesis/ transpiration ratio
plants m^{-2}	°C	s m^{-1}	mg H_2O m^{-2} s^{-1}	mg CO_2 m^{-2} s^{-1}	mg CO_2/mg H_2O
0	32.27a†	66.98a	247.0ab	1.5849a	0.006614a
1	32.92ab	80.49ab	234.9ab	1.3662b	0.006051b
4	32.99ab	70.15a	251.6a	1.4110b	0.005806b
12	33.34b	87.46b	215.1b	1.2386b	0.005832b

† Means followed by the same letter are not significantly different ($P < 0.05$) as determined by Student-Newman-Keuls Multiple Range Test. Means are from five sets of readings taken between 15 and 21 August.

measured (Table 1). Sorghum LAI on 21 August (74 DAP) was reduced to 80, 65, and 37% of that of weed-free sorghum by 1, 4, and 12 pigweed plants m^{-2}, while plant dry matter was reduced to 78, 34, and 17%, respectively. This indicates that early season competition reduced leaf growth by sorghum, but subsequent shading by the taller pigweed plants resulted in an even greater reduction in light interception by the sorghum plants. Head weight was reduced to 72, 34, and 17% of that of weed-free sorghum for the respective pigweed levels. Final grain yield was reduced to 74, 49, and 31% of that of weed-free sorghum by populations of 1, 4, and 12 pigweed plants m^{-2}.

In this study, the maximum effects of pigweed competition on sorghum light absorption were measured by monitoring light penetration into fully developed canopies. The effects of weed density were evident throughout the growing season. Once competition had caused reduced sorghum leaf area development, future potential light absorption was reduced also. On 45 DAP, prior to measurement of significant differences in sorghum LAI, midday leaf photosynthesis rates were significantly reduced in all weedy treatments, indicating possible competition for water at that time.

In work with smooth pigweed, foxtail (*Setaria* spp.), and crabgrass (*Digitaria* spp.), Burnside and Wicks (1967) found that if sorghum was kept weed free the first 4 wk after planting, subsequent weed growth did not significantly reduce yield because the larger sorghum plants could out-compete the weeds. Using experimental data from numerous studies to determine critical periods of crop-weed competition, van Heemst (1985) found sorghum to be very susceptible to weed competition, with a critical period of weed-crop competition extending to 21% of the length of the total growth cycle. Our study, however, indicates that pigweeds that germinate early in the season compete with sorghum throughout the entire season. Conditions were uniform in all plots for the first 30 d of the growing season, but the plants were very sensitive to differential competition throughout the rest of the season.

Results from this study show that competition for light is important in sorghum-pigweed mixtures. Even in well-watered, fertilized plots, drastic dry matter and yield reductions were seen, which corresponded to similar reductions in the amount of light intercepted by sorghum. Although there are many aspects of weed competition that are not well understood, the importance of light competition should not be underrated. Further studies are needed to describe the early effects and magnitude of light competition and help determine economically limiting threshold values of when competition for light becomes limiting.

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