

## Sheltering 3-dwarf with taller 2-dwarf grain sorghum\*

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**ABSTRACT.** — Two isogenic lines of 'RS 702' hybrid grain sorghum (*Sorghum bicolor* [L.] Moench) were seeded on four 45- by 90-m plots at the following proportions (percentages) by weight of 2- and 3-dwarf seed: 100/0, 13/87, 25/75, and 0/100. Sheltering by the tall, 2-dwarf plants grown interspersed among the shorter, 3-dwarf plants improved water stress relationships of the 3-dwarf, as indicated by higher leaf water potential and lower stomatal resistance. However, the shading reduced the amount of light for use by the 3-dwarf plants. Seeds produced by the 2-dwarf plants were bigger than those from 3-dwarf plants. For 2-dwarf, seed weight increased as the percentage of 2-dwarf plants decreased. Likewise, total grain and stover produced per culm of 2-dwarf plants increased as the percentage of 2-dwarf decreased. Yield of grain per culm was much greater for the 2-dwarf than the 3-dwarf even in solid stands. Two-dwarf mixed with 3-dwarf promoted grain/stover ratio of the 2-dwarf plants but suppressed this ratio in 3-dwarf plants.

Many crops have responded favorably to barrier-induced microclimates in the Great Plains macroclimate (15, 17, 20). One problem with wind barriers is that they occupy space which reduces the land area available for the main crop. Vegetative barriers compete for water, nutrients, and sunshine. However some barriers, like corn windbreaks, sheltering other crops, like sugar beets (1, 16) and soybeans (14) are themselves an economic crop. Even here the crop used for the barrier often is difficult to harvest. Our idea was to explore the possibility

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of using a single, adapted sorghum variety with isogenic lines for two heights, the main height grown commercially and a taller plant of the same variety interspersed to provide sheltering protection. Ideally, both the tall and short plants could be harvested together.

Theoretical considerations of such a scheme were explored in another paper (7). We demonstrated the possibility of reducing turbulent exchange from a crop by interspersing a few tall plants in it. We calculated that barrier plants 2 cm in diameter, 72 cm above the crop, and 40 cm apart would reduce shear stress by 50 % on the sheltered crop. A 35 % reduction could be achieved with 57 cm spacing.

A shelter system using tall interspersed plants has the obvious advantage of not being affected by wind direction. Such a system would work best to shelter nearly light saturated crops so that shading from the barrier crop would not substantially decrease photosynthesis in the shelter crop.

**MATERIALS & METHODS.** — June 1, 1973, we seeded two isogenic lines of 'RS 702' hybrid grain sorghum (*Sorghum bicolor* [L.] Moench) on four 45- by 90-m plots at the following proportions by weight of 2- and 3-dwarf seed: 100/0, 13/87, 25/75, 0/100.

On July 12, 24 and August 3 and 30, all leaves of five plants in each group were measured in detail. The leaf measurements were: distance from ground to leaf collar, angle between leaf blade and vertical axis of plant, distance from leaf collar to break in leaf, angle of leaf after break, leaf blade length and width (widest point), and percentage of leaf that seemed functional (deep green). Culm diameter near the ground was measured each time, except on July 12. Distance from ground to panicle, panicle length, and peduncle length were measured August 30.

August 8 leaf blade width was measured at 1-cm intervals on four leaves at each of four different heights from the ground to obtain a shape relationship of leaves. Third degree polynomial was fit to the data by method of least squares to obtain  $W/W_0 = f(L/L_0)$  where  $W$  is leaf width at  $L$ ;  $L$  is distance from point of leaf attachment along leaf blade to point in question;  $W_0$  is width of leaf at widest point; and  $L_0$  is total leaf length. The shape relationship was used in calculating leaf areas.

A computer program was written and used with the detailed leaf measurements as input data to calculate leaf area density profiles. The leaf area density profiles ( $F$ ) and canopy windspeed profiles, computed after Shin & Cionco (19), were used to calculate drag distribution  $[(U/U_h)^2 F]$  with depth into the vegetation (9).  $U = U_h \exp[\alpha(z/h - 1)]$  where  $U$  and  $U_h$  are windspeeds at height  $z$  and canopy top ( $h$ ), respectively;  $\alpha$  is coefficient characteristic of crop. For our measurements we used an  $\alpha$  value of 2.0, the value Shinn and Cionco (19) gave for corn.

Leaf-water potentials and stomatal resistances (both surfaces) were estimated with pressure bomb and stomatal resistance meter, res-

pectively, for selected days on 2- and 3-dwarf plants in both solid and mixed stands. Each observation consisted of at least four measurements.

Incoming short-wave radiation was measured with an Eppley<sup>3</sup> pyranometer and converted to photosynthetically active radiation (PAR) (400- to 700-nm waveband) from the relationship we found for PAR as a function of short-wave radiation. The 400-to 700-nm waveband was measured with Lambda Quantum Sensor (trade names are given for the benefit of the readers and do not imply endorsement or preferential use by the U.S. Dept. of Agriculture). Light reaching the bottom of the canopy was measured with Lambda Quantum Sensors mounted on a traversing mechanism so they would traverse 76 cm (1 row width) in a back-and-forth motion at approximately 2.5 cm/sec with a slight hesitation when changing directions. The sensors were read at 10-sec intervals by the computer-controlled, data-acquisition system.

The radiation fluxes at the upper and lower boundaries of the canopy and leaf area index data were used in the Bouguer-Lambert relation to determine an extinction coefficient. Bouguer-Lambert law is  $I = I_0 e^{-KL}$  where  $I$  and  $I_0$  are the radiation fluxes at the lower and upper boundaries;  $L$  is the leaf area index, and  $K$  is the extinction coefficient.

Assuming a constant extinction coefficient, using the Bouguer-Lambert relation and measured incoming radiation, we calculated radiation fluxes at 0.1-cm intervals in the canopy. Then, from the relationship (E. T. Kanemasu, unpublished data) between PAR flux densities and photosynthesis per unit leaf area, we calculated photosynthesis per unit leaf area for each 0.1-cm layer.

**RESULTS & DISCUSSION.** — Sheltering the short 3-dwarf by the taller 2-dwarf plants improved the water stress relationships of the 3-dwarf, as indicated by their higher leaf water potential and lower stomatal resistance (Table 1). However, the sparse 2-dwarf plants standing about 1 m above the 3-dwarf plants had a light-enriched environment; whereas, the 3-dwarf plants had a rather low-light environment because of shading. Competition for light apparently had more effect on the ability of the 2-dwarf material to produce than it did on the reduction of the 3-dwarf material. Neither grain per culm nor forage per culm among the three 3-dwarf plantings were significantly different at the 1 % level (Table 2).

The seeds produced by the 2-dwarf plants were bigger than the seeds from 3-dwarf plants. Two-dwarf seed weight increased as the percentage of 2-dwarf plants decreased. Likewise, total grain and stover produced per culm of the 2-dwarf increased as the percentage of 2-dwarf decreased and yield of grain per culm was much greater for the 2-dwarf than that for the 3-dwarf even in the solid stands. Two-dwarf mixed with 3-dwarf promoted grain/stover ratio of the 2-dwarf but suppressed this ratio in 3-dwarf.

The appearance of the 2- and 3-dwarf sorghum plants was identical for the first month or more after seeding. By 6 weeks after

TABLE 1. Leaf water potential and stomatal resistance of 2- and 3-dwarf grain sorghum grown together.

% by weight	Leaf water potential			Stomatal resistance	
	8/8/73**	21/8/73**	27/8/73*	21/8/73**	27/8/73**
	bars			sec/cm	
2-dwarf (13)	-11.3 bc	-17.2 c	-17.7 ab	2.4 a	2.8 a
2-dwarf (25)	-11.9 c	-13.5 b	-19.1 b	2.2 ab	3.1 a
2-dwarf (100)	-12.1 c	-16.5 c	-15.9 a	2.1 b	2.8 ab
3-dwarf (75)	-10.9 abc	-12.6 ab	-15.8 a	1.6 c	2.2 bc
3-dwarf (87)	-9.7 a	-11.0 a	-15.7 a	1.2	2.4 c
3-dwarf (100)	-10.0 ab	-16.3 c	-19.3 b	1.8 bc	2.1 c

\* and \*\* The 2-dwarf (13, 25) differs significantly from 3-dwarf (87, 75) counterpart at 0.05 and 0.01, respectively, according to T-test for means of two populations..

Means for each column followed by the same letter are not different at the 0.05 level according to Duncan's New Multiple Range test.

seeding (July 12, 1973) the 2-dwarf was about 20 cm taller (Fig. 1). Culm elongation of the 2-dwarf was rapid for 2 or 3 weeks. Between July 12 and 24 the leaves of 3-dwarf plants grew rapidly, increasing in leaf area index from 3.5 to 5.0 but their total height did not change. During the same period, leaves of the 2-dwarf plants also grew about the same as those of the 3-dwarf plants, but 2-dwarf culms elongated a little (Fig. 2).

Total leaf area index of both the 2- and 3-dwarf plants decreased by approximately 1/3 between July 24 and August 30 with a slightly modified leaf area density profile (Figs. 1 and 2). The decreased leaf area was caused mostly by senescence.

Most of the vertical transfer of horizontal momentum is in the upper portion of the plant canopy of the solid stands of 2- and 3-dwarf plants (Fig. 2). But in a mixed stand of 25 % 2-dwarf and 75 % 3-dwarf the leaf area density is low in high windspeed regions. As leaf area density gets larger in the lower canopy the windspeed is much slower, thus drag distribution with height is much more uniform (Fig. 2). The mechanisms for mass, momentum, and convective energy transfer in the bulk of either the solid 2-dwarf or solid 3-dwarf canopies will be much less than in the bulk of the mixed canopy.

TABLE 2. Comparisons of several growth and yield parameters of 2- and 3-dwarf grain sorghum grown in the indicated combinations.

	Seed planted	% by weight	Grain harvested		Forage per culm**		Grain/Forage ratio per culm*		Grain yield		Forage yield		Grain/Forage ratio		Seed weight**		Culm dia.*		Panicle length*	
			g	g	g	g	kg/ha	kg/ha	g/100	g/100	cm	cm								
2-dwarf	13	38	143 a	145 a	0.99 a	2688	2598	1.03	2.85 a	1.68 b	23.4 abc									
2-dwarf	25	68	125 a	134 a	0.93 a	5614	5773	0.97	2.61 b	1.72' b	22.4 bc									
2-dwarf	100	100	75 b	94 b	0.79. bc	9443	11481	0.82	2.43 b	1.72 b	21.2 c									
3-dwarf	75	32	38 c	54 c	0.70 c	2675	3646	0.73	1.64 d	2.42 a	24.2 abc									
3-dwarf	87	62	47 c	61 c	0.77 bc	4326	5487	0.79	1.58 d	2.38 a	26.4 a									
3-dwarf	100	100	49 c	58 c	0.84. b	8047	10195	0.79	1.89 c	2.14 a	25.1 ab									

\* and \*\* Means for each column followed by the same letter are not different at the 0.05 and 0.01 level, respectively, according to Duncan's New Multiple Range Test.

The 2-warf single plot (with subsampling) yielded 17 and 13 % more grain and stover, respectively, than the 3-dwarf (Table 2). Literature comparing yields from grain sorghums of two heights have shown that the taller one yielded more than the shorter one (2, 3, 5, 6, 11, 18, 21). These comparisons have included 1- and 2-dwarf (2), 2- and 3-dwarf (5), and 3- and 4-dwarf sorghums (18). Windscheffel et al. (21) and Casady (3) reported 13 and 10 %, respectively, greater yields for the 2-dwarf than the 3-dwarf. Usually the greater yields by taller plants was not explained. However, Graham & Lessman (5) suggested that less self-shading in taller plants likely allowed them to more efficiently use light than shorter plants.

Our calculations of photosynthesis from radiation flux density profiles and relationship between photosynthesis and radiation flux densities gave identical values for 2- and 3-dwarf canopies of the same leaf area index. Our simple model did not account for light fluctuations resulting from differences in structural rigidity of canopy nor differences in plant water stress conditions. Short light fluctuations

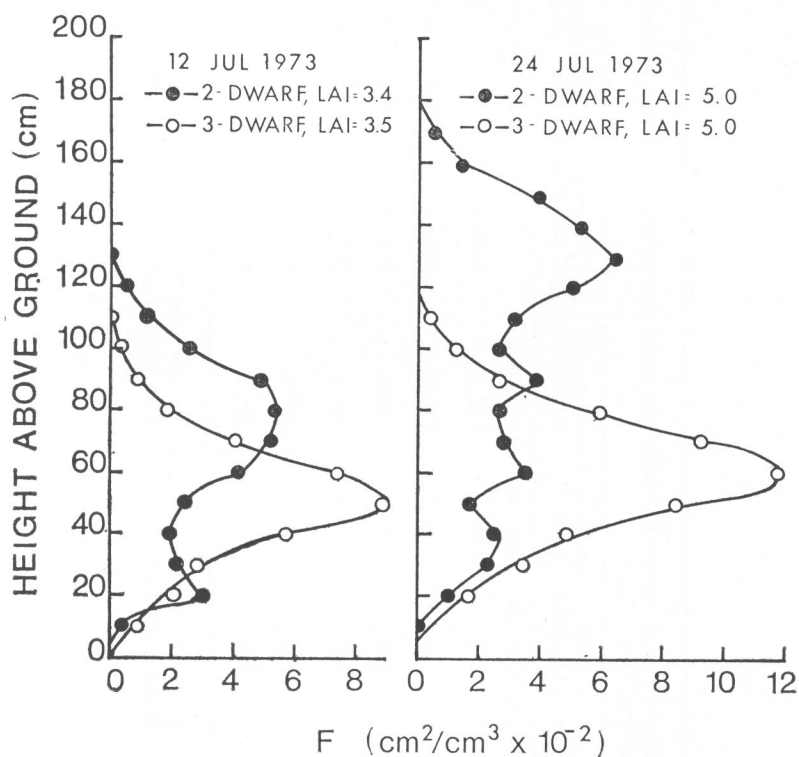


FIGURE 1. Leaf-area-density profiles (F) of 2- and 3-dwarf grain sorghum at Manhattan, Kansas.

(usually 3 sec. or less) have increased photosynthesis (8, 10, 12). The dark period after intense light can be used by the plant to complete the dark reactions of  $\text{CO}_2$  assimilations, thus alleviating the dark reactions as a major limitation to  $\text{CO}_2$  fixation (8, 13).

In our study the 2-dwarf plants with longer internodes, smaller culm diameter (Table 2), and less bracing from adjacent plants formed a much more flexible canopy which would have more light fluctuations. Desjardins et al. (4) found that more rigid strain of corn had fewer light fluctuations.

More light fluctuations and increased photosynthesis of some plants in response to light fluctuations suggests a possible explanation of the higher yields of taller grain sorghum. However, Desjardins et al. (4) concluded that the short-term light fluctuations they observed in corn would have little or no effect on the photosynthetic activity of a full-grown crop. McCree & Loomis (10) suggested that plants with a high photosynthetic capability (light saturation at high irradiance levels) would be less limited by dark reactions and, therefore, less likely to be increased in rapidly fluctuating light.

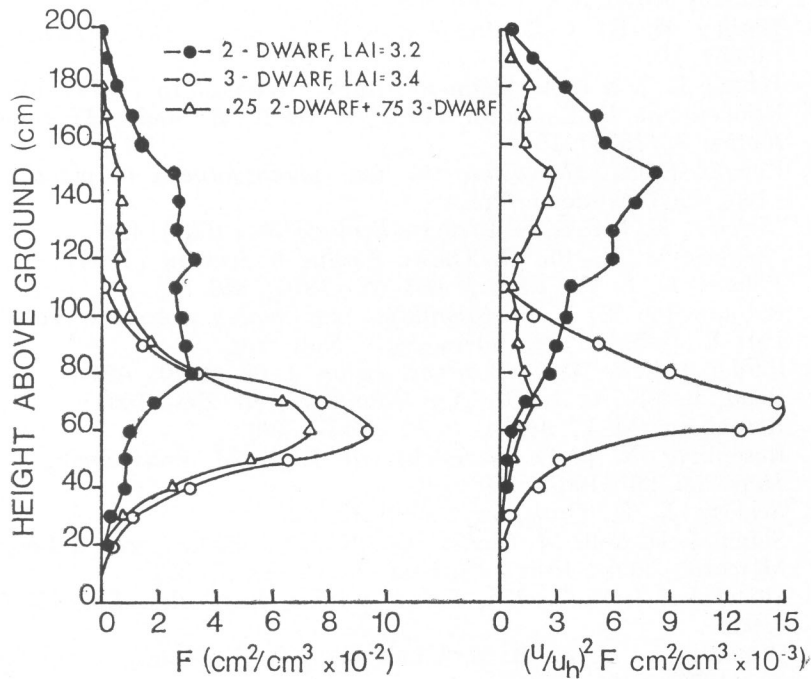


FIGURE 2. Leaf-area-density profile ( $F$ ) and drag distribution  $[(U/U_h)^2 F]$  in 2- and 3-dwarf grain sorghum at Manhattan, Kansas, on August 30, 1973.



Further study is needed to understand the mechanisms involved in the higher yields reported consistently for the taller isogenic lines of grain sorghum.

We found the taller plants more prone to lodge, like Windscheffel et al. (21) observed.

Our results showed promise for improving plant-water relations by sheltering with tall isogenic lines. However, shading apparently reduced photosynthesis of the sheltered plants while the tall plants' canopies were in a high-light environment. To further evaluate the net effect on yield of sheltering and shading, we need to replicate plots of 2-dwarf interspersed among 3-dwarf grain sorghum and also 2- and 3-dwarf grown under a variety of climatic conditions.

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