EFFECT OF LEAFLET TYPE IN SOYBEAN AND SOIL REFLECTANCE IN SOYBEAN AND SORGHUM CANOPIES ON NET CARBON DIOXIDE EXCHANGE

by

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INTRODUCTION

Sunlight is of basic importance in crop production. It is the energy source which drives the photosynthetic processes in the plant. An abundance of this energy, if efficiently used, can increase crop production by increasing photosynthesis. It is, therefore, desirable to maximize the efficient use of solar energy in the photosynthetic processes.

Photosynthetic efficiency is controlled by a large number of factors. Two major factors are the amount and distribution of sunlight intercepted by the crop canopy. Net carbon dioxide exchange (NCE) rates for both leaves and crop canopies are curvilinearly related to solar radiation with decreasing response at higher irradiances (Fig. 1) (Jeffers and Shibles, 1969; Bowes, Ogren, and Hageman, 1972; Brun and Cooper, 1967; Hesketh and Baker, 1967; and Waggoner, Moss, and Hesketh, 1963). Many leaves and canopies become light saturated at less than full sunlight (Kanemasu and Hiebsch, 1975). Because of this characteristic response curve and the uneven distribution of light in a crop canopy, it is anticipated that an additional quantity of light intercepted in the upper portion of the canopy where the light level is already high would not increase NCE as much as the same additional quantity intercepted in the lower portion of the canopy where the light level is relatively low.

An objective of this study was to investigate how plant morphology and crop management may affect NCE by allowing for greater interception or more even distribution of photosynthetically active radiation (PAR). In Chapter 1 the NCE of a narrow-leaflet soybean is compared with a near-isogenic normal-leaflet soybean at several populations and spacings. Hicks et al.

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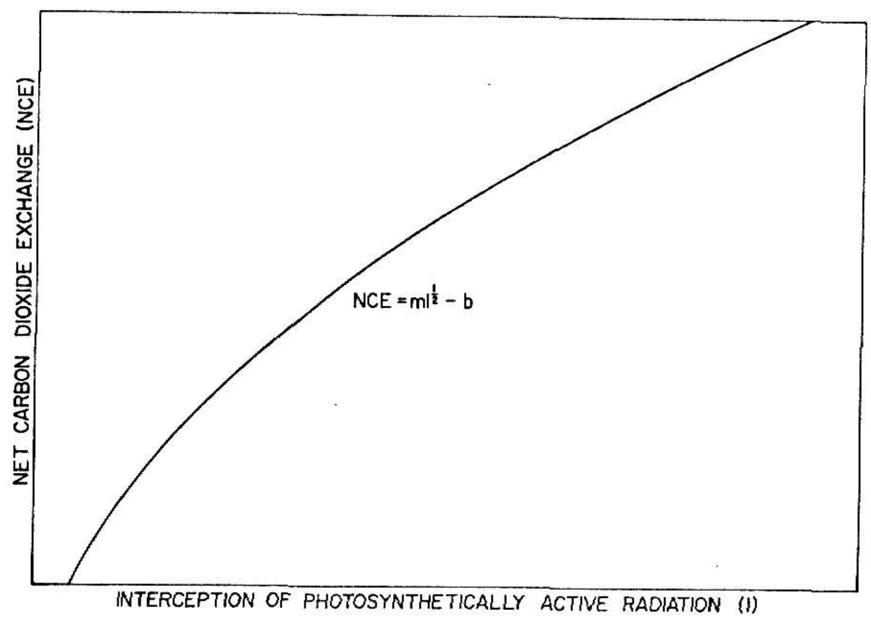

Fig. 1. Curvilinear relationship between net carbon dioxide exchange and interception of photosynthetically active radiation.

(1969) reported that light penetrated deeper into the canopy of the soybean with the narrow leaflet. In addition comparisons of light interception, water use, and water use efficiency (WUE) (yield per amount of water used, expressed in kg/ha) between narrow- and normal-leaflet soybeans are presented. The effect of increased soil reflectance on NCE of soybeans and sorghum is discussed in Chapter 2.

LITERATURE REVIEW

Using near-isogenic lines with narrow and normal leaflets of both the cultivars Harosoy and Clark, Hicks et al. (1969) reported that at the heights within the canopy where the normal-leaflet isolines were receiving 79 and 55% of the total insolation, the narrow-leaflet isolines were receiving 87 and 60%, respectively. The difference in light distribution within the canopies was particularly distinct within the upper strata. It was not clear as to whether the more even distribution of light interception in the narrow-leaflet isolines was due to the leaflet shape or smaller LAI reported. The redistribution of light could be of particular importance for a soybean canopy because (1) 90% of the sunlight is absorbed by the canopy periphery (Sakamoto and Shaw, 1967a) and (2) the canopy is light saturated before full sunlight (Sakamoto and Shaw, 1967b).

In the study of Hicks et al. (1969) yield was not affected significantly (P .05) by the difference in light distribution. Hartwig and Edwards (1970) also report no yield difference between near-isogenic lines of Lee with normal and narrow leaflets. The lack of a yield difference does not necessarily indicate, however, that NCE was not affected by the difference in distribution of light since in soybeans NCE is not directly related to yield

(Curtis, Ogren, and Hageman, 1969). Any discrepancy that might exist between yield and NCE in the normal- and narrow-leaflet near isolines could be due to podding characteristics. A single gene is responsible for both leaflet shape and number of seeds per pod, the narrow leaflet having more seeds per pod (Bernard and Weiss, 1973). Hicks et al. (1969) reported that the number of pods per plant was less, but the number of pods per plant with four seeds was greater in the narrow-leaflet soybean.

Data reported by Egli, Pendleton, and Peters (1970) indicate that at the proper spacing and population the narrow-leaflet type may have a larger NCE on a ground area basis than the normal-leaflet type. They reported that at equal populations, when the LAI of the Harosoy normal-leaflet was approximately 30% more than the Harosoy narrow-leaflet, the NCE rates on a ground area basis were not significantly different ($P<.05$). On a leaf area basis the NCE of the narrow-leaflet was then 28% greater. It would be of interest to make a comparison of NCE between the two leaflet types at more nearly equal LAI.

If, as reported by Hicks et al. (1969) and Egli et al. (1970), the LAI of the narrow-leaflet soybean is less than the normal-leaflet soybean then it is conceivable that transpiration rates and water use are less for the narrow leaflet. Thus, if yields are equal, the WUE (yield/water use) would be greater for the narrow leaflet. That could be advantageous where water supplies are short.

A reflective mulch on the soil could potentially have several effects upon plant growth. Surface soil temperatures would be reduced, causing either a favorable or unfavorable reaction depending on the optimum temperature required for root growth and germination. Reduced soil temperature would decrease evaporation from the soil which could allow for a more even moisture regime in the upper levels of the soil, encouraging root growth closer to the surface. Additional light reflected from the soil and intercepted by the plants may both increase NCE and transpiration. In our studies, kaolinite, a white clay, was spread on the soil surface for short time periods while soil moisture was adequate to minimize all effects except the effect of increased intercepted light upon NCE.

Several investigators have reported the effects of increasing the amount of light intercepted by the canopy either by supplemental electric lights or increased reflected sunlight. Pendleton, Egli, and Peters (1967) reported a theoretical yield of 23,710 kg/ha (377 bu/A), obtained in border rows which had large aluminum reflectors set at an angle to focus sunlight into the middle and lower parts of the canopy. That represented a 26% increase in yield over border rows without reflectors and was attributed not only to additional energy for the photosynthetic processes but to an associated elevated canopy temperature (Winter and Pendleton, 1970).

Pendleton, Peters, and Peek (1966) reported that the use of a white plastic mulch caused increases in yield of 7 and 12% for corn populations of 59,280 and 39,520 plants/ha, respectively. Since a black plastic mulch caused increases of 5 and 3%, respectively, for the two populations, they attributed the differences, 2 and 9%, to the additional intercepted light and the rest to soil water conservation.

Not all researchers have reported a beneficial effect of additional intercepted light. Aase, Kemper, and Danielson (1968) reported that under dry land conditions corn grown between white surfaces produced 29% less yield than between black surfaces. They suggested the reason for this reduction in yield caused by the white surfaces was due to slower emergence caused by cooler soil temperatures, greater evapotranspirative demands, and a 40% reduction in chlorophyll during the plants early growth caused by light-induced destruction. Yields reported would indicate that sunlight was not the limiting factor in this cropping situation, and an increase in the interception of sunlight only increased the stress; the highest yield recorded in four years was 4235 kg/ha.

Yields of C_3 plants have also been increased by placing a highly reflective mulch on the soil surface. Ashford and Read (1962) and Read and Ashford (1964) reported that a white Styrofoam mulch on pots growing sweet clover in the greenhouse caused an increase in the dry matter production when compared with pots without a mulch. They separated the contributions of soil temperature and moisture to increase in dry matter. The remaining increase they attributed to increased light interception by the plants.

Supplemental flourescent lights placed at three canopy levels, bottom, middle, and top, were reported by Johnston et al. (1969) to increase yields at the same levels by 30, 20, and 2%, respectively. The NCE rates of bottom leaves increased from 2.6 units (mg $CO_2 . dm^{-2}$ of leaf area hr^{-1}) to 4.5 units when the fluorescent lights were turned on and to 9.3 units when the canopy was opened and full sunlight allowed to strike the bottom leaves. The middle leaves increased from 12.1 units to 17.0 and 18.1 units for the fluorescent lights and sunlight, respectively. The NCE rate of the upper leaves in full sunlight was 20.2 units. These data indicate that the lowest leaves have the lowest photosynthetic capabilities. Johnston et al. (1969) suggests the lower efficiency "is due to both shading and an overall degeneration of the metabolic system with age." Burnside and Böhning (1957) reported that leaves of soybean plants raised in pots at less than 700 ft-c had maximum NCE rates under high light intensities of .8 as great as soybeans raised under full sunlight conditions. That study would indicate much of the loss of photosynthetic efficiency reported by Johnston et al. (1969) was due to age. Data reported by Beuerlein and Pendleton (1971) strongly indicate that acclimation to low light regimes is the cause of loss of photosynthetic activity. They reported that widely-spaced, debranched, field-grown soybeans had the same NCE rates for all leaves from the 10th to the 24th node under full sunlight. Bowes et al. (1972), growing soybeans in full sun and at three degrees of shading, reported "the light saturation intensity of field-grown soybeans was approximately equal to the maximum light intensity under which they were grown." The lower the light intensities under which the plants were grown, the lower the light saturation intensity. Those results also indicated acclimation to the light environment as suggested by Beuerlein and Pendleton (1971).

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CHAPTER I

EFFECT OF SOYBEAN LEAFLET TYPE ON NET CARBON DIOXIDE EXCHANGE, WATER USE, AND WATER-USE EFFICIENCY

Crop Science (has been submitted)

INTRODUCTION

Net carbon dioxide exchange in soybeans is considered to be limited by reduced light penetration into the canopy (Fuchs, 1972). Most PAR is absorbed by the periphery of the crop canopy (Hicks et al., 1969; Norman and Tanner, 1969; and Shaw and Weber, 1967). Sakamota and Shaw (1967) reported that about 90% of the sunlight was intercepted in the canopy periphery. Several investigators (Böhning and Burnside, 1956; Brun and Cooper, 1967; Curtis, Ogren, and Hageman, 1969; and Kriedeman, Neales, and Ashton, 1964) have reported that the light saturation level of individual soybean leaves is from 2,000 to 4,000 fc (20 to 40 percent full sunlight); therefore, leaves on the outer periphery of the soybean canopy are intercepting more light than is required for maximum canopy photosynthesis, while leaves within the canopy are not light saturated.

A major research effort has been to develop a canopy that allows more light to penetrate into the canopy (Anderson, 1964; Loomis, Williams, and Hall, 1971; Moss and Musgrave, 1971; and Newton and Blackman, 1970). Hicks et al. (1969) found that more light penetrated deeper into the canopy of soybeans with narrow leaflets than into those with normal leaflets. Egli et al. (1970) reported that Harosoy narrow-leaflet variety had a 28% greater mean daily NCE on a leaf area basis than did Harosoy normal-leaflet variety. They attributed the increased NCE to "better distribution of light throughout the canopy." However, at equal populations the leaf area index (LAI) of the narrow-leaflet Harosoy was sufficiently smaller than the LAI of the normal-leaflet Harosoy, so that NCE on a ground area basis did not differ significantly

($P < .05$) between the two types.

Hicks et al. (1969), growing Clark and Harosoy normal- and narrow-leaflet types over a two-year period, and Hartwig and Edwards (1970), growing the cultivars "Lee" and a near-isogenic line D49-2491 with narrow leaflets, reported no significant increase in yield with the narrow-leaflet type.

It might be hypothesized that at equal LAI the narrow-leaflet soybean may have an advantage through both greater NCE per ground area and yield; however, the data of Hicks et al. (1969) do not support the hypothesis for yield. Increasing the plant population did not increase yield; however, that does not remove the possibility of a higher NCE (per ground area basis) for the narrow-leaflet soybean type when LAI are equal, because NCE is often not reflected directly in yield (Curtis et al., 1969). It is likely that the harvest index of the narrow-leaflet soybean type would differ from the normal-leaflet type because the podding characteristics are different. The number of pods per plant is less and the number of pods with four seeds is greater in the narrow-leaflet soybean type (Bernard and Weiss, 1973 and Hicks et al., 1969).

If at equal populations, the LAI of the narrow-leaflet soybean type is less than the normal, it is likely that the transpiration rate may also be less. Such information is not available in the literature. Egli et al. (1970) reported that the transpiration rate of narrow-leaflet Harosoy for July 19, was 35% less than the transpiration rate of normal-leaflet Harosoy for July 26, however, climatic conditions for the two dates were not discussed. If the evapotranspiration rates are lower for the narrow-leaflet than for normal-leaflet type and yields are equal, water-use efficiency (yield/evapotranspiration) would be less for the normal-leaflet type. Such information is of economic value where soybeans are grown under marginal rainfall or under irrigation.

We, therefore, wanted to determine if the narrow-leaflet soybean type has an advantage over normal-leaflet type in NCE, yield, or WUE at various populations and spacings.

METHODS AND MATERIALS

The two cultivars of each maturity group were near isolines (Table 1); the cultivar designated as a normal-leaflet type had ovoide leaflets, while the narrow-leaflet type had rhomboid-lanceolate leaflets (Carlson, 1973). Typical leaf areas of fully developed trifoliolates of the normal- and narrow-leaflet types were 118 and 96 cm^2, respectively.

All cultivars were planted in a randomized complete block at 30 plants/m^2 in rows 76 cm apart. Clark 63 and SRF 400 were also planted at the same population in 38-cm rows and at 53 plants/m^2 at both the 38- and 76-cm row spacings in 3 factorial arrangements.

All plots were planted May 14, 1973, in north-south rows on an alluvial-deposited, silt loam soil at experimental fields 14 km south of Manhattan, Kansas. Soil fertility tests showed adequate amounts of N, P, and K; therefore no fertilizer was applied.

Net carbon dioxide exchange was determined by placing a plexiglass chamber over minimally disturbed plants growing in the field. The chamber covered a ground area of 1.2 m^2. Soil was placed around the base of the chamber to reduce air leakage. Air was circulated through the chamber at about 2.2 m^3/min under a slight, positive pressure (air

Table 1. Soybean characteristics of three near-isogenic pairs.

Maturity	Cultivar	Leaflet type	Genetic background
III (-5)*	Wayne	Normal	
	SRF 307†	Narrow	$Wayne^7$ x ($Dorman^5$ x PI 181.537)
IV (0)	Clark 63	Normal	
	SRF 400†	Narrow	Clark 63^7 x ($Dorman^5$ x PI 181.537)
IV (+5)*	Kent	Normal	
	SRF 450†	Narrow	$Kent^7$ x PI 88.818

* Indicated maturity as days earlier (-) or later (+) than Clark 63

† Narrow-leaflet cultivars developed by the Soybean Research Foundation, Inc., P.O. Box 72, Mason City, Illinois 62664

exchange rate of approximately 1.2 times/min). The air was circulated within the lower part of the crop canopy using four fans about 20 cm from the soil surface. Air samples from both the intake and exhaust tubes of the chamber were monitored for CO_2 concentration with an infrared gas analyzer (URAS II., Intertech Corp.). The analytical system has been described by Sij, Kanemasu, and Teare (1972) and Kanemasu, Powers, and Sij (1974). Two chambers were operated simultaneously to determine NCE of two treatments under the same atmospheric conditions.

Maximum NCE, determined from an average of the three highest 20-minute periods between 0900 and 1400 CST, were used to indicate photosynthetic capabilities of the plants tested.

Time and equipment limited NCE comparisons to only six of the twelve treatments. All treatments with Clark 63 and SRF 400 except those at 53 plants/m^2 in 38-cm row widths were compared with at least 2 replications (usually 3 or 4). All comparisons were made between July 10 and August 25 when leaf area indices ranged from 3.5 to 8.9 (Fig. 1). Variable meteorological conditions and changes in stage of growth made it impossible to compare NCE directly on different dates, so statistical comparisons were only on the NCE of the two treatments being tested.

Interception of photosynthetically active radiation (PAR) by the crop canopy was determined for each of the six treatments to determine if any differences in NCE might be attributable to percentage of PAR intercepted. PAR interception percentage was determined according to this equation:

$$\% \text{ intercepted} = \frac{PAR_o\downarrow - PAR_o\uparrow - PAR_s\downarrow + PAR_s\uparrow}{PAR_o\downarrow} \times 100 \qquad [1]$$

where the arrows represent direction of PAR and subscripts represent locations of the measured fluxes, either at the top of canopy (o) or soil surface (s). Light measurements were made using two PAR sensors (Lambda Instruments, Inc., Lincoln, Nebr.), one mounted facing upward and the other downward. Average PAR values were obtained by sampling the sensor output ten times as sensors were transversed normal to the rows above the canopy and 5 cm above the soil surface.

Leaf area was determined weekly from five plants taken randomly from one of the plots of each treatment.

Volumetric water content of the soil profile was determined from neutron attenuation meter (Troxler Model 2601) data taken from the center of each plot at ten depths from 0-152 cm. Evapotranspiration was estimated from precipitation and changes in soil water storage to a depth of 152 cm. Water movement below 152-cm was assumed to be constant or negligible.

RESULTS AND DISCUSSION

NCE rates did not differ significantly ($P < .05$) due to leaflet type, population, or row width (Table 2). As only two chambers were available for this study, comparisons in Table 2 can be made only horizontally.

NCE rates were determined for periods when the LAI of normal (Clark 63)- and narrow (SRF 400)-leaflet types were nearly equal (Fig. 1). On August 1, the NCE rates were 38.1 and 37.3 mg dm^{-2} ground area hr^{-1}, respectively for the normal- and narrow-leaflet type at a population of 30 plant/m^2. Again in mid-August, the NCE rates were 35.4 and 35.3 mg dm^{-2} ground area hr^{-1}, for the normal leaflet at 30 plants/m^2 and narrow leaflet at 53 plants/m^2. The NCE rates were measured on different

Table 2a. Net carbon dioxide exchange by normal- and narrow-leaflet soybeans.

	Average maximum NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$) Normal leaflet (Clark 63)	Narrow leaflet (SRF 400)	Average difference in NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$)	Standard deviation squared	t calculated
30 plants/m^2, 76 cm row	22.18	21.94	0.25	3.1	0.28*
30 plants/m^2, 38 cm row	38.17	41.61	3.44	15.7	1.73*
53 plants/m^2, 76 cm row	33.20	31.50	1.70	4.1	1.20*
Effect of leaflet type	30.78	31.72	0.94	11.7	0.87*

Table 2b. Net carbon dioxide exchange by populations of 30 plants/m^2 and 53 plants/m^2.

76 cm rows	Average maximum NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$) 30 plants/$m^2$	53 plants/m^2	Average difference in NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$)	Standard deviation squared	t calculated
Normal leaflet (Clark 63)	34.85	31.74	3.11	11.2	1.85*
Narrow leaflet (SRF 400)	31.10	30.73	0.37	3.9	0.32*
Effect of plant population	33.24	31.30	1.94	9.1	1.70*

Table 2c. Net carbon dioxide exchange by soybeans in row spacings of 76 cm and 38 cm.

30 plants/m^2	Average maximum NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$) 76 cm rows	38 cm rows	Average difference in NCE ($mg\ dm^{-2}\ grd\ hr^{-1}$)	Standard deviation squared	t calculated
Normal leaflet (Clark 63)	30.65	30.40	0.25	2.2	0.34*
Narrow leaflet (SRF 400)	27.04	29.97	2.93	5.7	2.45*
Effect of row width	29.10	30.21	1.11	5.9	1.21*

* not significant ($P < .05$).

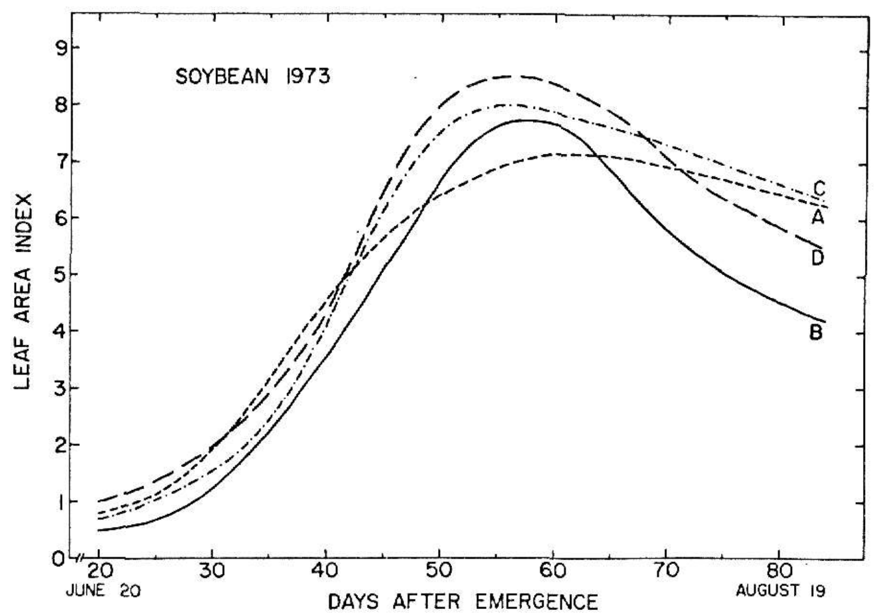

Fig. 1. Leaf-area index of soybeans in rows 76 cm apart. (A) Clark 63 (normal leaflet) at 30 plants/m^2; (B) SRF 400 (narrow leaflet) at 30 plants/m^2; (C) Clark 63 at 53 plants/m^2; and (D) SRF 400 at 53 plants/m^2.

dates (August 10 and 12); however, the meteorological conditions were nearly identical for the two days.

As NCE rates for the seven comparisons (Table 2) were equal, we anticipated that percentage of intercepted PAR also would be equal. The average intercepted PAR by both normal- and narrow-leaflet soybeans was 96 percent.

Water use was not affected by row spacing, population, or leaf type (Tables 3 and 4). The only significant ($P < .05$) difference in water use was related to maturity during the vegetative stage. Cultivars from maturity groups, III (-5) and IV(0), used more water than did cultivars in group, IV (+5), which matured later. That difference we attribute to larger leaf area indices during the vegetative stage of cultivars in maturity groups III (-5) and IV(0) (data not shown).

Yield was not affected by leaflet type (Table 3 and 4). It was, however, affected by maturity group. The earliest and latest maturing groups, III (-5) and IV(+5), had significantly ($P < .05$) higher yields than did the middle maturing group, IV (0). Highest yield for any population and spacing treatment came from 53 plants/m^2 spaced in rows 76-cm apart. The yield, 2967 kg/ha, was 567 kg/ha more than the average yields from other treatments in the middle maturity group, IV (0).

Because of the relatively small variation in water used, compared with wide variations in yield, the higher the yield, the greater the WUE. Leaflet type in the variety trials had no effect on WUE; however, an unexplained difference was found between Clark 63 and SRF 400 (Table 4) at 53 plants/m^2 in 38-cm rows.

Data indicate that narrow leaflets generally do not have any advantage or disadvantage over normal leaflets in soybeans. Net

Table 3. Effect of maturity group and leaflet type on water use, yield, and water-use efficiency in soybeans at 30 plants/m^2 and 76 cm row spacing.*

	Water use (cm)					
	Vegetative stage† 6/18-7/2	Flowering stage† 7/2-7/28	Pod and seed development† 7/28-9/6	Season 6/18-9/6	Yield kg/ha	Water-use efficiency (WUE) kg/cm
Cultivars						
Wayne	5.8	19.5	20.3	45.7	2651	58.1
SRF 307	5.4	18.1	23.7	47.2	2776	58.8
Clark 63	5.7	19.1	22.6	47.3	2370	50.2
SRF 400	5.8	19.1	21.6	46.5	2177	47.0
Kent	4.9	17.2	24.7	46.8	2724	58.5
SRF 450	4.8	17.0	24.0	45.8	2607	57.1
					($LSD_{.05}$ = 249)	
Maturity groups						
III (-5)	5.6	18.8	22.0	46.4	2714	58.5
IV (0)	5.7	19.1	22.1	46.9	2273	48.6
IV (+5)	4.8	17.1	24.4	46.3	2666	57.8
	($LSD_{.05}$ = 0.75)				($LSD_{.05}$ = 273)	($LSD_{.05}$ = 7.0)
Leaflet type						
normal	5.5	18.6	22.5	46.6	2582	55.6
narrow	5.3	18.1	23.1	46.5	2520	54.3

* statistical significance is present only when an LSD value is given for a particular column.

† *Hanway and Thompson* (1971).

Table 4. Effect of leaflet type at two soybean populations and two row spacings on water use, yield, and water-use efficiency, 1973.

Plant population plants/m^2	Row width cm	Cultivar	Water use (cm) Vegetative stage 6/18-7/2	Flowering stage 7/2-7/28	Pod and Seed development 7/28/9/6	For entire period 6/18-9/6	Seed yield kg/ha	Water-use efficiency (WUE) kg/cm
30	38	Clark 63	5.0	19.2	23.9	48.2	2527	52.6
		SRF 400	4.7	18.3	22.8	45.8	2526	54.9
		average	4.8	18.8	23.4	47.0	2527	53.7
53	38	Clark 63	7.1	16.5	21.9	45.6	2203	48.9*
		SRF 400	7.2	16.0	20.7	43.9	2479	56.3*
		average	7.2	16.2	21.4	44.7	2341	52.6
53	76	Clark 63	6.2	16.9	21.1	44.2	3030	69.1
		SRF 400	5.8	16.7	21.1	43.5	2903	66.8
		average	6.0	16.8	21.1	43.9	2967	67.9

*statistically different ($P < .05$).

carbon dioxide exchange, yield, and water use, were not affected by leaflet type.

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CHAPTER II

EFFECT OF SOIL REFLECTANCE

ON NET CARBON DIOXIDE EXCHANGE RATES OF SOYBEAN AND SORGHUM

Crop Science (to be submitted)

INTRODUCTION

Numerous studies indicate photosynthesis and yield under field conditions are limited by the amount of photosynthetically active radiation (PAR), particularly for leaves within the canopy which are shaded by upper leaves. Attempts have been made to increase the light level within a crop canopy both by supplemental light and by increasing the reflectivity of the soil. Much of that work has been done with corn and soybeans.

Pendleton, Peters, and Peek (1966) attributed increases in yield of 9 and 2% at 16,000 and 24,000 corn plants per acre, respectively, to the reflective qualities of a white plastic cover on the soil. Later Pendleton, Egli, and Peters (1967) reported large, aluminum-covered reflectors created a "light rich" environment for corn that increased grain yield by 26% in rows adjacent to the reflectors, however, that increase in yield could be attributed to the development of a more optimum environment in temperature as well as light (Winter and Pendleton, 1970). Ashford and Read (1962) and Read and Ashford (1964) suggest part of the increase in yield of sweet clover grown in pots with a Styrofoam mulch over that in pots with bare soil was not due to changes in soil temperature or moisture, but to an additional amount of intercepted light by the crop.

At least one research group, Aase, Kemper, and Danielson (1968), has reported a white reflective surface can reduce the yields of corn because of stress conditions resulting from the increased transpiration rate per leaf area.

Johnston et al. (1969) reported supplemental light provided by fluorescent bulbs and white reflective polyethylene strips placed on the ground between the rows of soybeans, increased the yields at the bottom, middle, and upper canopy positions by 30, 20, and 2%, respectively.

Fuchs (1972) postulated the increases in photosynthesis caused by increasing the reflectivity of the soil would be inversely proportional to the coverage of the soil by the crop. As less light reaches the soil through the crop canopy, the amount reflected back to the lower levels of the crop canopy would concurrently decrease.

Therefore, the value of a highly reflective coating over the soil would have a decreasing effect in increasing photosynthesis as crop coverage increased. When the crop coverage becomes nearly complete very little of the total PAR reaches the soil surface, as in the case with soybeans where crop transmittance is only 1 to 2% (Hicks et al., 1969); therefore no measurable increase in photosynthesis should be expected.

Few data are available illustrating the effect of increased soil reflectivity upon net carbon dioxide exchange (NCE) in relationship to time of the season. The objective of this study was, therefore, to observe that effect for sorghum (Sorghum bicolor (L.) Moench cv. Pioneer 846) and soybeans (Glycine max (L.) Merrill cv. Clark 63).

MATERIALS AND METHODS

Soybeans planted in rows 38 and 76 cm apart with 30 plants/m^2 and sorghum in rows 46 and 91 cm apart with 17 plants/m^2 were used in this study. The soybeans were planted on May 14, 1973, and the sorghum on June 1, 1973, both in north-south rows on an alluvial silt loam soil at the experimental field 14 km south of Manhattan, Kansas.

Kaolinite (Peerless kaolin, Vanderbilt Co., N. Y.) was placed on the soil at a rate of .6 kg m^{-2} on each of four plots in order to increase the reflectivity of the soil surface. The albedo of dry bare soil would be increased from 15 to 65% (Kanemasu et al., 1975). The spectral hemispherical reflectance of the soil-canopy complex was determined with a portable spectral radiometer (LI-187, Lambda Instrument Company, Lincoln, Nebraska). The sensor head was positioned from 1 to 2 m above the highest point of the reflecting surface with readings made both upwards and downwards (Kanemasu, 1974). Reflectance in seven spectral wavelength bands (6 in the visible and one in near infrared wavelengths) were measured; however, for simplicity we only report here data from four of the bands (Table 1). Reflectance for each band of light was expressed as the percent of total incoming light in that band.

Light sensors tailored to measure the quantum response in the visible wavelengths (LI-170, Lambda Instrument Company, Lincoln, NE) were used to measure PAR.

Net carbon dioxide exchange was determined by placing a plexiglass chamber over minimally disturbed plants growing in the field. The chamber covered a ground area of 1.2 m^2. Soil was placed around the base of the chamber to reduce leakage of air. Air was circulated through the chamber at about 2.2 m^3/min under a slight positive pressure (air exchange rate of approximately 1.2 time/min). The air was circulated within the lower part of the crop canopy using four fans placed about 30 cm from the ground. Air samples from both the intake and exhaust tubes of the chamber were monitored for CO_2 concentration with an infrared gas analyzer (Uras II Intertech Corp.). The analytical system has been described by Sij, Kanemasu, and Teare (1972) and Kanemasu, Powers, and Sij (1974).

Kaolinite application and removal on the soil was done through a door on the side of the chamber. The removal of kaolinite was performed

Table 1. Optical characteristics of the spectral radiometer

Sensor	Center Wavelength (nm)	Bandwidth (nm)
B	450	32.5
D	545	35
F	655	45
G	750	80

by cultivating the soil within the chamber until no visible evidence of the kaolinite remained.

Quantitative approximations as to the effect of the increased soil reflectivity on increasing interception of PAR were made assuming: (a) Lambertian surfaces, (b) no multiple reflections, and (c) diffuse radiation. The PAR intercepted by the crop canopy, I, was estimated by:

$$I = PAR\downarrow - PAR\uparrow - a_s \tau_c PAR\downarrow \qquad [1]$$

where $\downarrow$ and $\uparrow$ indicate the direction of the radiation stream; a_s is the absorptivity of the soil and is equal to $(1 - r_s)$; r_s is the reflectivity of the soil; and τ_c is a gross transmissivity of the crop-canopy complex.

Assuming τ_c is the same for bare and kaolinite-treated canopies, the difference in the amount of light intercepted by the two crop canopies can be described using [1] and expressed as:

$$I_k - I_b = PAR\downarrow \left[\left(\frac{PAR\uparrow}{PAR\downarrow}\right)_b - \left(\frac{PAR\uparrow}{PAR\downarrow}\right)_k + \tau_c(r_{sk} - r_{sb})\right] \qquad [2]$$

where the subscripts k and b indicate with kaolinite and bare soil, respectively; $\frac{PAR\uparrow}{PAR\downarrow}$ is measured reflectance from the soil-crop complex and $r_{sk} - r_{sb}$ was determined May 16 on non-vegetative soil (Figures 2 and 4).

Canopy transmissivity (τ_c) can be expressed by:

$$\tau_c = \left[\frac{PAR\uparrow_k - PAR\uparrow_b}{PAR\downarrow(r_{sk} - r_{sb})}\right]^{1/2} \qquad [3]$$

assuming that the portion of light reflected from the plants is the same for the treated and non-treated canopies. That permits the calculation of τ_c from radiometric determinations and, consequently, $I_k - I_b$ can be calculated from [2].

In order to determine the effect described by [2] on NCE, the shape of the light response curve for a canopy must be known. That curve, suggested by Kanemasu and Arkin (1974), is given by:

$$NCE = mI^{1/2} - b \qquad [4]$$

where m and b must be determined from measurements of NCE and I.

Because of the non-linear nature of [4] the irradiance at the absorbing level must be determined in order to calculate the effect of increased light at the bottom of the canopy on NCE. The increase in NCE was calculated from [4] by describing the difference in NCE over kaolinite and bare soil by:

$$NCE_k - NCE_b = m[(I_k - I_b) + I_{bz}]^{1/2} - b - NCE_{bz} \qquad [5]$$

where I_{bz} is the level of intercepted light at the level in the canopy where the additional light was assumed to be absorbed and NCE_{bz} is the calculated NCE at I_{bz} using equation [4].

RESULTS AND DISCUSSION

Kaolinite was either added to or removed from the soil seven times for each of the two row spacings between July 1 and August 6. The increased reflectance from the soil caused by the presence of kaolinite resulted in greater NCE in all cases, three examples being given in Fig. 1. In both the 46 and 91 cm row widths, the percent increase in NCE decreased from the July 1 to August 6. Percent increases for Fig. 1 were 16, 7.8, and 5.6 for July 1, 17, and August 6, respectively. The decline in effect of the soil reflectant on NCE was anticipated by closing of the canopy.

Shown in Fig. 2 are the trends in spectral reflectances of the treated (kaolinite) and untreated (no kaolinite) sorghum canopy. The reflectance on May 16 is for the soil surface without plants. As the season progressed, the effect of kaolinite on canopy reflectance was reduced,

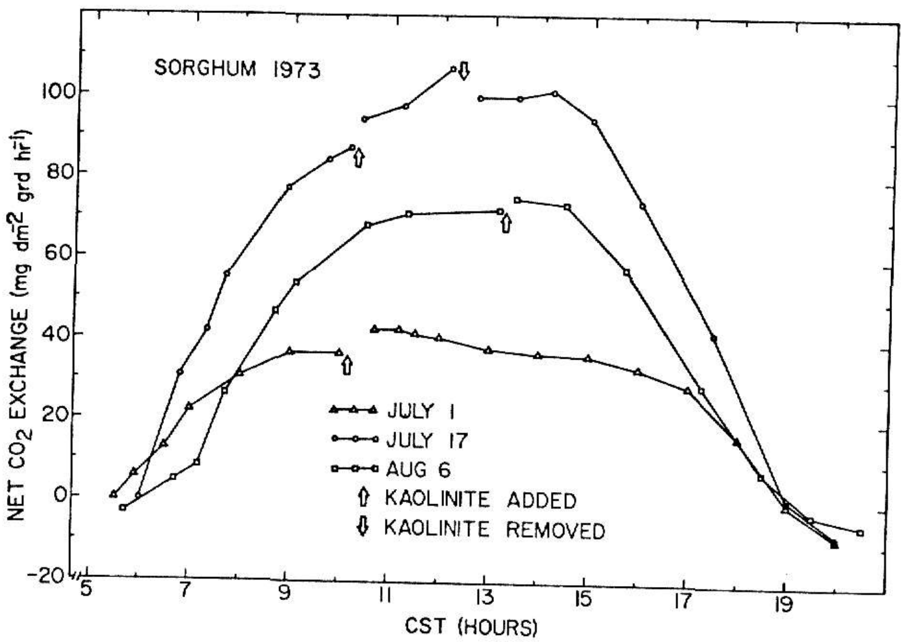

Fig. 1. The effect of the addition or removal of kaolinite to the soil surface in increasing or decreasing NCE of sorghum. July 1 and July 17 sorghum in rows 46 cm apart. August 6 sorghum in rows 91 cm apart.

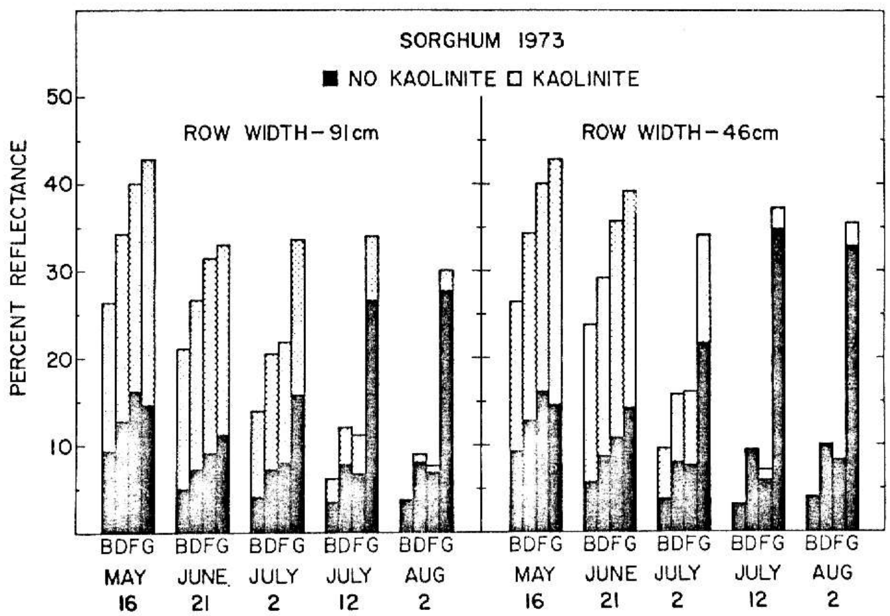

Fig. 2. Spectral reflectance for sorghum planted June 1, 1973. May 16 data taken on uncultivated soil without vegetation. Sensors B, D, F, and G measured spectral bands centered at 450, 545, 655, and 750 nm, respectively.

especially in the narrow row spacing. The high reflectivity and transmissivity by leaves of near-infrared radiation suggest a greater canopy closure for the narrow row spacing. Concomitant with the reduced reflectance effect by the kaolinite was its reduced effect on NCE.

Shown in Fig. 3 are the calculated transmittances using equation [3]. Transmittance of the narrow row sorghum canopy was lower than the wide row for much of the season.

Transmittance values for July 1, July 17, and August 6 (Table 2) were taken from the curves in Fig. 5 and increases in light interception were computed using [2]. In order to estimate the increase in NCE resulting from the increase in light, equation [5] was used. The m and b values were estimated for each of the above dates from NCE and light data. The NCE_{bz} values were determined by the transmittance value of canopy and the respective equation [5] for July 17 and August 6. For July 1, we assumed the increased light reflected from the kaolinite would be distributed similarly to light coming in from above the canopy because of the openness of the canopy at that time. Such an NCE estimate would be the minimum amount expected.

When comparing Fig. 2 and Fig. 4, it is apparent that on the same dates the effect of the kaolinite upon increasing reflectance was not as great for the soybeans as for the sorghum. This undoubtedly contributed to the fact that no measurable change in NCE was observed when kaolinite was added or removed; the first test was made July 5. Secondly, a reduction of photosynthetic efficiency in shaded leaves, as has been reported for soybeans by several researchers (Beuerlein and Pendleton, 1971, and Burnside and Böhning, 1957), would reduce the ability of the lower leaves to respond to increases in light.

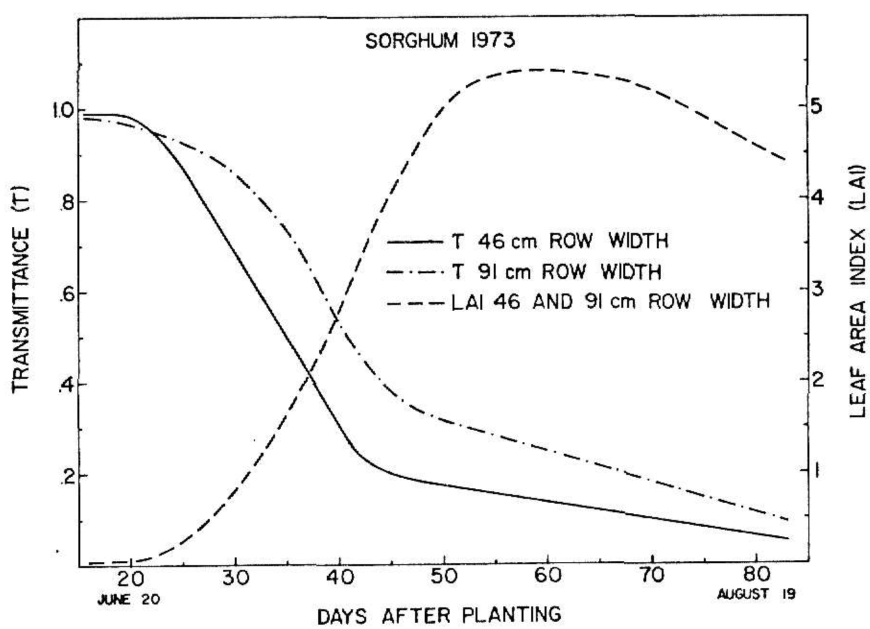

Fig. 3. Hand smoothed curves for calculated transmittance and measured leaf area index for two sorghum row spacings.

Table 2. Calculated transmittance and increases in light interception and NCE, sorghum, 1973.

Date	Treatment row width and K treatment	PAR $nE/cm^2/s$	τ_c	$I_K - I_B$ $nE/cm^2/s$	NCE Increase mg/dm^2 grd/hr Calc.	Obs.
7/1	46 cm K added	200*	.64	12.5	4.2	5.9
7/17	46 cm K added	180	.18	6.2	4.4	7.2
	46 cm K removed	216	.18	7.5	4.9	7.3
8/6	91 cm K added	204	.19	6.5	3.6	4.0

* typical clear day PAR intensity (no data before 7/11).

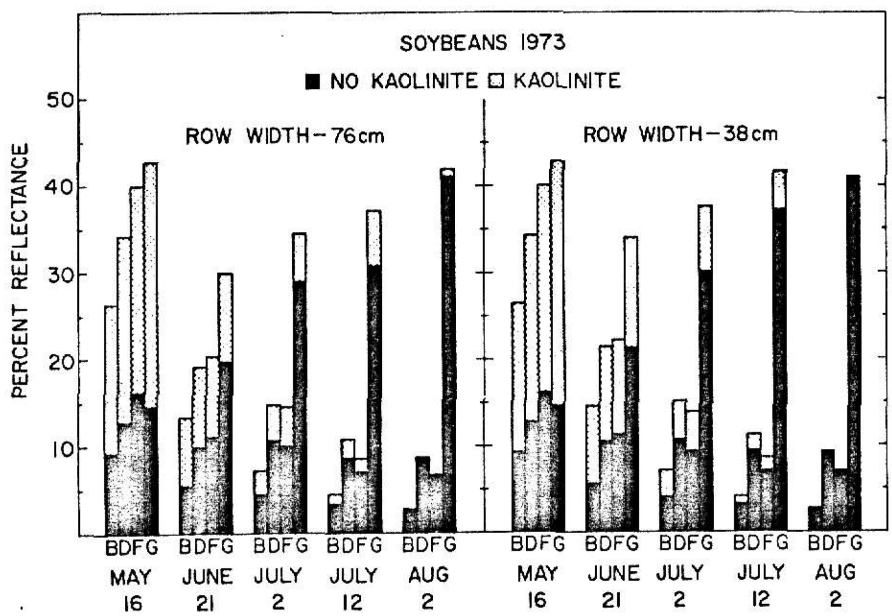

Fig. 4. Spectral reflectance for soybeans planted May 14, 1973. May 16 data taken on uncultivated soil without vegetation. Sensors B, D, F, and G measured spectral bands centered at 450, 545, 655, and 750 nm, respectively.

In conclusion, it was found that sorghum increased in NCE when the reflectivity of the soil was increased by applying kaolinite. That increase was approximately predicted using incoming and reflected PAR data taken above the crop canopy. The NCE of soybeans was not affected by increasing the reflectivity of the soil. This was attributed to the low PAR irradiance reaching the soil and the loss of photosynthetic efficiency of soybean leaves grown at low light intensities.

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APPENDIX I

CALCULATIONS OF LIGHT INTERCEPTION, TRANSMITTANCE, AND NET CARBON DIOXIDE EXCHANGE

Quantitative approximations as to the effect of the increased soil reflectivity on increasing interception of PAR were made assuming: (a) Lambertian surfaces, (b) no multiple reflections, and (c) diffuse radiation. The PAR intercepted by the crop canopy, I, was estimated by:

$$I = PAR{\downarrow} - PAR{\uparrow} - a_s \tau_c PAR{\downarrow} \qquad [1]$$

where ↓ and ↑ indicate the direction of the radiation stream above the canopy; a_s is the absorptivity of the soil and is equal to $(1 - r_s)$; r_s is the reflectivity of the soil; and τ_c is a gross transmissivity of the crop-canopy complex.

Assuming τ_c is the same for bare and kaolinite-treated canopies, the difference in the amount of light intercepted by the two crop canopies can be described using [1] and expressed as:

$$I_k - I_b = PAR{\downarrow} - PAR{\uparrow}_k - (1 - r_{sk})\tau_c PAR{\downarrow} - [PAR{\downarrow} - PAR{\uparrow}_b - (1 - r_{sb})\tau_c PAR{\downarrow}] \qquad [2a]$$

$$I_k - I_b = PAR{\uparrow}_b - PAR{\uparrow}_k + PAR{\downarrow}\tau_c[(1 - r_{sb}) - (1 - r_{sk})] \qquad [2b]$$

$$I_k - I_b = PAR{\downarrow}\left[\left(\frac{PAR{\uparrow}}{PAR{\downarrow}}\right)_b - \left(\frac{PAR{\uparrow}}{PAR{\downarrow}}\right)_k + \tau_c(r_{sk} - r_{sb})\right] \qquad [2c]$$

where the subscripts k and b indicate with kaolinite and bare soil, respectively; $\frac{PAR{\uparrow}}{PAR{\downarrow}}$ is measured reflectance of the soil-crop complex; and r_{sk} and r_{sb} are the soil reflectance with and without kaolinite, respectively.

Gross transmissivity (τ_c) of the canopy can be determined from:

$$PAR{\uparrow} = PAR{\uparrow}_p + \tau_c^2 r_s PAR{\downarrow} \qquad [3a]$$

$$PAR{\uparrow}_k - PAR{\uparrow}_b = PAR{\uparrow}_p + \tau_c^2 r_{sk} PAR{\downarrow} - (PAR{\uparrow}_p + \tau_c^2 r_{sb} PAR{\downarrow}) \qquad [3b]$$

$$PAR{\uparrow}_k - PAR{\uparrow}_b = \tau_c^2 r_{sk} PAR{\downarrow} - \tau_c^2 r_{sb} PAR{\downarrow} \qquad [3c]$$

and expressed as:

$$\tau_c = [\frac{PAR\uparrow_k - PAR\uparrow_b}{PAR\downarrow(r_{sk} - r_{sb})}]^{\frac{1}{2}} \quad [3d]$$

where $PAR\uparrow_p$ is the upward flux of light from the plants only and is assumed to remain constant regardless of soil reflectance.

In order to determine the effect described by [2c] on NCE, the shape of the light response curve for a canopy must be known. That curve, suggested by Kanemasu and Arkin (1974), is given by:

$$NCE = mI^{\frac{1}{2}} - b \quad [4]$$

where m and b must be determined from measurements of NCE and I.

Because of the non-linear nature of [4], the level (z) in the canopy where $(I_k - I_b)$ is absorbed and the irradiance (I_{bz}) at that level before the application of kaolinite must be determined. The irradiance (I_{kz}) at level (z) after the application of kaolinite to the soil then becomes:

$$I_{kz} = (I_k - I_b) + I_{bz} \quad [5]$$

Substituting the expression for I_{kz} into equation [4], NCE at level (z) becomes:

$$NCE_{kz} = m[(I_k - I_b) + I_{bz}]^{\frac{1}{2}} - b \quad [6]$$

The effect of the additional interception of light can then be expressed as:

$$NCE_k - NCE_b = m[(I_k - I_b) + I_{bz}]^{\frac{1}{2}} - b - NCE_{bz} \quad [7]$$

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EFFECT OF LEAFLET TYPE IN SOYBEAN AND SOIL REFLECTANCE IN SOYBEAN AND SORGHUM CANOPIES ON NET CARBON DIOXIDE EXCHANGE

by

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Amount and distribution of sunlight intercepted by the crop canopy affects both net carbon dioxide exchange (NCE) and water-use efficiency (WUE). Plant morphology and soil reflectance influence light interception within canopies. Studies using soybean (Glycine max (L.) Merrill) and sorghum (Sorghum bicolor (L.) Moench) were conducted to investigate several of the relationships suggested.

Three pairs of near-isogenic soybean cultivars - each pair composed of a normal- and narrow-leaflet cultivar - were field grown to determine the effect of leaflet type on NCE and WUE. Net carbon dioxide exchange rates were measured for Clark 63 (normal leaflet) and SRF 400 (narrow leaflet) at three populations and spacings using large portable chambers and an infrared gas analyzer. Water use was determined for all cultivars by monitoring soil water changes and precipitation. Water-use efficiency was determined from water use and grain yield. Leaflet type did not significantly ($P<.05$) affect NCE, percentage of light intercepted, water use, or yield. Water-use efficiency was only affected at 53 plants/m^2 in 38-cm rows, the WUE being greater for the narrow leaflet.

Net carbon dioxide exchange rates of soybean and sorghum canopies were measured in an effort to assess the effect of soil reflectance on photosynthesis. Soil reflectance was increased by applying a white reflective clay, kaolinite, to the soil surface enclosed by the chambers. Increased soil reflectance did not affect the NCE of soybean while the NCE of sorghum was increased by as much as 16% and decreased with increased crop coverage.

Spectral reflectance data taken over kaolinite treated and non-treated soil showed a reduction of additional reflected light from the treated plots as crop cover increased. By August 2, little or no difference between treated and non-treated plots was observed. From the spectral reflectance data, transmittance, amount of additional light intercepted by the canopy, and increase in NCE were calculated. Calculated increases in NCE compared favorably with measured values.