LIGHT INTERCEPTION BY GRAIN SORGHUM

by

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TABLE OF CONTENTS

LIST OF TABLES

TABLE PAGE

LIST OF FIGURES

FIGURE PAGE

INTRODUCTION

It is well known that light is of the utmost importance to all plants, since there would be no photosynthesis and consequently no plants without it. However, as the duration of sunlight does not vary appreciably from year to year, little work has been done with light on a field basis.

While there are crops grown in arid regions in which water is the dominant and perhaps even the sole factor in competition, and others, such as domesticated plants growing on soils where fertility is of paramount importance, in many cases growth limitations due to these factors have been reduced through man's modification of the environment. Man has learned the usefulness of such measures as regulating soil pH and fertility, of supplying supplemental water, and of reducing weed competition. As a result, production rates have been increasing. Along with these greater production rates have come increased plant competition for light energy.

One of the main purposes in agronomy is to relate productivity of crops to the various ecological parameters. By doing so we can learn the relative limitations that these parameters impose.

This experiment was initiated to determine the effect of row width and directional orientation as they influence the amount of light intercepted by the sorghum canopy, and how this relates to plant response.

REVIEW OF LITERATURE

Basically, plant expression measured in terms of yield or other observable characteristics results from the interaction between the genetic composition of a plant and its environment. One component of plant environment is the existence of plants themselves. The geometric arrangement of domesticated plants in the field exerts an impact on the environmental complex which in turn influences their performance.

Row Spacing

Interest in narrow-row culture (30-inch or less) has developed from crop production experiments designed to study row crop response in narrow row planting patterns as compared to traditional 40- or 42-inch row spacings. Experimental yields from narrow rows have varied from little, if any advantage, to superior as compared to normal row spacings, depending upon conditions surrounding the tests. Superior yields in narrow rows as compared to normal rows have been most consistently reported from the more humid areas or under irrigation, which assures adequate moisture for sorghum growth.

Non-irrigated grain sorghum yield comparisons in 20- versus 40-inch row spacings have been reported by Bond, Army, and Lehman (1964) at Bushland, Texas. Yields were related to the combination of soil moisture reserves at seeding time and expected rainfall during the growing season. With low soil moisture reserves at seeding time (below 5 inches) grain yields of 40-inch rows excelled. Twenty-inch row yields were greater than 40-inch row yields when soil moisture reserves at seeding time exceeded five inches.

Brown and Shrader (1959) reported non-irrigated grain sorghum yields at Hays, Kansas, for a two-year period, 1954-55. In 1954, a year of moderate drought, 20-inch row grain yields were 38.0 bushels per acre as compared to acre yields of 35.0 bushels in 10-inch rows and 31.8 bushels in 40-inch rows. During 1955, a year of great moisture stress, 10-, 20-, and 40-inch rows produced 11.8, 15.4, and 19.2 bushels per acre, respectively.

On non-irrigated loamy fine sand (Big Springs, Texas), Welch, Burnett, and Eck (1966) observed that a 40,000 plant population in 20-inch rows outyielded a like population in 40-inch rows in 1960; however, the trend toward a higher yield with 20-inch row spacing was not statistically significant in 1961.

Grimes and Musick (1960) compared irrigated grain sorghum yields at Garden City, Kansas, for two years, 1957-58. For rows spaced 7, 14, 21, and 28 inches, the authors found a significant regression equation indicating yield decreased with increased row width.

Non-irrigated grain sorghum yield studies by Stickler and Laude (1960), and Stickler, et al. (1961) have shown yield comparisons between normal and narrow row spacings at Manhattan, Kansas. Yields of one test, involving six varieties, each at two row spacings (20- and 40-inch), failed to show a significant variety x row spacing interaction (1961). With 10-, 16-, 20-, 24-, and 40-inch rows in 1954, grain yields did not significantly differ among row spacings at 52,000 plants per acre, but at 78,000 plants per acre, yields increased significantly as row spacing decreased (1960). Later, yield comparisons were reported for the 4-year period, 1953-56. Row spacing population interactions occurred during two of four years. Mean 20-inch row yields exceeded 40-inch row yields by 6 percent for the test duration (1961).

Under irrigated Southern Great Plains conditions, Porter, Jensen, and Sletten (1960) concluded that at a given population grain sorghum yields increased as row spacing decreased (12- to 40-inch row spacing range). Their conclusions were based on tests conducted over three years, 1956-58.

In Minnesota, Robinson, et al. (1964) concluded row spacing was an important cause of yield difference. Mean grain yields reported were 96.2, 82.7, 81.1, and 73.4 bushels per acre for 10-, 20-, 30-, and 40-inch row spacings, respectively.

The influence of varying row spacing on two components of yield, heads per acre, and seeds per head, have been reported. In Kansas, Stickler, et al. (1961) found that the number of heads per acre were greater in narrow as compared to normal rows, but the number of seeds per head decreased in five of six varieties. In Minnesota, Robinson, et al. (1964) found both number of heads per acre and number of seeds per head to be greater in the narrow row spacings.

Bond, et al. (1964) reported plant heights at maturity in 40-inch rows were 10 percent greater than 20-inch row plants. Similar observations were reported by Burnside, et al. (1964), and Porter, et al. (1960).

Incidence of lodging in narrow row spacing as compared to normal rows differs by locations. In Texas, Bond, et al. (1964) reported lodging was greatest in normal rows. In contrast, reports by Robinson, et al. (1964) at Minnesota, and Burnside (1964) at Nebraska indicate that plants of narrow rows lodged the most. Porter, et al. (1960) studied the influence of row spacing on plant mortality rate in grain sorghum stands. At constant seeding rates, mature plant counts in thousands were 122, 108, 104, and 93 for 12-, 20-, 30-, and 40-inch row spacings respectively.

Row Orientation

The influence of planting direction on crop productivity has been investigated only slightly. Stickler, et al. (1961) studied the influence of row orientation on grain sorghum yields on two row spacings (20- and 40-inch). With 20-inch row spacing, grain yields in east to west oriented rows were 2 bushels per acre greater (83 versus 81 bushels per acre) than in rows oriented north to south. In contrast, grain yields of rows placed 40-inches were 5 bushels per acre greater (72 versus 67 bushels per acre) in north to south than east to west rows.

In studies with corn, Yao and Shaw (1964) found that north-south oriented rows yielded 124 bushels per acre as compared to east-west row yields of 120 bushels per acre (42-inch rows at 14,000 plants/acre). However, with twice this population, east-west rows yielded 146 bushels per acre and north-south rows yielded 143 bushels per acre. The difference was not significant in either case.

Pendleton, Bolen, and Seif (1963) compared yields of corn in 4-row (40-inch spacing) and 6-row (24-inch spacing) strips bordered by equal numbers of soybean rows. Each treatment was oriented in two directions, north to south and east to west. Yield differences by direction were not significant, however, yields of individual border rows were of interest. The south corn row of strips planted east and west yielded considerably more than the north row, whereas with north-south orientation, the east corn row yielded more than the west row.

Light Relationships

For most plants the optimum light intensity for photosynthesis appears to be less than full sunlight as far as the individual leaf is concerned. However, when a large plant grows in full sunlight a great many leaves do not get enough light for maximum photosynthesis owing to shading by other leaves and to leaf orientation in relation to the direction of incident light. Because of this, full sunlight normally benefits the leaves within the canopy enough to more than offset the possible effect of supraoptimal lighting of the fully exposed leaves.

The influence of planting patterns on net radiation distribution in corn has been investigated by Aubertin and Peters (1961). They observed that radiant energy absorption by the leaf canopy was greater in narrow rows as compared to normal rows. Their findings were confirmed by Yao and Shaw (1964).

Results obtained by Denmead, Fritschen, and Shaw (1962) indicated that if corn rows were 40 inches apart there would be unshaded areas between rows no matter how close the plants were within rows. From their data the authors felt that with closer row spacings of 24 inches; one might expect an increase in the net energy expended in the crop and an increase in photosynthesis of 15-20 percent.

Bowers, Hanks, and Stickler (1963) concluded from their investigations with sorghum that total net radiation absorbed under cropped conditions was only slightly influenced by row spacing. They found no evidence of a significant influence by the row width-plant population interaction on the total net radiation.

Row width-plant population studies by Stickler and Laude (1960) have shown light intensity to be significantly less in 20-inch than in 40-inch sorghum rows. Light measurements at ground level one week after full bloom were 170 and 310 foot-candles respectively for the two row widths at 52,000 plants per acre.

Tanner and Peterson (1960) observed that the amount of light transmitted by a 16,000 plant per acre corn crop approaching maturity ranged from 26 to 44 percent with increasing row spacing (40- to 80-inch row spacing range).

Direction of row planting as it influenced radiation interception by soybeans was studied by Shibles and Weber (1966). North-south rows were shown to have a maximum light penetration through the crop canopy at midday, whereas east-west rows had a more uniform daily light penetration since the sun was not directly overhead at its highest point.

Idso and Baker (1967) determined that in the case of north-south row orientation, row crops accumulate a good deal of photosynthate in the morning for east facing leaves and in the afternoon for west facing leaves. With east-west rows the south facing leaves are photosynthetically the most important throughout much of the day, whereas north facing leaves receive direct insolation only in the early morning and late afternoon.

In net radiation studies with corn, Yao and Shaw (1964) found a greater retention of net radiation in leaf canopies of north to south oriented rows than in canopies of east to west rows (season average, 3 percent more; July 15 to August 15 average, 10 percent more).

With 40-inch row spacing, Tanner and Peterson (1960) found little difference between east-west and north-south row direction on the average amount of daily light transmission. The main variation between row direction was the hourly distribution. East-west rows provided more uniform amounts of light at the soil than north-south plantings.

Williams, Loomis, and Lepley (1965) measured light at midday above corn foliage and at ground level. This made it possible to calculate the amount of radiation intercepted by the crop canopy. Growth rate of the corn was closely associated with the amount of intercepted light and with the leaf area of the crop.

In experiments with grass communities, Broughman (1956) found that both percent solar radiation interception and rate of dry matter accumulation increased with leaf area development.

Dungan (1934) evaluated the dependence of dry matter production rate of corn on quantity of leaf surface. He found that with leaf blade removal to simulate injury, accumulation of dry matter was directly related to leaf area. Similar results have been asserted by Watson (1958).

Investigations by Shibles and Weber (1965) with soybeans showed that percent solar radiation interception and rate of dry matter production increased with increasing leaf area development; reached a maximum; and remained constant with further increase of leaf area index.

At Urbana, Illinois, a 3-year investigation by Pendleton, Peters, and Peek (1963) on the effect of light reflection on corn yield showed that a white reflective ground cover gave small, consistent corn yield increases over that on uncovered ground for 16 and 24 thousand plants per acre. The average yield increases for the 3-year period were 12 percent and 7 percent respectively. A non-reflective black ground cover provided average yield increases of 5 percent or less.

Studies by Pendleton, Egli, and Peters (1967) were conducted with corn in a "light rich" environment, where other ecological factors were deemed adequate. Grain yields were increased greatly by growing plants in front of large reflectors. Theoretical yields of 377 bushels per acre were obtained. This was 26 percent higher than grain yields in adjacent areas receiving only normal sunlight.

An experiment conducted by Stinson and Moss (1960) on shading corn plants has shown that the amount of light available is very important in plant productivity. Eleven corn hybrids were tested for their response to a shade environment under conditions of adequate soil moisture and fertility. In shade (net radiation reduced by 20 percent with cloth tents) the reductions of grain yield ranged from 11 to 45 percent.

Light Measurement

Light interception by a crop can be determined by measurements made above and below the foliage canopy.

Inherent limitations exist in relating such light measurements with the photosynthetic activities of green plants, however. Light relation in a plant community is complicated by both intensity and wavelength. As is well known, more than half of the incident solar energy falls in the infrared range, and does not take part in photosynthesis. The measurement of solar energy beneath the canopy of a crop, therefore, may lead to serious error in available light for photosynthesis.

The relative amounts of light of differing wavelengths transmitted through plant canopies have been shown by Geiger (1959), Billings and Morris (1951), and Singh, et al. (1968). Light transmission is fairly uniform in the visible range (400 mu-700 mu) with the greatest amount being observed in the region of green light.

Yocum, Allen, and Lemon (1964), used a spectrophotometer with a sensitive range lying between 300 mu and 1.000 mu to measure the spectral characteristics of radiation penetrating a dense stand of corn (29-inch rows, planted north to south, 26,000 plants per acre, and a leaf-area index of 4.3). Transmission of light was nearly constant for the range of 300 mu-700 mu. About 5 percent of the light in these wavelengths reached ground level on a clear day, and about 10 percent reached the soil on cloudy days. The range of wavelengths from 700 mu to 900 mu showed about 35 percent and 40 percent transmission for clear and cloudy days, respectively.

Methods of light measurement include the Eppley pyranometer, a multiple junction thermocouple, in combination with a millivolt recorder. While this instrument gives a continuous and dependable record of the amount of solar radiation, it has certain drawbacks which limit its use under field conditions. It is expensive and requires an external source of electricity to operate the recorder. The record obtained must be integrated in some fashion, which either requires additional time in making use of the data obtained or requires the purchase of a rather expensive integrating unit.

A self-powered light integrator for ecological research has been described by McKee (1963). The two main components are a self-generating photovoltoic cell, and an ampere-hour meter. The photovoltoic cell converts radiant energy directly into electrical energy. The amount of electrical energy is then recorded as an accumulation directly on the ampere-hour meter.

A portable integrating light meter using batteries to supply current and a photocell has been described by Sprague and Williams (1943). The minute current from a photocell charges a condenser producing a potential difference which gradually increases. When the potential across the condenser reaches the breakdown voltage of a cold cathode relay tube in parallel with the condenser plates, the gas in the tube ionizes discharging the condenser and at the same time discharging a larger condenser through a sensitive counter.

Other photocell light integrators similar in design to the one described above have been described by Middleton (1953), Somers and Hamner (1951), and Blackman, et al. (1953). Cost of assembly parts is about $40. Light integrators of this type are somewhat bulky, sensitive to moisture, relatively expensive, and require batteries or an external source of power.

Thermometers have been used in certain instances to measure radiation. Suomi and Kuhn (1958) have used thermometers between black surfaces and between white surfaces as an approach to this measurement. The difference in temperature between the two thermometers varies with differing light intensities.

Lowry (1957) described a procedure for measuring light by utilizing two thermometers with a blackened metal plate mounted between their bulbs. Radiation was based on temperature difference between the two opposite faces of the blackened layer. Methods discussed utilizing thermometers are only of moderate accuracy and have no recordability. The instruments are relatively large and because of their size it is difficult to locate them within the crop canopy close to the plants.

Among the low-cost field techniques for gauging light quantities are photochemical tubes. Dore (1958) has described a chemical light meter to measure radiation in plant habitats. It utilizes the property of anthracene in benzene solution to polymerize into insoluble dianthracene upon exposure to sunlight. A spectrophotometer reading is used to check the quantity of color left due to the amount of unconverted anthracene remaining.

Brodie (1964), Heinicke (1963), and Atkins and Poole (1930) have described photochemical methods using oxalic acid as the reagent and a uranium salt as the catalyst. The chemicals, after exposure to sunlight, are titrated at intervals of several days to determine the amount of oxalic acid broken down and this is then related to radiation received for that period.

The decomposition of either hydriotic acid in sulfuric acid or potassium iodide in sulfuric acid have been used by Ridgway (1918) and McCrea (1923). The methods require varying concentrations of the reagents for differing light intensities and temperature corrections. Titrations are carried out immediately after exposure to radiation.

Photographic methods have been used and are easier to read than chemical light meters. The degree of darkening of panchromatic film with standard exposure can be used for light measurement according to Klugh (1925).

McCree (1968) has described the use of Kodak ectachrome film in conjunction with light filters to investigate light relations. The method was used primarily to obtain information about the red/far-red ratio of radiation under forest canopies, however.

A camera with a 180 degree field of view has been used by Anderson (1964), and Evans and Coombe (1959) to measure the light climate in woodlands. A grid was superimposed on the photograph and the percent reduction of illumination was determined by counting the number of segments clear and those obstructed. The method is only of moderate accuracy and requires the use of a darkroom.

Friend (1961) has described a light meter for measuring integrated values of light energy under field conditions. A stack of photosensitive Ozalid paper is exposed for daily periods; the amount of light energy received is estimated from the number of layers of paper penetrated by light, revealed after a dry development with ammonia vapor.

METHODS AND MATERIALS

Measurement of Light and Plant Response

Tests were conducted at Kansas State University, Agronomy Farm, Manhattan, Kansas, through a two-year period, 1967-68, to study light interception by grain sorghum with different planting arrangements. Plant arrangements included combinations of north to south row direction as opposed to east to west row direction, and 20-inch row spacing as opposed to 40-inch row spacing. This gave the following four treatment combinations:

1. E to W rows, 40-inch row spacing
2. E to W rows, 20-inch row spacing
3. N to S rows, 40-inch row spacing
4. N to S rows, 20-inch row spacing

Experiments for each of the two years were of split-plot design with directional orientation as main plots and row width as subplots. Each of the four treatments was replicated four times, giving a total of 16 plots during each of the two years.

RS-610 grain sorghum was selected for use in these studies due to its wide usage and amount of other research information available. Tests were conducted under natural rainfall on silty clay loam having only a slight slope. Experimental plots were planted at approximately 40,000 plants per acre with a tractor mounted vacuum planter having a 40-inch row spacing. Twenty-inch rows were obtained by "splitting" the 40-inch rows in appropriate plots. To establish equal population levels in both row widths, the 20-inch and 40-inch rows were planted at the same rate per row and the 20-inch rows hand thinned within four weeks after planting by removing alternate plants in each row.

During the season, at equal sampling intervals, data were taken on plant leaf area, dry matter accumulation, and light interception for each of the four treatments. Plot length for both years was 53 feet in order to have a sizeable area from which plant samples could be obtained. Twenty-inch row spacing plots were planted 12 rows wide, and 40-inch row spacing plots were planted 10 rows wide.

Plant leaf area determinations were made by measuring length and width of each of the green leaves on a plant and multiplying these times a correction factor. Leaves that were fully extended were measured for length from the leaf tip to the collar and for width at the widest point. Areas of these fully extended leaves were then determined by multiplying maximum length x maximum width x 0.747, as described by Stickler, Wearden, and Pauli (1961). Leaves in the early part of the season that were only partially extended were measured for length from the tip downward to the point where the leaf was rolled together and formed a "V". When this length was multiplied times maximum width times the correction factor of 0.747, the resulting values for leaf areas were incorrect. Therefore a representative sample of 40 partially unrolled leaves at different degrees of extension were removed from plants at the point where the leaf blades overlapped. These portions of leaves were then outlined on paper and maximum width and maximum length were measured. Each leaf outline was then traced with a planimeter and the area recorded. The average planimeter value found for these leaves was 0.593 times maximum length times maximum width. However, it was noted that leaves measured with only a small portion of the tip unrolled were nearly triangular in shape and had a correction value of about 0.55, whereas leaves that were almost fully unrolled had a correction value of about 0.70. Therefore the correction value for each of these representative leaves was multiplied times its actual leaf area to "weight" the values according to their relative importance as determined by leaf size. This gave a correction factor of 0.664 and hence leaf area determination for leaves not fully extended were obtained by multiplying length x maximum width x 0.664.

Dry matter accumulation at each sampling date was determined from the same plants used to find leaf areas. Plants were divided into the component parts of leaf blade, leaf sheath, culm, and inflorescence. Leaf blades were removed immediately above the collars, sheaths were removed at the nodes, heads were cut off immediately below the panicle, and the remainder with the roots trimmed off composed the culm. These component parts were then oven dried for five to seven days at 65 degrees Centigrade and weights were taken.

Light interception was determined by light meters of the Ozalid booklet type as described by Friend (1961). The method will be discussed in detail in a later section. Incoming solar radiation was measured by placing five light meters above the sorghum canopy at equal distances from each other. Eighty light meters were distributed equally among the four experimental treatments, and positioned at ground level under the foliage.

Light meters positioned above the crop canopy to measure incoming radiation were located on wooden posts with a small platform attached to the top. Three nails were partially driven into each wooden platform in a triangular arrangement to hold the light meter in place.

Light meters distributed within the crop at ground level were placed in groupings of five per plot. Boards, 48 inches long, painted black so as not to reflect light, were permanently located perpendicular to the rows and used as a level surface on which to place the light meters. Sixteen boards, each made to hold five light meters at 10-inch intervals, were placed one per plot near the middle of each of the 16 plots. Three nails, partially driven into the boards at each of the five spacings were positioned to hold the light meters in the correct location during each light measurement period.

Each board was given a painted identification letter ranging from A through P. Positions on each board were painted with numbers 1 to 5. Posts for positioning light meters above the crop received identification letters of Q through U. The light meters received matching labels including A1, A2, A3, A4, A5, B1,.....P5, and Q, R, S, T, and U. This made it possible to identify where each light meter was to be positioned in the field as well as where they had been exposed once they were collected.

In each of the 40-inch row spacing treatments, the two end light meters on a board at positions 1 and 5 were located directly under the sorghum rows, whereas light meters at positions 2, 3, and 4 on the board were located between the rows (see figure 1). With 20-inch row spacing treatments, light meters at positions 1, 3, and 5 on a board were located directly under the sorghum rows, whereas light meters at positions 2 and 4 were located at midpoints between the rows (see figure 2).

Metal posts painted florescent red were placed either at the north end or at the east end of each board (depending on board orientation due to row direction) to facilitate finding these test areas at night. Number one position on each board was placed closest to the luminescent marker.

Light measurements above and below the crop were taken as the accumulated amount for one day periods. Light meters were placed into position during the night preceeding the day of measurement. The following day the accumulated amounts of light received were recorded by the light meters. That night the light meters were collected and taken to the laboratory for later analysis.

Fig. 1. Light meters positioned under 40" rows.

Fig. 2. Light meters positioned under 20" rows.

Incoming radiation values from light meters having been exposed above the crop were correlated with the number of langleys radiation received on the sampling date as recorded by an Eppley pyranometer on Cardwell Hall at Kansas State University. The light received at ground level in each plot was determined after finding the number of langleys represented by each of the light meters on a board. The average light value shown by these five light meters was not truly representative of the average amount of light at ground level because of the greater representation by light meters positioned directly under the rows. Therefore, in all plots, the average langley value represented by the two end light meters on a board was first determined. This average langley value was then added to the langley values determined from light meters at positions 2, 3, and 4 on a board and the average of these four values was used to determine light at ground level. Interception of light by the sorghum in each plot was determined as the difference between incoming radiation and the amount present at ground level.

Upon maturity of the crop, treatment effects were further measured in terms of grain yields, forage yields, and plant population levels. Fifteen feet from two center rows were harvested from each of the 20-inch row spacing plots and 15 feet was harvested from one of the center rows in 40-inch row spacing plots. This gave equal harvest areas of 50 sq. ft. for all plots.

Grain yield from each plot was determined by cutting the heads from plants in each harvest area and machine threshing. The amount of grain obtained in each case was weighed, adjusted to 12.5 percent moisture and 56 pound test weight, and converted to a bushel per acre basis.

Forage yield from each plot was determined by collecting the remainder of plants topped for grain yield. These plants were removed at ground level, placed in a labeled burlap bag, and put into a dryer set at 60 degrees Centigrade. Dehydration continued until moisture loss per sample was less than one-tenth pound in 24 hours, at which time samples were weighed. Heads were considered to have been 20 percent vegetative material. Therefore, after grain samples had been corrected for moisture, the grain yields were multiplied times 0.25 to estimate forage quantity of the heads. This amount was added to plant dry matter weights to get total forage production on each plot, and then converted to equivalent yields of forage on an acre basis.

The number of heads in each plot was determined from counts made during head removal for grain yield determinations. The number of heads resulting from each treatment was then converted to the equivalent number of heads per acre.

In 1967, the experiment was planted on June 6 and kept relatively weed free throughout the season by hand cultivation. Sampling dates for leaf area, dry matter accumulation, and light interception data were at five-day intervals beginning July 9. Leaf area measurements and dry weight of component plant parts were obtained for each treatment from five plants randomly selected from the four replicates of each treatment. These plants were selected during the morning of each sampling date and taken to the laboratory to be analyzed.

Certain sampling dates came on Sundays, in which case light interception data were taken as usual, but plant samples were selected, put into air-tight plastic bags, and stored in a cooler at 5 degrees Centigrade to be analyzed the following day. After September 27, sampling dates were discontinued because the sorghum was judged to be at physiological maturity. On October 16 the plots were harvested.

In 1968, the experiment was planted on June 21 and maintained relatively weed free during the season by the application of atrazine (1.5 lbs. a.i. per acre). Data on leaf area, dry matter accumulation, and light interception were taken at seven-day intervals beginning July 17. Four plants per treatment were selected for leaf area and dry matter accumulation data by taking one plant from each of the four replications of a treatment. After October 9, sampling dates were discontinued because the sorghum was nearly mature and had been subjected to freezing temperatures. On the final sampling date, light interception data were taken as usual, but no plant samples were gathered for analysis. Plots were harvested on October 23.

Since plant response reflects the nature of the environment, certain weather data are given in table 1. These data give indication of the climatic conditions prevailing during the two seasons.

Table 1. Weather data showing precipitation, temperature, and light during 1967 and 1968.

	Precipitation (inches)		Temperature (departure from normal)		Light (ave. no. langleys/day)	
	'67	'68	'67	'68	'67	'68
April	4.84	3.19	--	--	--	--
May	2.95	3.80	--	--	--	--
June	6.70	2.92	-2.7	-1.0	460	607
July	3.12	6.84	-5.9	-2.7	483	515
August	1.43	5.00	-5.6	-2.7	506	430
Sept.	7.83	1.51	-5.4	-2.8	359	387
Total	26.87	23.26	--	--	--	--
Ave.	--	--	-4.9	-2.3	452	485

Light Measurement Technique

The principle that light sensitive diazo compounds form deeply colored addition compounds on short exposure to ammonia vapor has been used by the Ozalid Company and other firms to manufacture diazotype paper, and "photographic" copying material. Paper coated with a diazo compound together with a suitable coupler, is used to make direct positive "blue prints"; upon exposure to light the unmasked area of diazotype paper is bleached. After a dry development in ammonia vapor, the unbleached area of diazotype paper becomes brightly colored. The method used for measuring light in this experiment was described by Friend (1961) using booklets of Ozalid paper, a diazotype paper.

The type of paper used was Sepia Ozalid paper, number 402ITX, 8½ x 11 inches in size. The paper was obtained from Drexel, Incorporated, Kansas City, Kansas, a distributor for the Ozalid Company. Cost of the paper was about six dollars for 500 sheets.

A stack of 12 sheets of Ozalid paper, all placed with the blue-green coated side uppermost was stapled at eight equal intervals across each end. A paper cutter was then used to cut a one-inch strip from one of the ends and to divide it into eight equal booklets. Further stapling and cutting resulted in 88 booklets, each one and one-sixteenth by one inch in size. These operations were carried out in a photographic dark room, although other dimly lighted areas would have served as well. The Ozalid booklets were then stored in a dry, darkened, cardboard container until needed.

Containers to enclose the booklets and protect them from wind and rain during exposure in the field were assembled from pyrex petri dishes, foam rubber, black paper, and rubber dish seals (see figure 3). Round "disks" of one-inch thick foam rubber were cut out, and placed in the bottom half of each 15 x 100 mm. petri dish so that when an Ozalid booklet was placed on top and the lid replaced, the sensitive surface of the booklet was held flat against the inner surface of the lid. A piece of black paper with a round central hole one-half inch in diameter, allowing light to reach the sensitive surface of the booklet, was fitted and glued inside each lid. Rubber dish seals were placed around the dishes to hold them together and to keep out moisture. Under these conditions there was no bleaching at the edges of the booklets and moisture entrance during precipitation was seldom a problem. The relatively small size of the petri dishes and the protection afforded by the rubber dish seals made storage and handling quite simple.

The operation of putting an Ozalid booklet into each petri dish was carried out in dim light. Each Ozalid booklet was marked on the underside with a field location label to match the label marked on the underside of the foam rubber pad in each petri dish. Petri dishes were loaded in advance and then stored in a closed metal box until used in the field.

Upon exposure to light, the top sheet in an Ozalid booklet became bleached. This bleached layer then allowed light to penetrate to the second sheet. Bleaching of further sheets continued with additional light penetration. The time required to bleach a layer was progressively longer as more sheets were penetrated.

After one day exposure in the field the light meters were collected and stored in a closed metal box until a satisfactory time was available for unloading them. Unloading of the light meters in a dimly-lit room was followed by a dry development process in ammonia vapor. The exposed booklets were put into a small basket made from plastic screen stapled together and the basket was then placed onto a perforated plastic stand (the inverted bottom two inches

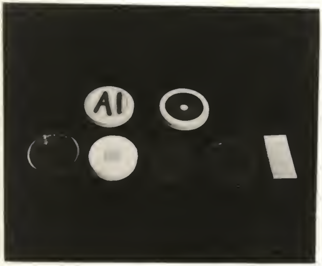

Fig. 3. Light meter components below; assembled light meters above.

Fig. 4. Chart showing the range of partial sheet bleaching.

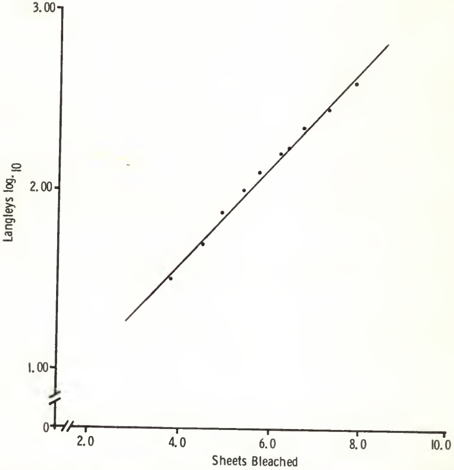

Fig. 5. Calibration line for Ozalid booklets.

of a quart plastic bottle) in a large-mouthed gallon jar. About 30 ml. of concentrated ammonium hydroxide was poured into the jar and the lid replaced. Development time was about 20 minutes in order for the ammonia vapor to penetrate the booklets but there was no problem with over-development up to about two hours.

The development process caused unbleached sheets and the areas around bleached circles on exposed sheets to become dark brown. The number of layers whitened by the action of light could then be counted. In order to make the readings of bleached pages more precise, the number of fully bleached sheets were counted and the amount of partial bleaching of the next sheet was estimated in tenths. A chart was made of "between paper" readings to use for making these partial sheet estimations (see figure 4). The time was determined at which exposure to a constant light source just visibly bleached the third layer in a booklet, as shown after development. This exposure time was about 30 minutes in a growth chamber at 1,000 foot candles. These second and third sheets then gave the 1.0 and 0.0 range of "between paper" divisions. Further exposures showed that 62½ minutes were required to completely bleach the third layer of paper. The time interval between bleaching of the second and third layers was then divided logarithmically into five intervals. Exposure of further booklets for these durations provided four additional integrades of bleaching. The six papers were then mounted on cardboard so that they could be viewed for easy comparison with developed Ozalid booklets from the field. When not in use, this scale was kept in the dark to prevent fading.

To calibrate the paper, a series of light meters were exposed to different amounts of light energy ranging from 32 to 385 langleys and the number of sheets bleached in each booklet were counted. These exposures were made on the roof of Cardwell Hall so that a nearby Eppley pyranometer with recorder and counter could be used to determine the amount of radiation each light meter received. The exposure process is logarithmic in that sheets take progressively longer to bleach as light penetrates a greater number of layers. In order to obtain a straight line calibration, the number of pages bleached, as shown after development, were plotted against the logarithm of the light energy received. These points and the resulting calibration line are shown in figure 5. Further exposures showed no observed differences from the above calibration line in the rate of bleaching of booklets under differences of temperature, intensity of light, cloudiness, or time of day.

A chart showing the spectral sensitivity of the Ozalid paper used was reprinted by permission from the Ozalid Company and is shown in figure 6.

Since the Ozalid paper was shown to be bleached primarily by ultraviolet and violet light, and glass was commonly known to intercept ultraviolet light, a portion of a petri dish was tested for its light filtering qualities. The results obtained from a recording spectrophotometer (figure 7)

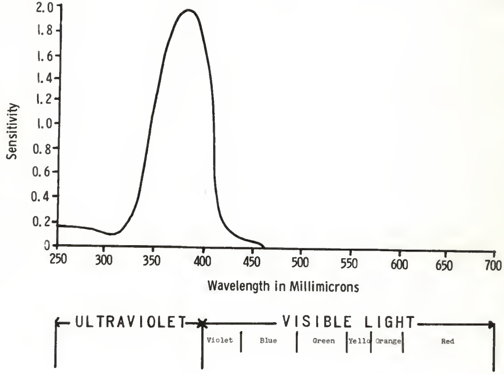

Fig. 6. Spectral sensitivity of Ozalid paper.

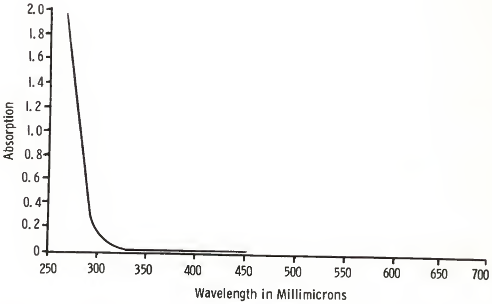

Fig. 7. Spectral absorption by Pyrex glass.

show that the pyrex glass filtered light below about 300 millimicrons. Both this chart and the preceeding one showing the spectral sensitivity of the Ozalid paper used have a logarithmic scale on the y-axis with absorption, and paper sensitivity, respectively, being 0 percent at 0.0, 90 percent at 1.0, and 99 percent at 2.0. Ozalid booklets in petri dishes were therefore bleached by light in about the 300 to 450 millimicron range.

RESULTS AND DISCUSSION

Light Measurement Technique

During the 1967 season, when the original supply of Ozalid paper became low, a new supply was purchased and used on the last three sampling dates. Upon exposure and development of booklets made from the second shipment of Ozalid paper, a noticeable change occurred in the number of sheets bleached. Therefore, upon termination of sampling dates, a calibration line was plotted for booklets made from the second shipment of Ozalid paper.

When daily values of light energy received were available at the end of the growing season (courtesy of the Physics Department, Cardwell Hall), sheets bleached in all booklets were counted. The logarithm of the light energy received on a sampling date was plotted on the calibration line. From this point the expected number of pages to have been bleached for booklets exposed to gross radiation were found. However, the actual number of pages bleached in these booklets did not agree with what had been expected. Deviations in the number of sheets bleached from the calibration lines are shown in figure 8. Points are numbered 1-17 in the order that light measurements were taken during the season. Points 1-13 show deviations in the number of sheets bleached from calibration line number one and points 15-17 show deviations in the number of sheets bleached from calibration line number two.

Since the amount of bleaching of booklets exposed above the canopy had deviated from the calibration lines, it was assumed that the amount of bleaching in booklets exposed under the canopy had deviated in a similar manner. Thus, in order to determine light under the canopy from booklets that had been exposed there, an estimated calibration line was drawn for each date from two points. The lower point was taken as 0.0 for sheets bleached and for the logarithm of the light energy received. The upper points used were plotted from the booklets exposed to gross radiation on each date as was shown by the points in figure 8.

Since the number of sheets bleached in the booklets tended to be progressively less during the 1967 season, tests were conducted to see if the paper aged with time. In June, 1968, a series of booklets were exposed to a constant flourescent light source for varying lengths of time. Additional Ozalid paper was stored in a cooler at five degrees Centigrade and exposed to the same light source in September, 1968. The results shown in figure 9 indicate that aging of the paper occurred.

During the 1968 season, Ozalid paper was stored in a cooler and a series of booklets were exposed on the roof of Cardwell Hall during each sampling date. Calibration lines were plotted from these exposures and at the end of the

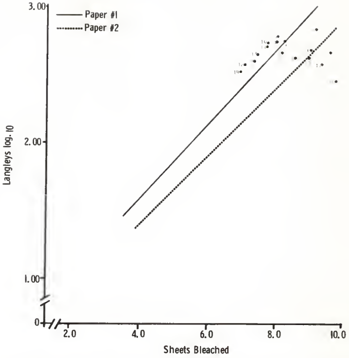

Fig. 8. Seasonal variation in booklet bleaching, 1967.

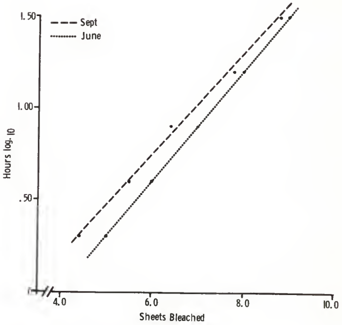

Fig. 9. Aging of Ozalid paper.

season, calibration lines were tested and found to be statistically different at the one percent level. (Analysis of variance for calibration lines and all further ANOV's are shown in the appendix). Therefore, the calibration line obtained for each date was used to analyze light data taken on that date.

Accuracy of light measurement was tested by analyzing the "gross radiation" readings from each of the 17 sampling dates in 1967 and from each of the 13 sampling dates in 1968. Variance in the number of sheets bleached in each of the five booklets from the mean number of sheets bleached on that date was used to find the variability about a point. This gave a coefficient of variability of 2.25 percent in 1967, 1.38 percent in 1968, and 1.91 percent for the two years combined.

Light Interception and Plant Response

Average percent light interception by sorghum for each treatment over all sampling dates for 1967 and for 1968 is shown in table 2. Statistical analysis of light interception data showed a significantly greater amount of light intercepted by sorghum in 20-inch rows than in 40-inch rows for each of the two years. Light interception was 14.9 percent and 15.4 percent greater in 20-inch row treatments than in 40-inch row treatments for 1967 and 1968, respectively. Row direction was not shown to have significantly influenced light interception by sorghum in either year, however, an interaction between row direction and row width was shown to have occurred during 1968 with E-W 40-inch rows intercepting 3.3 percent more light than N-S 40-inch rows and no similar response in the 20-inch rows. No row width x row direction interaction was shown in 1967.

Table 2. Percent light interception as affected by row width and direction in 1967 and 1968.

Year	Treatments			
	E-W 40"	N-S 40"	E-W 20"	N-S 20"
1967	64.3	65.1	79.6	79.6
1968	70.4	67.1	83.8	84.5

Light interception by sorghum on each sampling date during 1967 and 1968 are shown in figure 10 and figure 11, respectively. Only averages from 20-inch row treatments and from 40-inch row treatments are shown in the figures since light interception was not found to be significantly different by row direction. Data points for July 29, 1967, were omitted as many of the booklets had become moistened, and bleached erratically. Light interception by sorghum was shown to be particularly low during the early stages of plant growth before large amounts of leaf area had developed.

Levels of light interception by the corresponding row spacings were shown to be lower in 1967 than in 1968. Although this difference for the two years may be real, the levels of light interception for 1967 may be questioned somewhat since the calibration line for each sampling date was

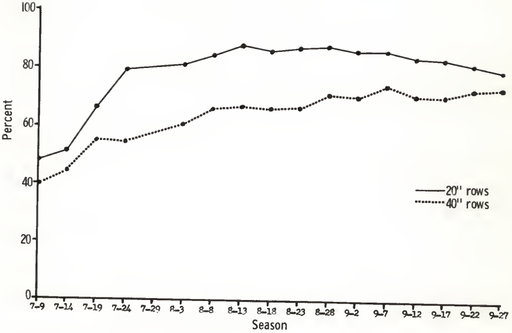

Fig. 10. Light interception during the 1967 season.

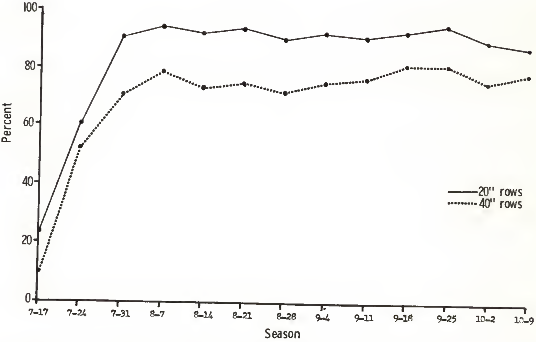

Fig. 11. Light interception during the 1968 season.

plotted from only two points. However, even if the calibration lines for 1967 were in error, causing incorrect levels of light interception to be shown, the relative differences in light interception shown by the two row spacings should still be correct.

Twenty-inch and 40-inch row spacing sorghum is pictured in figure 12. Due to the overlapping of leaves in adjacent 20-inch rows, light reaching ground level had to penetrate a rather continuous leaf canopy, whereas in 40-inch rows, the leaves of adjacent rows did not overlap and allowed light to penetrate to ground level through a discontinuous leaf canopy. Canopies of 20-inch row treatments and of 40-inch row treatments not only allowed different amounts of light to reach ground level, but also caused the spatial distribution of light at ground level to be quite different.

Since row direction was important in spatial distribution of light at ground level, the light distribution under each treatment is shown in figure 13. Spatial distribution of light was determined as the average percent of light received at various locations under the sorghum canopy for the combined sampling dates on September 4, 11, 18, and 25, in 1968. The _1_ position in figure 13 represents the amount of light indicated by light meters at position number one on a board, which was either at the north end or at the east end of the group of five light meters on a board, depending upon row orientation.

Fig. 12. Sorghum in 20" and 40" row spacing.

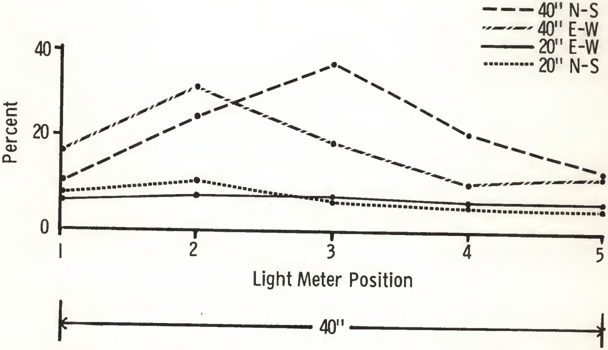

Fig. 13. Spatial light distribution under sorghum rows.

Light penetration through sorghum canopies of 20-inch row treatments was shown to be rather constant with different locations under the canopy, regardless of directional orientation of the rows. This was expected, since sorghum in 20-inch rows formed a rather continuous canopy, regardless of row direction. With 40-inch row treatments, the amount of light reaching ground level was much greater than in 20-inch row treatments and the distribution of light was not nearly as constant as in 20-inch row treatments. With 40-inch sorghum rows oriented N-S, the accumulated amounts of light at ground level during sampling dates was greatest at the midpoint between rows and was progressively less closer to the rows. With E-W oriented sorghum rows, the sun was at a southerly angle to the rows during much of the day, and caused the most light to reach ground level near the south side of each sorghum row.

The use of narrow rows, regardless of directional orientation, has been shown to increase the amount of light intercepted by the sorghum canopy. Since close row spacing reduces the light energy available at the ground and increases the light energy available to the crop canopy, there is a decrease in the energy available for water loss through evaporation from the soil, and presumably a corresponding increase in the energy available for water loss through transpiration.

The average leaf area per plant for each treatment during all sampling dates of 1967 and of 1968 is shown in table 3. Leaf areas during 1967 were shown to be significantly greater in E-W row treatments than in N-S row treatments and also significantly greater in 40-inch row treatments than in 20-inch row treatments. Leaf areas during 1968 were not shown to be significantly different by row direction, but were shown to be significantly greater in 20-inch row treatments than in 40-inch row treatments. The discrepancy indicated by greater leaf area in 40-inch row sorghum in 1967 and by 20-inch row sorghum in 1968 was due to only small differences in each case and may have been influenced by tillering differences during the two years. During 1967 a small amount of tillering occurred late in the season. During 1968 considerable tillering occurred shortly after emergence of the plants, particularly in the 20-inch rows.

Table 3. Leaf areas as affected by row width and row direction in 1967 and 1968.

	Treatments			
Year	E-W 40"	N-S 40"	E-W 20"	N-S 20"
1967	2,450	2,357	2,298	2,179
1968	2,270	2,242	2,415	2,685

Due to the inherent problem involved in choosing "average" plant samples, data on leaf area and dry matter accumulation were inconsistent for each treatment on various sampling dates. Therefore figures showing leaf area and dry matter accumulation were plotted from averages for all treatments on each sampling date in order to make the resulting points more consistent and to avoid indicating misleading variability of the plant growth pattern.

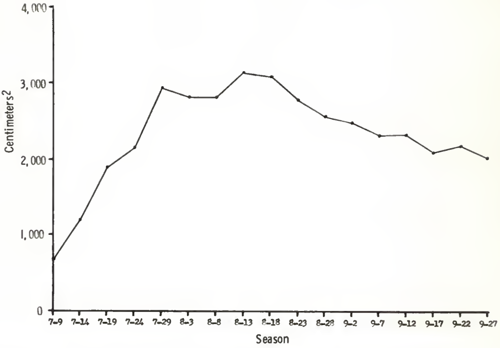

Fig. 14. Plant leaf area during the 1967 season.

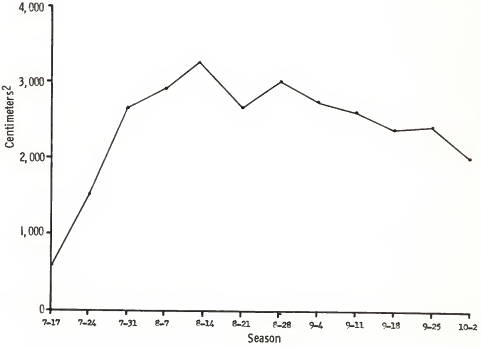

Fig. 15. Plant leaf area during the 1968 season.

The average leaf area per plant on sampling dates during 1967 and 1968 is shown in figure 14 and in figure 15, respectively. Leaf area increased rapidly, reached a maximum early in the season, and was observed to be closely related to the amount of light interception by the sorghum during this period. As the lower leaves continually became senescent, photosynthetically active leaf area decreased after the maximum was reached but without as great a simultaneous decrease in light interception. Since leaf area measurements represent only the green leaf area of sorghum plants, the senescent leaves that remained on most plants were not measured for leaf area. However, these senescent leaves undoubtedly continued to intercept light and probably were the reason why light interception did not decrease greatly with decreased green leaf area.

Dry matter accumulation on a plant basis is shown for 1967 and 1968 in figure 16 and figure 17, respectively. Late planting in 1968 caused the sorghum to continue productivity late in the fall and although the sorghum was near maturity, freezing temperatures shortly after the October 2 sampling date terminated plant dry matter accumulation. The observation that dry matter was still being produced in 1968 when the killing frost occurred is confirmed by figure 17 in that lines connecting points showing dry matter accumulation of the head and of the whole plant are steeply sloping through October 2.

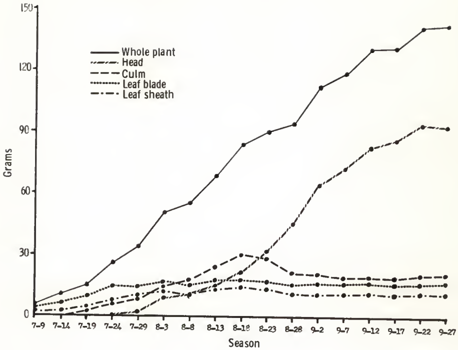

Fig. 16. Dry matter accumulation during the 1967 season.

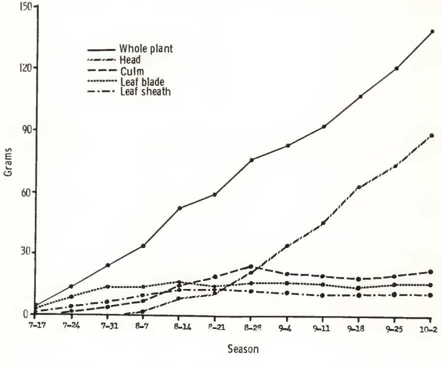

Fig. 17. Dry matter accumulation during the 1968 season.

Accumulation of dry matter in the early part of each season was less rapid than after maximum leaf area and maximum light interception were reached. Upon termination of increases in leaf area, the light interception percents and dry matter accumulation rates were rather consistent throughout the rest of the season.

Grain yields, forage yields, and head counts for 20-inch row treatments and for 40-inch row treatments from 1967 and from 1968 are shown in figures 18, 19, and 20, respectively Analysis of data for each of these factors from each of the two years showed significant differences by row width only, and in no case by row direction. Data for each factor were combined for the two years and statistical analyses are given on this basis.

Grain yields were shown to be 15.5 percent greater in 20-inch row treatments than in 40-inch row treatments for the two years combined. The significantly higher grain yield by 20-inch row sorghum was shown from levels of grain yield that were considerably higher in 1967 than in 1968.

Forage yields were shown to be significantly greater in narrow rows for the two years with 20-inch row treatments producing 14.8 percent more dry matter than 40-inch row treatments. Levels of forage production were not significantly different for the two years, and with this in mind, the levels of grain production in 1968 would probably have been comparable with those in 1967 if killing frost had not prevented the sorghum from reaching its potential.

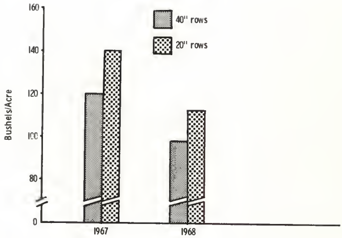

Fig. 18. Grain yields.

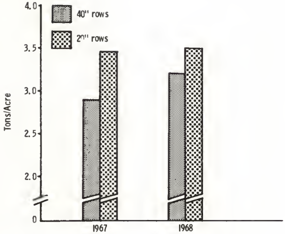

Fig. 19. Forage yields.

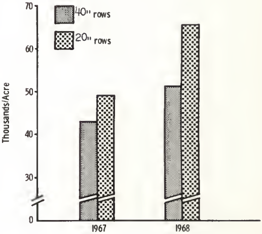

Fig. 20. Heads per acre.

The number of heads per acre in 20-inch row treatments was significantly greater than in 40-inch row treatments, being 13.5 percent and 28.6 percent greater for 1967 and for 1968 respectively. A significant year x row width interaction indicated that the number of heads per acre were relatively greater in 20-inch rows as compared to 40-inch rows in 1968 than in 1967. Analysis of data also showed a significantly greater number of heads resulting from all treatments in 1968 than in 1967. The greater number of heads caused by profuse tillering in 1968 may have resulted from a more optimum environment encountered with late planting.

Although heads per acre are one component of grain yield, the head size in 1968 was observed to have been smaller than in 1967, which would partially explain why grain yields were not proportional to the number of heads per acre. Seed size also appeared to have been smaller in 1968 than in 1967, which would further explain why yields were not proportional to head counts for the two years. It would have been interesting to note the grain yields that would have resulted in 1968 had a killing frost not intervened.

Greater interception of light by sorghum in narrow rows was accompanied by greater sorghum yields in narrow rows for the two years of this study. Although the yield advantage shown by narrow rows may not have been wholly due to greater light interception, the author feels that with the high levels of production involved, increased light interception by narrow rows played an important role in increasing sorghum yields.

CONCLUSIONS

Light Measurement Technique

The Ozalid method of measuring light was not highly sensitive; however, by using the "between paper" readings, the light received during the course of a clear summer day bleached about 10 papers, equal to 50 "between paper" readings. Because of the great variability of light conditions in the field, this sensitivity was probably more than adequate. The simplicity and cheapness of the method allowed the use of the large number of replicates needed for adequate sampling of the habitat, and the sensitivity and accuracy were sufficiently high for field use.

Light Interception and Plant Response

As other growth requirements are being supplied more fully, competition for light in agricultural crops is becoming more vital. Since the inefficient use of light reduces yields at high production levels, light wastage can be minimized by properly adjusting row spacing. Since increased levels of production are a primary concern in agronomy, more complete utilization of the available light should be considered in order to prevent unnecessary light wastage. Although plant spacing in narrow rows will allow plants to intercept more of the available light, such factors as leaf area index, dispersion of the leaves, and leaf angle are all aspects of leaf arrangement which should be studied. These factors may gain greater recognition and concern in the near future.

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APPENDIX

TABLE I. 1967--Radiation on Sampling Dates

Date	Langleys	Sheets Bleached	Weather Conditions
7-9	480.3	9.05	Cloudy
7-14	670.2	9.22	Clear
7-19	413.1	8.98	Cloudy
7-24	414.7	8.62	Cloudy
7-29	608.8	8.10	Clear
8-3	554.3	8.30	Ptly cloudy
8-8	457.8	8.18	Cloudy
8-13	552.3	8.06	Ptly cloudy
8-18	396.0	7.44	Cloudy
8-23	536.6	7.84	Clear
8-28	534.6	7.82	Clear
9-2	381.8	7.14	Cloudy
9-7	451.7	7.48	Clear
9-12	331.8	7.00	Cloudy
9-17	278.6	9.78(x)	Cloudy
9-22	461.2	9.66(x)	Clear
9-27	381.9	9.44(x)	Cloudy
Ave.	465.0	--	--

(x)Paper #2

TABLE II. 1968--Radiation on Sampling Dates

Date	Langleys	Sheets Bleached	Weather Conditions
7-17	553.9	9.9	Ptly cloudy
7-24	228.2	8.2	Cloudy
7-31	321.6	8.7	Cloudy
8-7	561.0	9.6	Clear
8-14	375.9	9.0	Cloudy
8-21	546.0	9.9	Clear
8-28	172.3	8.0	Cloudy
9-4	364.9	9.1	Cloudy
9-11	498.7	9.4	Clear
9-18	428.5	9.1	Cloudy
9-25	440.3	8.9	Clear
10-2	377.8	8.7	Clear
10-9	399.3	8.6	Clear
Ave.	405.3	--	--

TABLE III. 1968--Calibration Lines

Date	y-intercept	Slope (langleys log.10/ sheets bleached)
7-17	-.01	.279
7-24	-.21	.307
7-31	-.59	.355
8-7	-.59	.341
8-14	-.11	.299
8-21	-.05	.282
8-28	-.05	.286
9-4	.10	.272
9-11	.21	.262
9-18	.04	.282
9-25	-.38	.340
10-2	.32	.256
10-9	.13	.286

TABLE IV. 1968--Calibration Lines--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Dates	1	19.32	322.00**
Calibrations	12	4.49	74.83**
Error	46	.06	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE V. 1967--Light Interception (percent)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	39.7	39.5	48.5	46.9
7-14	40.1	48.0	51.4	50.3
7-19	49.5	60.5	67.8	65.2
7-24	54.2	54.0	78.2	81.2
7-29(x)	80.7	81.8	91.4	93.8
8-3	61.2	59.6	81.7	80.8
8-8	65.3	66.6	82.3	86.4
8-13	67.2	67.4	85.9	90.3
8-18	64.6	68.0	85.4	87.0
8-23	67.6	65.7	86.9	88.2
8-28	70.1	73.1	88.6	87.2
9-2	69.8	70.1	86.2	86.1
9-7	74.2	73.6	86.9	85.7
9-12	71.1	69.6	84.0	83.0
9-17	72.9	70.2	84.5	82.4
9-22	75.3	70.9	83.4	79.2
9-27	74.7	68.4	79.6	79.1

(x)Moisture entrance in light meters.

TABLE VI. 1967--Light Interception--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	328.43	
Dates	16	2,118.81	43.25**
Error (A)	48	50.61	
Row Direction	1	12.24	0.40
Date x Direction	16	29.00	0.95
Error (B)	51	30.65	
Row Width	1	15,038.63	510.01**
Date x Width	16	119.06	4.04**
Direction x Width	1	11.41	0.39
Date x Direction x Width	16	29.62	1.00
Error (C)	102	29.49	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE VII. 1968--Light Interception (percent)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	12.8	6.9	24.1	23.5
7-24	50.8	54.4	57.7	65.6
7-31	72.4	72.1	90.0	91.9
8-7	80.2	77.7	95.4	94.0
8-14	74.6	72.4	92.5	92.6
8-21	76.0	74.4	93.4	95.2
8-28	72.4	71.6	90.4	91.0
9-4	77.1	73.6	91.7	93.1
9-11	79.2	73.5	91.5	90.0
9-18	83.4	80.5	93.3	92.8
9-25	87.0	75.7	95.6	94.4
10-2	79.0	71.7	89.5	89.8
10-9	79.0	78.0	88.2	86.8

TABLE VIII. 1968--Light Interception--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	46.89	
Dates	11	6,694.62	290.18**
Error (A)	33	23.07	
Row Direction	1	82.56	3.62
Date x Direction	11	35.38	1.55
Error (B)	36	22.82	
Row Width	1	11,391.38	415.56**
Date x Width	11	42.97	1.57
Direction x Width	1	197.44	7.20**
Date x Direction x Width	11	7.06	0.26
Error (C)	72	27.41	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE IX. 1967--Leaf Area per Plant (centimeters^2 ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	722.5	605.5	637.3	676.6
7-14	1,216.6	1,089.9	1.361.4	1,203.0
7-19	1.906.4	2,018.6	1,966.2	1,604.7
7-24	2,879.8	2,417.6	2,657.4	2,608.8
7-29	3,045.7	2,671.4	3,108.5	2,904.0
8-3	2,911.1	2,772.8	2,876.0	2,642.1
8-8	3,045.3	2,893.7	2,528.8	2,740.3
8-13	3,113.5	3,083.5	2,859.6	2,828.1
8-18	2,960.7	2,946.8	3,021.6	2,833.7
8-23	2,085.6	2,982.4	2,678.2	2,748.
8-28	2,905.8	2,697.8	2,467.7	2,219.2
9-2	2,645.8	2,454.5	2,406.8	2,437.4
9-7	2,670.5	2,478.3	2,172.6	1,985.1
9-12	2,574.1	2,425.0	2,401.9	1.951.7
9-17	1,996.4	2,104.2	2,183.8	2,108.7
9-22	2,306.0	2,426.1	2,034.5	1.990.9
9-27	2,248.8	2,338.2	1,883.5	1.669.1

TABLE X. 1967--Leaf Area per Plant--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	4	125,756	
Dates	16	8,605,099	77.57**
Error (A)	64	110,940	
Row Direction	1	957,075	7.76**
Date x Direction	16	84,776	0.69
Error (B)	68	123,349	
Row Width	1	2,314.290	19.49**
Date x Width	16	254,063	2.14**
Direction x Width	1	15,817	0.13
Date x Direction x Width	16	78,224	0.66
Error (C)	136	118,713	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XI. 1968--Leaf Area per Plant (centimeters^2 ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	483.6	442.8	768.8	575.3
7-24	1,204.7	1,424.9	1,671.8	1,831.8
7-31	2,102.8	2,436.0	2,692.2	3,452.7
8-7	2,933.7	2,809.3	2,953.1	2,995.6
8-14	2,908.6	3,363.2	2,981.6	3,820.9
8-21	2,707.1	2,956.5	2,409.2	2,574.4
8-28	2,534.2	2,788.9	3,653.4	3,087.4
9-4	2,437.9	2,434.8	2,341.8	3,535.4
9-11	2,455.5	2,094.2	3,011.4	2,985.8
9-18	3,024.6	2,055.2	2,132.6	2,332.9
9-25	2,363.1	2,160.4	2,426.0	2,723.4
10-2	2,086.6	1,940.3	1,938.1	2,051.0

TABLE XII. 1968--Leaf Area per Plant--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	1,120,511	
Dates	11	8,719,382	18.11**
Error (A)	33	481,507	
Row Direction	1	701,075	2.01
Date x Direction	11	497,802	1.43
Error (B)	36	348,936	
Row Width	1	4,143,638	14.76**
Date x Width	11	601,433	2.14*
Direction x Width	1	1,064,456	3.79
Date x Direction x Width	11	354,175	1.26
Error (C)	72	280,820	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XIII. 1967--Leaf Blade Dry Matter per Plant (grams ave.)

Date	Treatment E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	3.6	3.1	3.5	3.4
7-14	7.2	5.1	8.1	6.3
7-19	8.8	8.5	9.9	8.1
7-24	14.6	14.2	14.1	14.3
7-29	14.8	12.2	14.8	14.2
8-3	16.0	15.6	16.3	15.6
8-8	16.5	15.7	14.0	14.8
8-13	17.3	17.6	15.9	17.4
8-18	17.7	17.4	18.2	16.9
8-23	16.7	17.6	16.2	17.8
8-28	17.1	17.0	13.5	14.6
9-2	16.7	15.8	15.6	16.8
9-7	16.9	17.0	16.4	15.2
9-12	18.2	16.4	17.8	16.4
9-17	14.1	15.9	16.7	16.5
9-22	16.2	16.8	15.0	16.9
9-27	18.0	17.5	17.5	15.0

TABLE XIV. 1968--Leaf Blade Dry Matter per Plant (grams ave.)

Date	Treatment E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	2.1	1.8	3.5	2.9
7-24	6.4	8.0	9.0	10.5
7-31	10.8	12.9	15.0	18.1
8-7	14.4	14.2	14.6	14.8
8-14	14.6	18.1	15.2	20.5
8-21	11.9	15.8	14.2	16.0
8-28	14.8	14.3	19.2	18.9
9-4	14.0	13.5	15.5	23.1
9-11	14.1	11.5	19.0	18.0
9-18	17.6	12.8	14.2	13.8
9-25	15.8	14.5	17.0	16.6
10-2	15.0	16.6	15.6	16.6

TABLE XV. 1967--Leaf Sheath Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	1.1	0.9	1.1	1.1
7-14	2.5	1.9	2.7	2.4
7-19	3.7	4.0	4.1	3.3
7-24	7.7	6.0	7.4	7.7
7-29	10.9	8.5	10.5	10.0
8-3	11.8	12.1	12.7	12.1
8-8	12.6	12.7	11.1	11.2
8-13	14.1	14.3	12.6	13.6
8-18	14.4	14.4	15.4	13.4
8-23	12.8	13.5	12.9	14.0
8-28	12.1	13.4	10.6	10.6
9-2	10.9	11.4	11.0	11.5
9-7	11.6	11.6	11.1	10.2
9-12	12.4	11.5	12.2	11.4
9-17	9.5	10.8	11.3	11.3
9-22	11.5	11.8	11.0	11.5
9-27	12.6	12.0	12.0	11.1

TABLE XVI. 1968--Leaf Sheath Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	0.8	0.5	1.0	0.9
7-24	2.7	3.7	3.8	4.4
7-31	4.9	6.0	6.2	5.8
8-7	9.8	10.4	10.3	9.5
8-14	11.1	13.6	12.1	15.8
8-21	15.2	13.0	12.0	12.2
8-28	11.9	10.8	14.8	13.6
9-4	10.1	9.2	11.0	16.5
9-11	10.0	8.5	13.1	13.8
9-18	12.5	12.0	10.4	9.8
9-25	12.0	11.2	13.5	11.1
10-2	11.0	12.8	10.5	12.2

TABLE XVII. 1967--Culm Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	0.3	0.2	0.3	0.2
7-14	0.8	0.6	1.0	0.8
7-19	1.7	1.9	2.9	1.5
7-24	5.6	3.1	5.6	7.7
7-29	10.0	6.4	8.2	7.6
8-3	13.6	15.5	14.3	12.9
8-8	16.6	16.6	14.8	14.7
8-13	23.9	24.6	23.0	23.7
8-18	29.8	29.6	32.3	28.5
8-23	27.3	26.1	27.0	30.5
8-28	19.9	25.8	10.0	21.1
9-2	19.0	22.4	20.1	20.6
9-7	21.2	18.9	18.1	16.0
9-12	21.3	18.1	19.5	19.6
9-17	17.4	18.8	20.2	18.7
9-22	20.4	21.0	19.8	20.8
9-27	20.5	21.3	21.8	20.0

TABLE XVIII. 1968--Culm Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	0.1	0.2	0.4	0.1
7-24	1.0	1.0	1.5	1.5
7-31	3.0	3.4	3.9	5.0
8-7	6.8	7.7	7.1	7.1
8-14	11.2	16.0	11.2	16.5
8-21	19.2	21.6	19.9	18.6
8-28	23.2	19.6	29.8	26.6
9-4	19.2	16.0	19.1	28.2
9-11	19.0	16.8	20.5	23.1
9-18	20.0	16.5	19.0	17.1
9-25	20.0	19.0	23.8	18.0
10-2	24.2	24.5	20.0	23.2

TABLE XIX. 1967--Head Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	--	--	--	--
7-14	--	--	--	--
7-19	--	--	--	--
7-24	0.2	0.1	0.2	0.1
7-29	1.3	0.9	1.5	1.2
8-3	8.3	8.2	9.8	8.7
8-8	11.6	12.1	11.2	11.8
8-13	14.2	15.5	12.9	14.0
8-18	21.2	20.7	20.3	22.0
8-23	27.6	32.2	32.5	34.9
8-28	44.1	46.2	45.4	44.3
9-2	62.9	59.5	68.4	67.6
9-7	78.8	74.9	71.4	80.2
9-12	88.6	74.8	85.8	82.2
9-17	79.8	83.1	94.4	85.3
9-22	94.3	93.2	92.2	95.6
9-27	92.8	90.6	101.9	85.4

TABLE XX. 1968--Head Dry Matter per Plant (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	--	--	--	--
7-24	--	--	--	--
7-31	--	--	--	--
8-7	1.7	1.9	2.4	1.0
8-14	7.2	9.2	7.2	9.8
8-21	11.0	10.6	12.5	12.0
8-28	23.7	18.0	23.4	22.8
9-4	31.8	33.2	30.8	40.2
9-11	40.5	31.5	69.4	40.0
9-18	73.4	56.8	60.8	61.4
9-25	83.0	68.4	72.0	68.8
10-2	96.8	96.1	72.8	88.2

TABLE XXI. 1967--Whole Plant Dry Matter Accumulation (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-9	5.0	4.3	4.9	4.7
7-14	10.5	7.6	11.8	9.5
7-19	14.2	14.4	16.8	12.8
7-24	28.0	23.4	27.3	22.4
7-29	37.0	28.0	34.8	33.0
8-3	49.7	49.2	53.1	49.3
8-8	57.5	57.2	51.1	52.5
8-13	69.6	70.0	64.5	68.6
8-18	83.2	82.1	86.1	80.8
8-23	84.4	89.5	88.6	97.2
8-28	93.2	102.4	89.5	90.6
9-2	109.5	109.0	115.0	116.5
9-7	128.5	122.4	117.0	105.7
9-12	140.4	120.8	131.3	129.7
9-17	120.8	128.6	142.6	131.8
9-22	142.4	142.8	138.0	142.8
9-27	143.9	141.4	153.2	131.4

TABLE XXII. 1968--Whole Plant Dry Matter Accumulation (grams ave.)

	Treatment			
Date	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
7-17	3.0	2.5	4.9	3.9
7-24	10.0	12.5	14.2	16.5
7-31	18.6	22.2	25.1	31.4
8-7	32.7	34.2	34.4	32.4
8-14	44.2	57.0	45.9	62.5
8-21	57.3	61.0	58.5	58.8
8-28	73.6	62.6	87.2	81.9
9-4	75.0	72.0	76.4	108.1
9-11	83.6	68.2	122.0	94.9
9-18	123.5	98.0	104.4	102.1
9-25	130.8	113.2	126.2	114.5
10-2	147.0	150.1	119.0	140.5

TABLE XXIII. 1967--Grain Yields (bushels/acre at 12.5% moisture)

	Treatment			
Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
1	118.4	115.0	141.1	135.2
2	116.8	116.5	128.7	152.1
3	116.9	118.1	141.4	134.9
4	134.1	124.6	152.6	136.7
Average	121.6	118.6	141.0	139.7

TABLE XXIV. 1967--Grain Yields--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	83.18	.82
Row Direction	1	17.85	.18
Error (A)	3	101.83	
Row Width	1	1,646.33	48.84**
Direction x Width	1	3.15	.09
Error (B)	6	33.71	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXV. 1968--Grain Yields (bushels/acre at 12.5% moisture)

Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
	Treatment			
1	99.7	96.7	119.0	108.5
2	95.9	98.7	101.2	107.0
3	103.9	90.4	105.5	121.7
4	98.0	97.9	123.7	107.0
Average	99.4	95.9	112.4	111.0

TABLE XXVI. 1968--Grain Yields--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	29.19	.77
Row Direction	1	22.56	.59
Error (A)	3	37.94	
Row Width	1	789.61	127.05**
Direction x Width	1	4.62	.07
Error (B)	6	62.15	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXVII. 1967 and 1968--Grain Yields--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Years	1	5,209.65	74.54**
Replicates/Years	6	56.18	0.80
Row Direction	1	40.27	0.57
Year x Direction	1	0.14	0.00
Error (A)	6	69.89	
Row Width	1	2,358.13	49.20**
Width x Years	1	77.81	1.62
Width x Direction	1	7.70	0.16
Width x Years x Direction	1	0.07	0.00
Error (B)	12	47.93	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXVIII. 1967--Forage Yields (tons/acre dry matter)

	Treatment			
Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
1	2.83	2.59	3.51	3.12
2	2.78	2.91	3.17	3.77
3	3.08	2.87	3.43	4.08
4	2.86	3.07	3.51	3.13
Average	2.89	2.86	3.40	3.52

TABLE XXIX. 1967--Forage Yields--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	.08	.89
Row Direction	1	.01	.01
Error (A)	3	.09	
Row Width	1	1.40	20.00**
Direction x Width	1	.02	.28
Error (B)	6	.07	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXX. 1968--Forage Yields (tons/acre dry matter)

	Treatment			
Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
1	3.05	3.51	3.62	3.42
2	2.98	3.22	3.54	3.10
3	3.34	3.20	3.22	3.90
4	3.30	2.95	3.40	3.80
Average	3.17	3.22	3.44	3.56

TABLE XXXI. 1968--Forage Yields--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	.03	1.00
Row Direction	1	.02	.67
Error (A)	3	.03	
Row Width	1	.37	3.70
Direction x Width	1	.01	.10
Error (B)	6	.10	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXXII. 1967 and 1968--Forage Yields--Analysis of Variance

Source of Variance	Degrees of Freedom	Mean Squares	F
Years	1	0.25	4.17
Replicates/Years	6	0.06	1.00
Row Direction	1	0.03	0.50
Year x Direction	1	0.00	0.00
Error (A)	6	0.06	
Row Width	1	1.61	20.12**
Width x Years	1	0.16	2.00
Width x Direction	1	0.03	0.38
Width x Years x Direction	1	0.00	0.00
Error (B)	12	0.08	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXXIII. 1967--Head Counts (number/acre)

Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
1	44,431	43,560	53,143	53,143
2	43,560	41,818	46,174	54,014
3	42,689	41,818	45,302	43,560
4	42,689	42,689	53,143	42,689
Average	43,342	42,471	49,440	48,352

TABLE XXXIV. 1967--Head Counts--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	11.75	1.17
Row Direction	1	20.25	2.01
Error (A)	3	10.08	
Row Width	1	132.25	6.64
Direction x Width	1	6.25	.31
Error (B)	6	19.92	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXXV. 1968--Head Counts (number/acre)

	Treatment			
Replicate	E-W 40" plots	N-S 40" plots	E-W 20" plots	N-S 20" plots
1	54,014	60,113	67,082	65,340
2	45,302	58,370	59,242	64,469
3	51,400	47,045	67,954	69,696
4	45,302	46,174	67,954	62,726
Average	49,004	52,926	65,556	65,556

TABLE XXXVI. 1968--Head Counts--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Replicates	3	37.58	1.08
Row Direction	1	20.25	.58
Error (A)	3	34.92	
Row Width	1	1,122.25	37.94*
Direction x Width	1	20.25	
Error (B)	6	29.58	

*Significant at the 5% level.
**Significant at the 1% level.

TABLE XXXVII. 1967 and 1968--Heads per Acre--Analysis of Variance

Source of Variation	Degrees of Freedom	Mean Squares	F
Years	1	1,740.50	77.36**
Replicates/Years	6	24.67	1.10
Row Direction	1	0.00	0.00
Year x Direction	1	40.50	1.80
Error (A)	6	22.50	
Row Width	1	1,012.50	40.91**
Width x Years	1	242.00	9.78**
Width x Direction	1	24.50	0.99
Width x Years x Direction	1	2.00	0.08
Error (B)	12	24.75	

*Significant at the 5% level.
**Significant at the 1% level.

98

LIGHT INTERCEPTION BY GRAIN SORGHUM

by

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B. S. Kansas State University, 1967

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Tests to study light interception by grain sorghum and to correlate this with plant response were conducted during 1967 and 1968 at Kansas State University, Agronomy farm, Manhattan, Kansas. Planting arrangements included 20-inch and 40-inch row spacing in conjunction with east-west and north-south row orientation.

During each season, at equal sampling intervals, data were taken on plant leaf area, dry matter accumulation of component plant parts, and light interception, for each planting treatment. Upon crop maturity, treatment effects were further measured by grain yields, forage yields, and head counts.

Light was measured by the Ozalid booklet technique described by Friend (1961). Light interception by the crop was determined by positioning light meters above the crop canopy and others at ground level, each for one day periods, and noting the differences in accumulated light. Ozalid booklets were found to age with time such that a calibration was required with each usage of the light meters. Accuracy of light measurement by this method was found to be quite satisfactory with the coefficient of variability of bleaching about a point for "gross radiation" readings on all sampling dates being 1.91 percent.

Light interception and leaf area were closely related during the early part of the season, but leaf area decreased after reaching a maximum, whereas light interception remained at a high level. Percent light interception and rate of dry matter accumulation were also closely related, with each being nearly constant after maximum leaf area was attained.

Row direction caused no significant effect upon percent light interception or upon the plant responses measured in this experiment, however, spatial distribution of light under the crop canopy was different by row direction. Row width caused a significant difference in percent light interception and in all plant responses measured and analyzed statistically.

The average percent light interception by sorghum in 20-inch rows during all sampling dates of 1967 and 1968, was 79.6 percent and 83.2 percent, respectively, which was 14.9 percent and 15.4 percent greater than in 40-inch rows for the same years. Grain yields and forage yields in 20-inch rows were greater than in 40-inch rows by 15.5 percent and 14.8 percent, respectively, for the two years combined. Number of heads per acre was significantly greater in 20-inch rows than in 40-inch rows, being 13.5 percent and 28.6 percent greater for 1967 and 1968, respectively.

Although the yield advantage shown by narrow rows may not have been wholly due to greater light interception, the author feels that with the high levels of production involved, increased light interception by narrow rows played an important role in increasing sorghum yields. As other growth requirements are being supplied more fully, competition for light in agricultural crops is becoming more vital.