Influence of Light on Biomass of Soybean in Narrow Strip Cropping of Oat, Corn, and Soybean

Kyujung Van*†

*School of Plant Science, Seoul National University, Suwon 441-744, Korea

ABSTRACT: The strip intercropping system has used due to many advantages. Many researches supported these crop systems are usually equal to or better than monoculture crop systems in both total production and profit. There was no research to examine the important ecological factors in the competition between crops. A strip intercropping system composed of adjacent narrow strips of corn, soybean, and oat/legumes has been investigated in Iowa, USA. This study conducted to investigate why and how the differences in soybean yield are produced and affected by light, one of the microclimate, of the strip intercropping system. In height, the two rows of soybean closest to corn were taller than the two rows near the then-empty oat strip. The height of each crop decreased as the amount of light received increased. Weight of plant parts was lowest in row 1, nearest corn, and highest in row 4, next to the vacant oat strip. Daily photon flux density (PFD) increased with increasing distance from corn, with the highest value occurring on the edge next to the empty oat strip. Analyses of the relationship between light and biomass of soybean showed that all biomass measurements had a positive relationship to total PFD per day except height.

Keywords : soybean, microclimate, intercropping system, photon flux density (PFD)

Many farming systems have used strip intercropping for centuries in order to maximize total production (Pendleton *et al.*, 1963; Francis *et al.*, 1986; West and Griffith, 1992). Advantages of these crop systems include reduced soil erosion, less runoff in the surface layer, higher infiltration rate, greater macroporosity, easy control of pests, ability to rotate crops from one season to the next, and increased total crop yields (Francis *et al.*, 1986; Logsdon *et al.*, 1993; Martin *et al.*, 1989). Pendleton *et al.* (1963) investigated the effects of the adjacent narrow environment between alternating strips of corn and soybean. They found corn yield is increased by 20%, but soybean is decreased by 20% compared to monoculture crop systems. Ecological factors such as light, water, and nutrients could have caused these changes. Pendleton *et al.* (1963) concluded that the advantage of strip intercropping would rely on the relative yields and the market price for each crop.

Francis *et al.* (1986) also concluded that the strip intercropping system is usually equal to or better than monoculture crop systems in both total production and profit. They also mentioned that there was no research to examine the important ecological factors in the competition between corn and soybean.

Crop yields could be determined by nutrient level, competition with weeds, and types of agricultural system in the strip intercropping system. Liebhardt *et al.* (1989) studied a transition from a conventional agricultural system using pesticides and fertilizers to a low-input system in 1981 through 1985. A conventional corn-soybean rotation was compared to two low-input rotations that utilized oat, red clover, and winter wheat, in addition to corn and soybean. Corn grain yields in the low-input systems were 75% of those in the conventional agricultural system. Weed competition and insufficient N limited low-input corn yields. Soybean yields in the low-input systems were equal to or greater than those in the conventional agricultural system. The transition from input-intensive cropping to low-input system is suitable, but only if crops that demand less N and are competitive with weeds, such as small grain, soybean, or legume hay, are used in the crop rotation.

A strip intercropping system composed of adjacent narrow strips of corn, soybean, and oat/legumes has been investigated in Iowa. Studies in 1989~1991 showed that yield of each crop was different for different row positions in a strip depending on the kinds of adjacent crop (Garcia-Prechac, 1991). Yield of corn or oat on the edges of a strip was increased, whereas yield of soybean next to corn was decreased, compared with the yield in the middle of a strip. The largest differences for yield in the strip intercropping system, compared to a monoculture system, came from the edges of each strip. These differences apparently resulted because each crop changed the environment of the adjacent crop.

Jurik (personal communication) studied why and how the differences in yield are produced and affected by the microclimate of the strip intercropping system. Microclimate is

†Corresponding author: (Phone) +82-31-290-2316 (E-mail) kyujung-van@hotmail.com <Received October 21, 2002>

the climate near the ground. The changes in environmental conditions near the surface and the rate of these changes could make microclimate very different between near the ground and 1~2 m above ground, or at the edges of adjacent strips. The upper-middle canopy of soybean received the highest amount of light in rows furthest from corn and the lowest amount in rows closest to corn. For corn, light was slightly higher for the two outer rows than for the two inner rows. This study suggested that light was an important variable that changed substantially with position in a strip.

This research is focused on relating patterns of light, the significant environmental factor, to patterns of biomass of soybean across rows in a corn-oat-soybean strip intercropping system. The purpose is to determine how one crop changes another crops microclimate, how these changes in environmental factors affect soybean growth, and how such changes in growth are related to soybean yield.

MATERIALS AND METHODS

Field Site and Crops

The strip intercropping system was studied in 1993 on the Douglas Alert farm in Franklin County, about 7 miles south of Hampton, Iowa, USA.

The strip intercropping rotation was composed of corn (Pioneer 3417), followed by soybean (Latham 440), and followed by oat. All crops were planted in a north-south row direction. The 1993 corn was grown on the oat strips of the preceding year (1992). In 1993, soybean was grown on the corn strips of the preceding year and oat were grown on the soybean strips of the preceding year. From west to east, sets of strips were composed of corn, soybean, and oat. Six sets of strips, bordered by a large field of corn on the west and a large field of soybean on the east, were used. Corn and soybean strips were composed of four rows spaced at 96.5 cm. There were 22 rows of oat spaced evenly over the 4 ridges and furrows of the previous soybean crop. Oat was planted on 30 April 1993. Corn was planted on 20 May 1993 and soybean was planted on 4 June 1993. Tillage operations in 1993 were included planting on ridges, cultivation, and ridge-building cultivation.

Statistical Analysis

Data were analyzed using the analysis of variance (ANOVA) or the general linear models (GLM) procedure of SAS (SAS Institute Inc., 1985) with α=0.05. During any measurement period including several days when sensors were not moved, values on different days were treated as repeated measures and sensors were the replicates. The means of the different positions within a strip were compared by the rows or relative positions. Fisher's least significant difference and Duncan's multiple range test were applied for comparisons between two or more means (Ott, 1988) (α=0.05).

Biomass Experiment

Shoot height was measured in each row of a strip in each of 5 replicate strips. Soybean in 1-m lengths of row was measured on 22 June, 15 July, 29 July, and 17 September. Different locations in the strips were sampled on each date. The height of soybean was determined by measuring the tallest part of the plants.

Soybean was measured in detail on 17 September. Area was determined for 1 leaf taken randomly from each of five shoots in a 50 cm section of row, for each of two 50-cm sections in each row of a strip in each of 4 replicate strips. Leaf, stem, and pod dry weight of all soybean plants in a 50 cm section of row were measured with two replicate 50 cm sections in each row of a strip in each of 4 replicate strips. Soybean still had mostly green leaves in the canopy and pods were almost filled. Leaves, stems, and pods were separated and dried in an oven at 65°C for three days.

Photon Flux Density

Photosynthetically active radiation (400~700 nm) was monitored with quantum sensors that measured photosynthetic photon flux density (PFD). The height of soybean varied over the season as the plants grew. The sensors were placed at the height of the upper-middle part of the canopy of each crop, on the outer edge of the canopy of a given row. The sensors were positioned where leaf area was high and presumably the greatest proportion of the crop's photosynthesis and transpiration occurred. Sensors were located along a cross section through the adjacent strips, so that a profile of conditions from one strip through another could be determined. Two replicates of sensors were used in a row. Readings were made at 1-minute intervals and stored as the average over 15-minute intervals. The values were recorded using 21X Microloggers (Campbell Scientific, Inc., Logan, UT, USA). Measurements were made on 3~17 September. Values for each sensor were integrated over each day by multiplying the average value for each 15-minute interval by 0.25 hour and summing values over the day.

Analyses of variances were based on 1-day PFD for several days, depending on weather. If the open area sensors received over 30 mol m^{-2} for 1-day PFD, that day was called a sunny day, otherwise it was termed a cloudy day.

RESULTS

Biomass Experiment

Soybean had no significant difference in height until 17 September (Table 1). Soybean had essentially completed stem extension by 17 September. Rows 1 and 2 were significantly taller than rows 3 and 4, i.e., the two rows of soybean closest to corn were taller than the two rows near the then-empty oat strip.

Soybean growth was analyzed in detail on 17 September, when plants were near maturity but before there was noticeable yellowing or loss of leaves (Table 2). There was no significant difference between rows in mean area of individual leaves. However, mean dry weight of individual leaves was highest in row 4. Leaf weight per unit leaf area was significantly lower in rows 1 and 2 than in rows 3 and 4. Total leaf area per m of row was lowest in row 1. Total stem dry weight per m of row increased from row 1 to row 4. Total stem dry weight per unit height (g/cm) per m of row was calculated with September data in Table 1 and 2. Rows 1 (1.40) and 2 (1.47) had lower values, but rows 3 (1.80) and 4 (1.91) had higher values in total stem dry weight per unit height per m of row. Total stem dry weight per unit height per m of row was increased as the distance from corn was increased. Total pod weight per m of row was lowest in row 1. In general, weight of plant parts was lowest in row 1, nearest corn, and highest in row 4, next to the vacant oat strip.

Table 1. The height (cm) of soybean, by date, for different rows in a strip. Values are means ± 1 standard error.

Date	Rows west 1	2	3	east 4
22 June	$6.7^{a} \pm 0.5$	$7.1^{a} \pm 0.3$	$7.0^{a} \pm 0.2$	$7.5^{a} \pm 0.3$
15 July	$22.7^{a} \pm 0.4$	$23.7^{a} \pm 1.6$	$25.7^{a} \pm 1.5$	$25.2^{a} \pm 0.9$
29 July	$39.3^{a} \pm 2.2$	$37.5^{a} \pm 1.1$	$39.6^{a} \pm 3.8$	$39.7^{a} \pm 2.1$
17 Sept.	$67.1^{ab} \pm 1.1$	$70.4^{a} \pm 0.9$	$66.8^{b} \pm 1.5$	$63.4^{c} \pm 1.1$

^{abc}Means with the same superscripted letter (within a date) were not significantly different.

Photon Flux Density (mol m^{-2} day^{-1})

In September, there were no significant differences between relative positions in daily total PFD of soybean on cloudy days (Table 3). However, on sunny days, soybean have totally different scenario compared to cloudy day. On sunny days, soybean next to corn had significantly lower PFD values, because of the shading by corn. Daily PFDs increased with increasing distance from corn, with the highest value occurring on the edge next to the empty oat strip.

On a sunny day, the corn edge of a strip, the oat edge of

Table 2. Biomass Measurement of soybean on 17 September for different rows. Values are means ± 1 standard error.

Measurement	Rows west 1	2	3	east 4
1 Leaf area (cm^2)	$33.7^{a} \pm 1.0$	$33.6^{a} \pm 1.0$	$33.9^{a} \pm 1.2$	$36.4^{a} \pm 1.2$
1 Leaf dry weight (g)	$0.12^{b} \pm 0.005$	$0.12^{b} \pm 0.004$	$0.13^{b} \pm 0.006$	$0.15^{a} \pm 0.008$
1 Leaf dry weight/leaf area (g/cm^2)	$35.7^{b} \pm 0.8$	$36.1^{b} \pm 0.7$	$38.6^{a} \pm 0.7$	$40.3^{a} \pm 1.2$
Total leaf dry weight (g/m)	$60.8^{b} \pm 3.4$	$71.8^{ab} \pm 3.8$	$81.0^{a} \pm 4.4$	$82.2^{a} \pm 4.8$
Total stem dry weight (g/m)	$94.2^{c} \pm 4.6$	$103.6^{bc} \pm 5.4$	$120.0^{ab} \pm 5.2$	$121.0^{a} \pm 7.4$
Total pod dry weight (g/m)	$167.6^{b} \pm 13.0$	$196.1^{ab} \pm 12.0$	$219.8^{a} \pm 7.8$	$221.6^{a} \pm 11.8$

^{abc}Means with the same superscripted letter (within a variable) were not significantly different.

Table 3. Daily total photon flux density (mol m^{-2} day^{-1}) of soybean on 3-17 September, by position in a strip, for sunny and cloudy days. Values are means ± 1 standard error.

	Relative Position west 1	2	3	4	5	6	east 7
Cloudy	$9.5^{a} \pm 1.8$	$13.1^{a} \pm 3.1$	$10.6^{a} \pm 2.0$	$12.1^{a} \pm 3.2$	$11.9^{a} \pm 3.4$	$9.6^{a} \pm 2.4$	$12.5^{a} \pm 2.2$
Sunny	$24.4^{c} \pm 1.3$	$29.9^{abc} \pm 1.7$	$28.3^{abc} \pm 1.5$	$36.3^{a} \pm 1.5$	$29.2^{abc} \pm 1.9$	$25.8^{bc} \pm 1.7$	$33.6^{ab} \pm 1.1$
All days	$18.0^{b} \pm 1.8$	$22.7^{ab} \pm 2.8$	$20.8^{ab} \pm 2.7$	$25.9^{a} \pm 3.7$	$21.8^{ab} \pm 2.9$	$18.9^{b} \pm 2.6$	$24.5^{ab} \pm 2.3$

^{abc}Means with the same superscripted letter (within a line) were not significantly different.

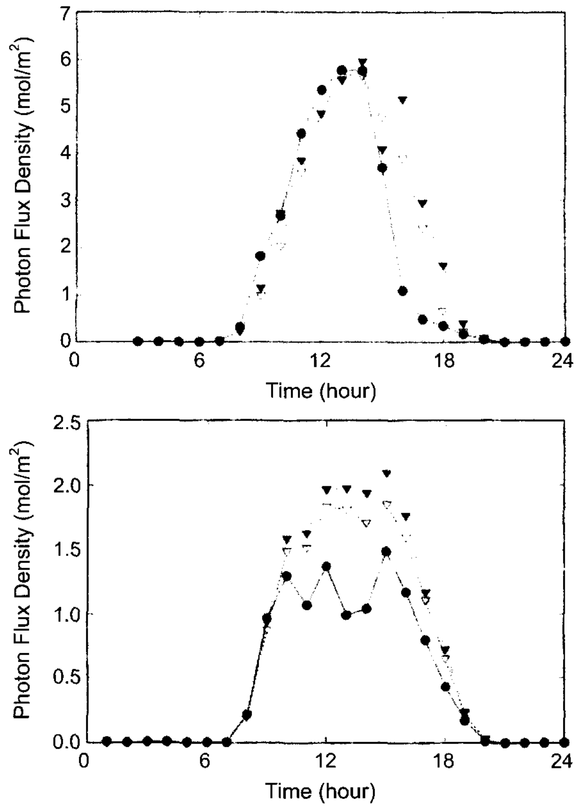

Fig. 1. Daily time course of PFD for different positions of the soybean strip on a sunny day (4 September) (**A**) and on a cloudy day (15 September) (**B**). —●— corn edge, --- ▽ --- middle of the strip, ··· ▼ ··· oat edge.

the strip, and the middle of the strip received the same amount of the light in the morning (Fig. 1A). Soybean received very different amounts of light in the course of the day on cloudy day depending on the location in a strip (Fig. 1B). The corn edge of a soybean strip also got less light than the oat edge and the middle of the strip during midday, even on a cloudy day.

Relationship Between Light and Biomass

Fig. 2 shows the relationship between light and height of soybean. The height of soybean decreased as the amount of light received increased. To receive more light or dominate the competition for receiving the light, shaded plants grew taller than the other plants that originally received more light.

Analyses of the relationship between light and biomass of soybean showed that all biomass measurements had a positive relationship to total PFD per day. One leaf area, one leaf dry weight, and one leaf dry weight per leaf area increased as the amount of light received increased (Fig. 3). Total leaf, stem, and pod dry weight increased as the amount of light received increased (Fig. 4).

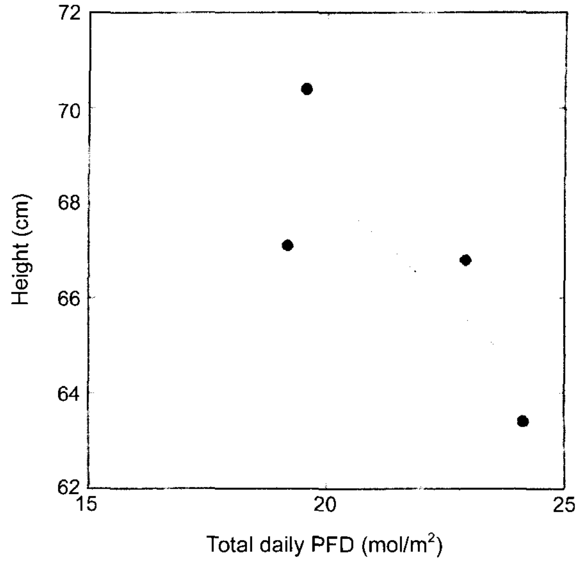

Fig. 2. The relationship between total daily PFD and height of soybean with September data. The regression equation was $y=-0.92x+86.55$ ($R^2=0.79$; slope < 0, $p < 0.05$).

DISCUSSION

Various cropping systems are needed in the Corn Belt of the U.S., including Iowa, because of economical, biological, and environmental reasons (Garcia-Prechac, 1991). A rotation that includes soybean and that reduces pest problems and soil erosion can increase total crop yield (Francis *et al.*, 1986; Martin *et al.*, 1989; Garcia-Prechac, 1991). Previous studies of strip intercropping corn and soybean indicated that corn strip yields were among 10 to 40% higher than solid cropping yields, whereas soybean strip yields were reduced among 10 to 30% (Garcia-Prechac, 1991). However, these studies did not reveal how the differences in yield were produced.

Soybean in the middle of a strip had less effect of shading by other rows of soybean because the plants were shorter and the space between rows (canopies) in a strip was wider. Soybean was highly affected by the proximity of corn.

In Table 2, all biomass measurements for soybean were analyzed in detail using larger numbers of plants. There were significant differences between rows for the one leaf dry weight, and one leaf dry weight per leaf area measurements as expected. Total leaf, stem, and pod dry weights were determined by adding up whole shoots in a 50 cm section of row. The cumulative effect of small, mostly statistically nonsignificant differences among rows was a significant difference in biomass per row across the strip.

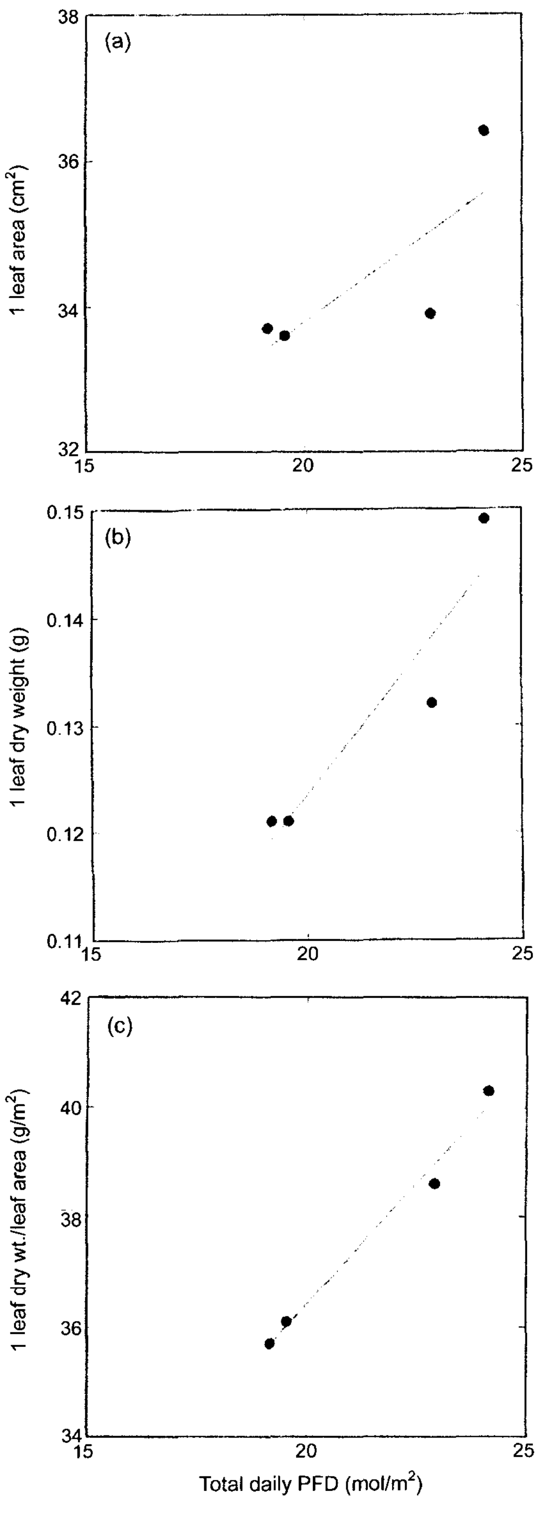

Fig. 3. The relationship between total daily PFD and 1 leaf of soybean with September data. A, 1 leaf area. The regression equation was y=0.43x+25.25 (R^2=0.78; slope > 0, $p < 0.05$). B, 1 leaf dry weight. The regression equation was y=0.005x+0.023 (R^2=0.94; slope > 0, $p < 0.05$). C, 1 leaf dry weight/leaf area. The regression equation was y= 0.88x+18.91 (R^2=0.99; slope > 0, $p < 0.05$).

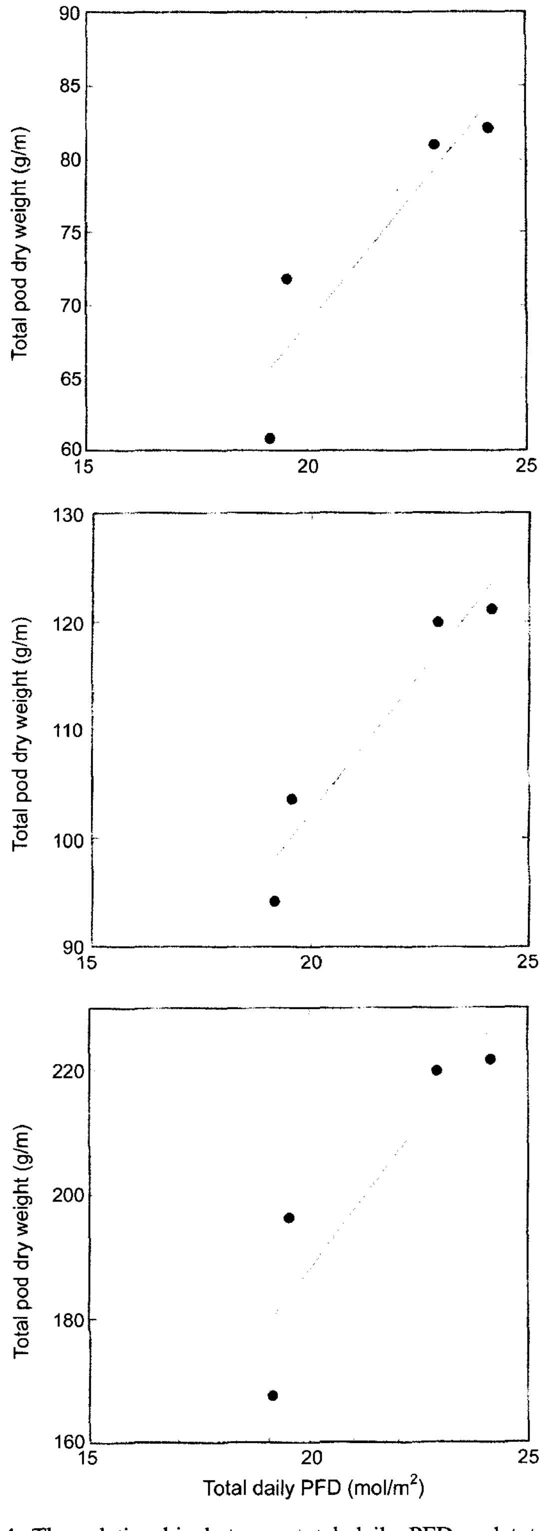

Fig. 4. The relationship between total daily PFD and total dry weight of soybean with September data. **A**, Total leaf dry weight. The regression equation was y=3.67x-4.64 (R^2= 0.91; slope > 0, $p < 0.05$). **B**, Total stem dry weight. The regression equation was y=5.12x+0.08 (R^2=0.96; slope > 0, $p < 0.05$). **C**, Total pod dry weight. The regression equation was y=9.26x+2.73 (R^2=0.90; slope > 0, $p < 0.05$).

Differences for these six measurements between rows cumulatively would lead to differences in soybean yield.

Light is the most variable and essential environmental factor for plants. However, differences in light received across a strip varied with the radiation climate on any given day. The days monitored were divided into two kinds of days: sunny days and cloudy days. Days with total PFD per day for the open area sensor of over 30 mol m^{-2} were arbitrarily called sunny days. This value, although arbitrary, effectively divided sample days into two groups, with values mostly below 20 or above 40 mol m^{-2} day^{-1}. Cloudy days received mostly diffuse radiation, whereas sunny days received diffuse plus direct solar rays. Cloudy days thus would have little differential effect on crop growth and yield across a strip. On the other hand, light had a tremendous effect on the environment on the sunny days, showing that the amount of light received was significantly different across strip. The daily PFD values increased as soybean were located farther away from corn (Table 3). The differences in a total amount of light received per day were reflected in changes in soybean biomass and yield across a strip. On a sunny day, the corn edge of a strip, the oat edge of the strip, and the middle of the strip received the same amount of the light in the morning (Fig. 2A). The corn edge of a strip got less light than the oat edge and the middle of the strip after solar noon because corn affected the light received for the corn edge of the strip. Soybean received very different light in the course of the day on cloudy day depending on the location of a strip (Fig. 2B). The corn edge of a strip also got less light than the oat edge and the middle of the strip during midday, even on a cloudy day. Soybean in the oat edge of a strip received more light than any other location of the strip in the course of the day on cloudy day. Corn affected the light received for the corn edge of the strip, even on a cloudy day.

The biomass measurement and the light environment were investigated separately. The relationship between light as an environmental factor and biomass was analyzed with September data. Soybean has a negative relationship between total daily PFD and height. To receive more light or dominate on the competition for receiving the light, they grow taller than the other plants in the edge rows that originally received more light. The positive relationship shows between the other biomass measurements of soybean and total daily PFD. The more the amount of light received, the larger the area and the heavier the soybean dry weight. Thus, light is one of the effective environmental factors determining biomass.

In sum, changes in the crop light environment by the spatial arrangement of corn, oat, and soybean planted in narrow strips leads to differences in biomass across rows. The biomass of soybean is lowest in the corn edge. The crop light environment has effects on biomass. Yield for large-field monoculture soybean near the strip was 30 Bu./Acre, whereas that of the strips was 31.04 Bu./Acre. The strip intercropping system was better than monoculture crop systems in total soybean production.

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