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Interrelationship Between Leaf Area, Light Interception and Growth Rate in a Soybean-wheat System

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Abstract: A field study of soybean (*Glycine max* L. Merr.) relay intercropped with winter wheat (*Triticum aestivum* L.) was designed to test the hypothesis that growth of wheat-soybean system depends on relative plant density and amount of light intercepted by each crop. Intercrop soybean did not influence leaf area index (LAI) and dry matter accumulation (DMA) of intercropped wheat compared with monocrop wheat because intercrop soybean was not large enough during the competitive period to disrupt wheat growth. However, intercrop wheat altered the soybean LAI, DMA and crop growth rate (CGR) compared with monocrop soybean. Leaf growth and increase in photosynthetically active radiation (PAR) intercepted by soybean was slow in the intercrop compared to monocrop soybean during early stages but the rate increased during late sample periods. Monocrop soybean approached 95% PAR interception and the rate of increase slowed as the monocrop approached a critical LAI 4.0. Among the intercrops; alternate narrow rows was more efficient than wide rows in the amount of PAR intercepted per unit of LAI and CGR per unit of relative PAR interception. Crop growth rate of intercrop soybean was linearly related to PAR interception, but rates remained below those for monoculture.

Key words: Soybean (*Glycine max*), wheat (*Triticum aestivum)*, leaf area index (LAI), light interception, photosynthetically active radiation (PAR) and crop growth rate (CGR)

Introduction

Adaptation of crop plants at high latitude is mainly limited by solar radiation and rainfall patterns. Cropping systems involving grain crops in humid temperate regions are based on warm season annuals and cool season cereals. Central and northern Ohio, are at the boundary where double cropping of winter wheat and soybean is possible because of late wheat harvest (mid July) and early fall frost which could damage the soybean crop (Jeffers and Triplett, Jr., 1979). Relay intercropping i.e. growing two or more crops simultaneously during part of the growing season of each (Andrew and Kassam, 1976) can be a viable alternative of double cropping because more of the season is utilized for crop growth, in that soybean is established before wheat is harvested. During the early growth stages of a wheat-soybean system, wheat grows faster than soybean because of a low temperature requirement and competition for moisture and incidence of photosynthetically active radiation (PAR). The greatest photosynthetic efficiency of wheat leaves was observed at 13 to 18°C temperature (Beuerlein, 1987) while optimum temperature required for soybean development is 30°C (Hay and Walker, 1989). Therefore, the performance of each crop is influenced by the time of interplanting the soybean and by interspecific competition for sunlight. PAR interception is usually manipulated by varying row width. Presumably, crop growth rate (CGR) I. e. the gain in plant dry weight per unit of land and time (Gardner *et al.,* 1985) of the soybean is proportional to the amount of PAR intercepted as is the case with monocrop soybean (Shibles and Weber, 1965). For maximum crop growth rate, enough leaves must be present in the canopy to intercept most of the incident PAR. Therefore, growth is often expressed on a leaf area basis. Leaf area index (LAI) is the ratio of the leaf area of the crop to the surface area (Watson, 1947). The dry matter (DM) accumulation rate per unit of leaf area and time is defined as the net assimilation rate (NAR), which is a measure of the mean photosynthetic efficiency of leaves in a crop community. Thus, when NAR is multiplied by LAI, the resulting product is CGR (Gardner *et al.,* 1985 and Wilson, 1987). However, past research has not elucidated correlation among leaf area index, light interception and growth rate for intercropped soybean at varying spatial arrangements. Therefore, this study was conducted to test the hypothesis that growth of intercropped soybean into wheat depends on relative plant density and amount of PAR intercepted by each crop.

Material and Methods

A three year (1986-89) study of intercrop soybean (*Glycine max* L. Merr.) and winter wheat (*Triticum aestivum* L.) was conducted at the Ohio Agricultural

Research and Development Center (OARDC), Woostor, Ohio, USA. The soil was silt loam moderately well drained and acidified with 1-3% organic matter (Bureau *et al.,* 1984). Wheat cultivar "Backer" was selected for monocrop as well as for intercrop planting because of its good straw length and low lodging characteristics. An International Grain Drill having a 3 m intra -wheel distance with 16 furrows spaced 0.18 m apart was used for sowing. Wheat was planted in the first or second week of October, at a planting rate of about 60 and 76 seeds per meter of row for monocrop and intercrop, respectively. Monocrop wheat was seeded in all 16 furrows and intercrop wheat was seeded in skip-rows by plugging furrows holes to achieve the required row spacing. Rows were planted East-West during 1986 and planted North -South during 1987 and 1988 in 3 x 32 m^2 plots.

Intercrop soybean was planted in green standing wheat by shifting unit planters to get the required row spacing in skip-row wheat. Late maturing soybean cultivars "Union" (MG 4) "Williams-82" (MG 3) and "Regal" (MG 4) were selected in the first, second and third year, respectively. These cultivars were essentially isolines and their agronomic performance was similar (Athow *et al.,* 1987; Bernard and Cremeens, 1982 and 1988). Both monocrop and intercrop soybean was seeded in the first or second week of May. Soybean planting rates for monocrop (0.36 m rows) and narrow row (0.36 m rows) intercrop were maintained at 30 seeds per meter of row while the wide row (0.53 m rows) intercrop were plated at 36 seeds per meter of row. At soybean interseeding, wheat plant height was about 0.25 to 0.30 m which corresponds to growth stage 3 (Stem elongation) described by Zadoks *et al.,* 1974. Supplementary irrigation with overhead sprinklers was applied to maintain the soil moisture content closer to optimum level during 1988 and 1989. These irrigation rates are added to the rainfall amounts in 10 or 11day increments for presentation. All other agronomic practices including ploughing, fertilizer, herbicide, insecticide etc. were kept normal as recommended for these soils (Jeffers and Triplett, Jr., 1979).

Five experimental treatment including two monocrops (wheat or soybean) and three intercrop soybean spatial arrangements with wheat were randomized in the following arrangements:

NR = Alternate wheat and soybean each planted in 0.36 m rows (eight rows of each crops)

SR = 2-1 skip row wheat (0.18 m and 0.36 rows) with soybean planted in the skip rows 0.53 m apart (eleven rows wheat, five rows soybean).

WR = Alternate wheat and soybean each planted in 0.53 m rows (six rows wheat, five rows soybean).

MW = Monocrop wheat, sixteen 0.18 m rows

MS = Monocrop soybean, eight 0.36 m rows

Row spacing were main plots and periodic samples were subplots assigned randomly to alternate ends of each main plot. Agronomic characteristics; leaf area index (LAI), photosynthetically active radiation (PAR) and dry matter (DM) accumulation were measured periodically during competitive period (June / July). Leaf area of 20 plants from each crop was measured with area meter (LI-3050A, Lambda Instruments Corp. Lincoln, NE, USA) 2 to 3 times in a week. LAI was calculated on the basis of harvested area. Incoming PAR at the top of the canopy measured with LI-190S quantum sensor having 0.01 m^2 surface area. PAR measurements below the canopy were recorded by using a line quantum sensor (LI-191 SA) having a surface area of 0.012 m^2. These sensors were connected with two different sets of LI-550 (190 M module) printing integrator (Lambda Instruments Crop. Lincoln, NE, USA). PAR measurements above and below the canopy were recorded at 10 minute intervals from each treatment on clear sky days between 1200h and 1500h (EDT) in June/ July as suggested by Gardiner *et al.,* (1979). Measurements were made on central rows leaving at least one row of soybean from each outside edge of the plot. PAR intercepted by the soybean canopy is therefore determined by subtracting from the PAR intercepted by both crop and the PAR intercepted by wheat after soybean removal. It was assumed that PAR intercepted by wheat would not be significantly changed by absence of soybean. All measurement were recorded as counts per minute and calculated in $\mu E\ m^{-2}\ s^{-1}$. Data are presented on the basis of percent PAR interception for monocrop and intercrop soybean by comparison with above canopy readings assumed as 100% incident PAR (Natarajan and Willey, 1985; Thimijan and Heins, 1983). Dry matter accumulation was determined by sampling and weighing fresh whole shoots 2 to 3 times in a week and oven dried at 55°C for three days. Dry samples were weighed and DM yield was calculated on g m^{-2} basis. By taking derivatives of function of describing soybean DM accumulation as a function of time (days), crop growth rate (CGR) was calculated and relationship between CGR vs % PAR interception were determined. Treatment responses; LAI, % PAR interception and CGR overtime were examined with regression analyses and difference among treatments were examined by using SAS models to compare regression lines for each pair of treatments at 5% probability level (SAS Institute, 1985).

Results and Discussion

Wheat: Wheat LAI was negatively correlated and DM was positively correlated with days after inter- planting soybean (DAIS) in both monocrop and intercrop wheat. Soybean intercropped treatments; alternate narrow rows, 2-1 skip rows and alternate wide rows had no major effect on wheat growth rate and leaf area development compared with monocrop wheat, because intercrop soybean was not large enough during the competitive period to disrupt PAR interception in intercrop treatments. Wheat had already achieved most of its vegetative growth and had passed the anthesis stage (Zadok's Scale=6) by the time of any significant soybean growth. Therefore, intercrop soybean during its early stages did not suppress the rate of LAI and DM (Ali, 1990).

Soybean: Relative PAR interception ranged from 1 to 59% of the total incident PAR for LAI range of 0.32 to 1.88 on the first PAR sampling date during 1987. Monocrop soybean achieved 95% PAR interception at a critical LAI 4.0 while intercrop treatments did not reach a critical LAI during the sampling period. Alternate wide rows attained 64% PAR interception at LAI 3.1, alternate narrow rows reached 47% at LAI 2.6 and 2-1 skip rows achieved 45% at LAI 2.0 on the last sampling date (day after planting, DAP). Correlation between relative PAR interception and LAI is strongly positive and curvilinear (Fig. 1a). First regression coefficient (b_1) is positive in all treatments, and the second regression coefficient (b_2) is positive for alternate wide rows and 2-1 skip rows and negative for alternate narrow rows and monocrop soybean. Mean square error (MSE) and coefficient of variation (CV) are larger in 2-1 skip row compared to other intercrop and monocrop treatments (Table 1). Regression lines are non-parallel with each other except for alternate narrow rows (NR) and 2-1 skip rows (SR) which are parallel (Table 3). During 1988, relative PAR interception and LAI values varied with days among monocrop or intercrop soybean. Monocrop soybean intercepted 95% of the total incoming PAR at a critical LAI 4.1 on 74 DAP. While intercrop; alternate wide rows, alternate narrow and 2-1 skip rows attained 75, 44 and 35% of the total incident PAR at LAI 2.3, 2.0 and 1.5, respectively, on the same day. Correlation between relative PAR interception and LAI is strongly positive and non -linear (Fig. 1b), First regression coefficient (b_1) is positive and second (b_2) is negative. MSE and CV are larger for intercrop treatments than monocrop soybean (Table 1). Intercrop 2-1 skip row (SR) regression line is statistically non-parallel with monocrop (MS) and alternate wide row (WR) regression lines. Alternate narrow row (NR), is not parallel with alternate wide row (WR) and monocrop (MS) regression lines, but alternate wide row is parallel with monocrop (Table 3). Monocrop soybean intercepted 95% of total incident PAR at a critical LAI 3.7 during 1989. On the same sampling date (71 DAP) alternate NR and 2-1 SR intercepted 62 and 46% PAR at LAI 1.7 and 1.5, respectively. PAR interception estimated for alternate WR, is 79% at 2.3 LAI. The relationship between relative PAR interception and LAI in all row spacing is strongly positive and non-liners (Fig. 1c). First regression coefficient (b_1) is positive in all treatments except intercrop 2-1 skip rows and alternate wide rows, and is negative in alternate narrow rows and monocrop soybean (Table 1). All intercrop regression lines are significantly non-parallel with the monocrop regression line. The intercrop 2-1skip row regression line is non-parallel with alternate wide rows and parallel with narrow rows at 0.05 probability level (Table 3).

Crop growth rate was 14 g m^{-2} d^{-1} in 1987 when relative PAR interception reached 95 percent of the total incident PAR measured above the canopy for monocrop soybean. Maximum CGR was 7 g m^{-2} d^{-1} in alternate WR and alternate NR and 4 g m^{-2} d^{-1} in 2-1 SR at relative PAR interception of 70, 50 and 51%, respectively, of the total incoming PAR measured above the canopy. These were maximum values at the last sampling date and do not account for increases after that date. Correlation between CGR and relative PAR interception by each treatment is strongly positive and linear (Fig. 2a). Regression coefficient (b_1) is positive in all monocrop and intercrop row spacing. Mean square of error is larger in monocrop soybean because of generally larger CGR values, recorded after 95% relative PAR interception was reached (Table 2). The CGR vs. PAR response incase of Intercrop 2-1 SR is not a statistically parallel regression line compared to monocrop. However, alternate NR) and alternate WR response is similar to MS. Alternate NR response is different than alternate WR and 2-1 SR while the latter two treatment regression lines are parallel with each other (Table 3). In 1988, when monocrop growth rate was 15 g $m^{-2}d^{-1}$ at the critical LAI, intercrop soybean did not yet achieve its 95% PAR interception and plants were growing at a different rate in each treatment. Crop growth rate and relative PAR interception was correlated positively and linearly (Fig. 2b and Table 2). Intercrop alternate WR regression line is significantly non-parallel with MS and is parallel with alternate NR and 2-1 SR. Alternate NR regression line is not parallel with monocrop and is parallel with 2-1 SR. However, 2-1 SR regression line is parallel with all regression lines (Table 3). In 1989, maximum CGR of 10 g m^{-2} d^{-1} in MS was achieved when the canopy intercepted 95% of the incoming PAR on 71 DAP. On the same date alternate wide rows, alternate narrow rows and 2-1 skip rows intercepted 79, 62 and 46%

Table 1: Parameter estimates for soybean from relative PAR interception Vs LAI regression analyses,1987-89

		Regression coefficients				
Year	Treatments	Intercept$_{(b0)}$	Linear$_{(b1)}$	Quadratic$_{(b2)}$	MSC	CV (%)
1987	NR	-5.78	44.111	-9.1959	6.5	18.0
	SR	-6.97	24.715	0.6710	11.0	45.2
	WR	16.73	13.622	0.4895	9.9	22.1
	MS	-13.38	48.410	-5.3227	8.1	10.2
1988	NR	-14.24	78.500	-24.5843	7.9	35.2
	SR	-2.05	50.264	-16.9813	5.2	28.5
	WR	-10.57	67.843	-13.3819	12.7	45.1
	MS	-10.70	44.985	-4.6852	3.7	7.1
1989	NR	-9.07	74.983	-19.6375	7.4	19.3
	SR	15.27	-28.984	33.1111	8.1	32.9
	WR	18.17	17.614	3.7461	6.9	13.0
	MS	33.31	30.678	-3.8122	4.4	6.0

NR= alternate narrow row, SR= 2-1 skip row, WR= alternate wide row, MS= monocrop soybean

Table 2: Parameter estimates for soybean from CGR Vs relative PAR interception Vs LAI regression analyses,1987-89

		Regression Coefficients			
Year	Treatments	Intercept$_{(b0)}$	Linear$_{(b1)}$	MSC	CV (%)
1987	NR	-0.835	0.1636	1.105	22.8
	SR	1.333	0.0783	0.677	20.8
	WR	0.703	0.958	0.982	19.5
	MS	1.306	0.1604	2.142	15.2
1988	NR	0.015	0.0948	0.939	43.6
	SR	-0.198	0.1129	0.924	49.3
	WR	0.123	0.0737	0.961	43.7
	MS	0.920	0.1456	1.231	14.5
1989	NR	0.040	0.0884	0.697	20.3
	SR	1.870	0.0294	0.392	15.0
	WR	2.795	0.0206	0.163	4.1
	MS	-3.113	0.1317	0.643	9.90

NR= alternate narrow row, SR= 2-1 skip row, WR= alternate wide row, MS= monocrop soybean

Table 3: Comparison of regression lines (quadratic or linear) for each pair of soybean treatments, 1987-89

	Probability >			F		Value
	Relative PAR vs LAI			CGR vs Relative PAR		
Treatment comparison	1987	1988	1989	1987	1988	1989
NR : SR	0.384	0.089	0.068	0.0055	0.542	0.000
NR : WR	0.053	0.009	0.008	0.0424	0.316	0.000
NR : MS	0.008	0.001	0.042	0.9950	0.032	0.015
SR : WR	0.039	0.044	0.003	0.4015	0.154	0.176
SR : MS	0.006	0.000	0.000	0.0290	0.277	0.000
WR : MS	0.024	0.079	0.031	0.0951	0.000	0.000

NR= alternate narrow row, SR= 2-1 skip row, WR= alternate wide row, MS= monocrop soybean
If P= 0.0000, then P< 0.0005

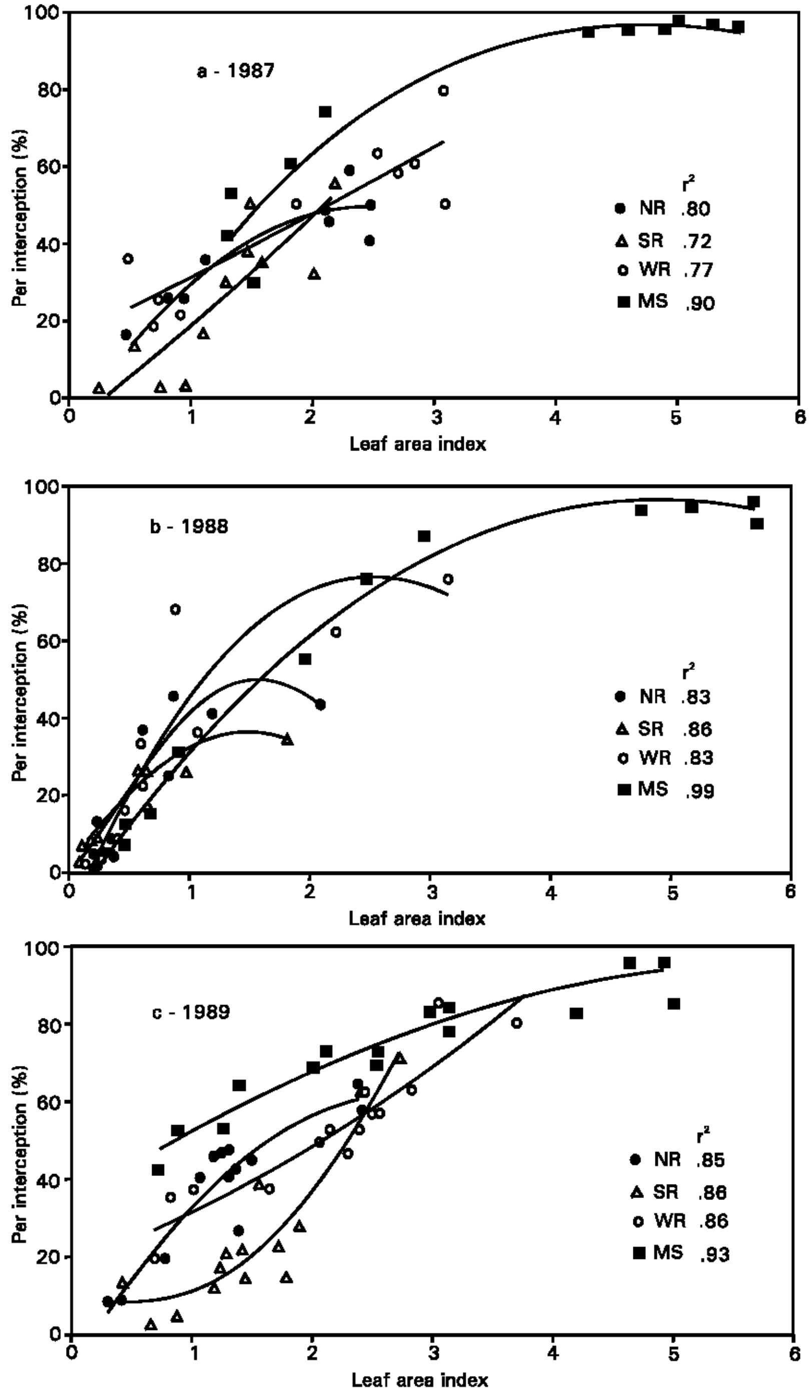

Fig. 1: Relationship between relative bhotosynthetically active rediation (PAR) interception and soybean leaf area index (LAI), 1987. 1988 and 1989
NR = alternate narrow row, SR- 2-1 skip row, WR= alternate wide row, MS= monocrop soybean

and gained CGR of 5, 6 and 3 g m^{-2} d^{-1}, respectively (Fig. 2c). The relationship between CGR and relative PAR interception is positive and has a linear response. Mean square of error was larger in alternate narrow rows compared to alternate wide row (Table 2). Intercrop regression lines are statistically non-parallel with the monocrop regression line. Among intercrops only alternate WR and 2-1 SR regression lines are parallel at 5% probability level (Table 3).

Relative PAR intercepted by intercrop and monocrop

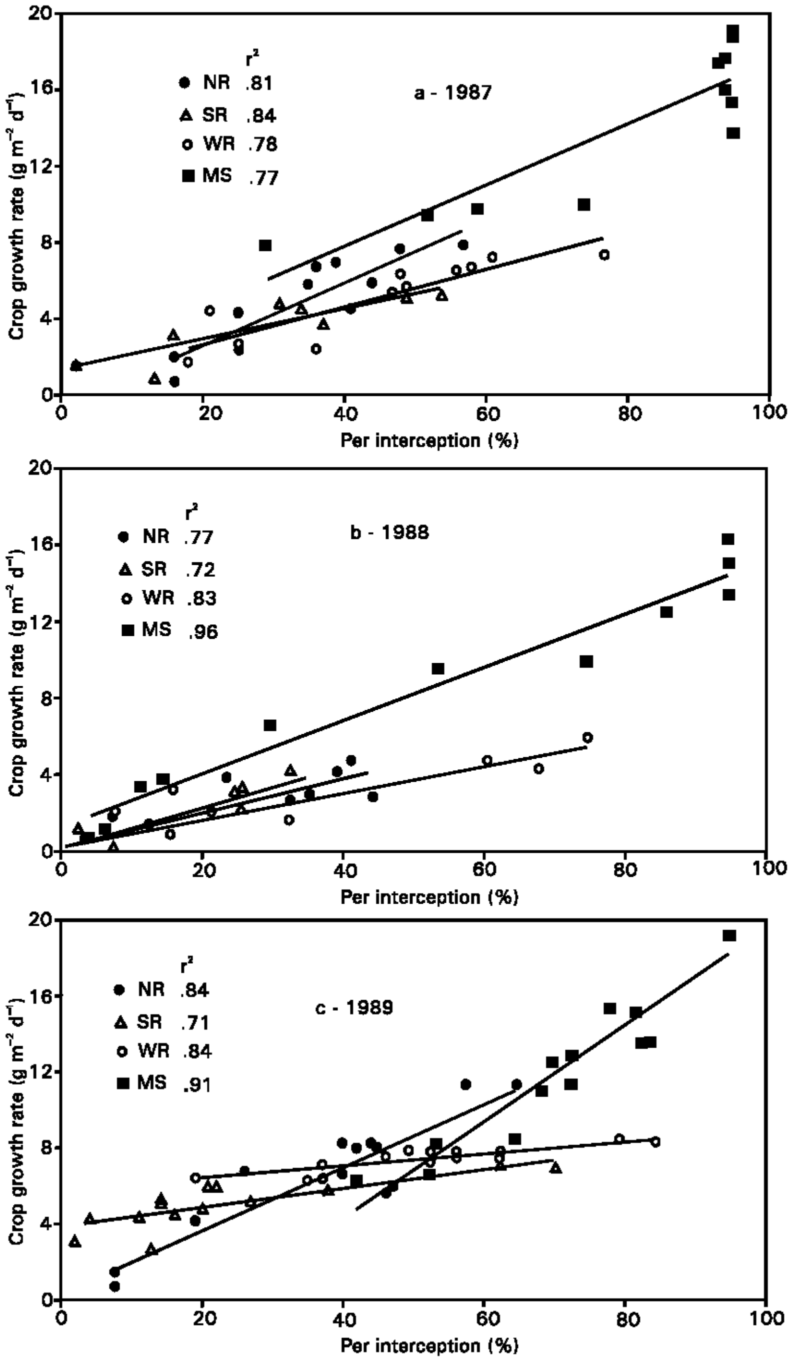

Fig. 2: Relationship between crop growth rate (CGR) and relative photosynthetically active rediation (PAR) interception in soybean, 1987. 1988 and 1989
NR = alternate narrow row, SR- 2-1 skip row, WR= alternate wide row, MS= monocrop soybean

soybean over time was somewhat lacking in consistency among the three year. Highest rate of increase in PAR interception usually occurred in the monocrop treatment at canopy closure, followed by all intercrop treatment equally except during 1988, when alternate wide rows had a similar rate to monocrop, and in 1989, when alternate wide and narrow rows had a rate of increase in PAR interception similar to monocrop planting. PAR intercepted usually followed MS > WR > NR > SR. This could be expected based on row spacing and competition from wheat. Differences in PAR intercepted per unit of leaf area index were not fairly consistent among all treatments and years, especially during 1989 (Table 1). This inconsistency could be due to the delay in monocrop planting for 6 days, and to the water stress. The timing of the samples affected the shape of the monocrop response curve (Fig. 1c) compared to other treatments in 1989. Inconsistency among years indicates, there may be no unique relationship describing PAR interception per unit leaf area for intercrop soybean. May 1988 was too dry for early development and June and July were also dry even though supplementary irrigation of 250 mm was applied in an attempt to keep the moisture level optimum. It was apparent that both crops suffered some stress before moisture levels were brought back to normal. Temperature in late June and early July was also above normal. Soybean also faced water stress in 1989 as noted on 49 and 61 DAP where soil moisture content was 29 to 62% below field capacity in general. Soil moisture content in alternate wide rows was 4 to 12% lower than other treatments (Ali, 1990). Variations in soybean and wheat growth and variations in canopy morphology indifferent environments may preclude describing PAR interception with any consistency.

Monocrop soybean maximum CGR was 14, 15 and 10 g m^{-2} d^{-1}, respectively, in 1987, 88 and 89 while Shibles and Weber, 1965 achieved a maximum CGR of 12 g m^{-2} d^{-1} in monoculture soybean in Iowa. At the same time CGR in intercrop soybean was 5.2, 3.4 and 4.9 g m^{-2} d^{-1}, respectively, for alternate narrow rows, 2-1 skip rows and alternate wide rows for a 3 year average. Crop growth rate increase per unit of intercepted PAR was higher in 1988 and 1989 in monocrop soybean (MS) compared to most intercrop soybean treatment. Monocrop was also among the highest in 1987 (Table 2). Alternate narrow row rate of increase in CGR was similar or closely followed the monocrop soybean CGR. Alternate wide row and 2-1 skip row CGR increase per unit of PAR was consistently lower than the monocrop and the absolute level of CGR was also usually lower than the monocrop treatment. Narrow rows CGR was larger than wide rows because soybean canopy closure in narrow rows occurred earlier compared to wide rows (Parvez *et al.,* 1984). The wide row soybean suffers a disadvantage in having a greater between row space to fill as found by Shibles and Weber, (1965). Increase in PAR intercepted by soybean was slow in the intecrop during early stages but the rate increased during later sample period. Over the same period monocrop soybean approached 95% PAR interception and the rate of increase slowed as the monocrop approached a critical LAI of about 4.0. Alternate narrow rows were more efficient than wide rows in the amount of PAR intercepted per unit LAI and CGR per unit of relative PAR interception. Crop growth rate of intercrop soybean is linearly related to PAR interception, but rates remained those for monoculture.

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