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Dry Matter and Leaf Area Accumulation in Relay Intercropped Winter Wheat and Soybean

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Abstract: The research was conducted to determine levels of intercrop competition to a varying extent depending on the relative density of each crop under the field conditions that are commonly used in normal production. Soybean was interplanted in green wheat during the jointing (1987, 1989) to fully headed (1988) stage of wheat. Results showed that soybean does not significantly compete with wheat in this cropping system. Crop growth rate in narrow rows soybean, as leaf area increased, eventually approached that of monocrop soybean at 6 to 7 g m^{-2} d^{-1} in 1987 and 1989, but not in 1988 when crop growth rate was similar for narrow rows, skip rows and wide rows. Temperature and precipitation data suggest that a residual stress effect on crop growth rate occurred in 1988 despite the use of irrigation. Crop growth rate for skip rows and wide rows soybean never equaled monocrop soybean nor displayed a trend toward 'catching up' with monocrop soybean during the sample period indicating that other residual effects may be occurring in addition to the obvious row width differences.

Key words: Intercropping, leaf area index, dry matter accumulation, crop growth rate

Introduction

There have been a number of reports demonstrating the practicality of intercropping winter wheat (*Triticum aestivum* L.) and soybean (*Glycine max* L. Merr.) as an alternative to ordinary double cropping or to monoculture (Chan *et al.*,1980; Reinbott *et al.*, 1981; Jeffers, 1987). Optimum soybean planting time seems to vary with weather and other environmental conditions, but usually crop growth rate (CGR) responds to the early jointing to fully headed stage of wheat. Equipment modifications are usually required to minimize traffic damage to both wheat and soybean while planting soybean or harvesting wheat. Reinbott *et al.* (1987) reported that soybean yields were enhanced by using lower rates of N (0 or 56 versus 112kg ha^{-1}) for the wheat, interplanting soybeans at the wheat heading stage versus early jointing and using narrow rows (0.2 versus 0.8 m). Chan *et al.* (1980) observed that wheat yields were not reduced by interplanting soybean, but rows 0.4, 0.6 and 0.8 m wide yielded 79, 66 and 47% of the yield of 0.2m rows, respectively. Interplanted soybean yields ranged from 0 to 91% of monoculture depending on row width and season. Only 0.8 m rows consistently produced significant soybean seed yield (32 to 82 % of monoculture). Recommendations to growers include lodging-resistant wheat cultivars, a limit of 50kg ha^{-1} N fertilizer, a skip row wheat arrangement with approximately 0.4 m barren spaces left for soybean, 0.5 to 0.7 m soybean rows, and full season (maturity group four) soybean cultivars. Typical wheat and soybean yields have been 90 and 70% of monoculture, respectively (Jeffers, 1987).

Interpretation is further complicated by the long duration of a two crop season and by a very short duration of significant competition between wheat and soybean. For various row arrangements it would be helpful to know the relative soybean efficiency as measured by growth rate per unit of leaf area or per unit of solar radiation intercepted. Presumably, the growth rate of interplanted soybean would always be much less than in monoculture until the wheat is senescent or is harvested. Following wheat harvest, intercrop soybean growth rate should eventually 'catch up' with monoculture as leaf area approaches the critical leaf area index (LAI) in the manner of Shibles and Weber (1965). This presumes that there is no change in photosynthetic efficiency of leaves in the two environments.

In this study dry matter accumulation (DMA) was determined by serial sampling of wheat and soybean in several row arrangements during the period of intercrop competition and immediately following wheat harvest. The objective was to determine the efficiency of these planting patterns in terms of CGR.

Materials and Methods

Field experiments were conducted at the Agronomy farm of the Ohio Agricultural Research and Development Center, Wooster, Ohio, USA (81^{0} 55' West, 40^{0} 55' North) during the period October 1986 to October 1989.

Soils are acidic silt loams with 1 to 3 % organic matter. Soils at the experimental sites have been limed to pH 5.8 to 6.3 and maintained at fertility levels optimum for wheat and soybean. In the spring prior to establishing wheat plots, the soil was fertilized with NPK fertilizer at 27, 50 and 90kg ha^{-1}, respectively, and planted to solid drilled soybean. This was combine harvested in the fall and the soil was moldboard plowed, disked and harrowed for wheat plots. During the optimum period in each year (17 Oct, 1986; 6 Oct, 1987; 3 Oct, 1988), 'Becker' wheat was planted with a 16 row drill, rows spaced 0.18 m, at a rate of about 60 seeds per meter of row for monocropping and 76 seeds for intercropping. Becker is a stiff-stemmed lodging-resistant upright cultivar. Supplementary N fertilizer at 60kg ha^{-1} as ammonium nitrate was applied to the wheat in early April. Intercrop soybean was planted into green skip-row wheat by shifting tractor wheels and by moving unit planters on a tool bar to achieve the required row spacing. Planters and wheels (0.36 m wide) followed the barren strips (also 0.36 m wide) and ran over a minimal amount of wheat. Late-maturing soybean cultivars 'Union', 'Williams-82' and 'Regal' were planted 1st May 1987, 1st June 1988, and 18th May (intercrop) or 24th May (monocrop) 1989, respectively. In 1988 a 4th May planting failed and was replanted. These cultivars are essentially isolines, differing slightly in maturity or Phytophthora root rot resistance. Wheat was at early jointing in 1987, heading in 1988, and mid jointing in 1989 at the time of soybean planting. Supplementary irrigation with overhead sprinklers was applied in 1988 and 1989 to maintain soil moisture closer, to optimum levels. Five treatments, including three intercrop spacing treatments and monocrop wheat and soybean were used in the following arrangements:

NR	=	Alternate narrow rows, wheat and soybean each in 0.36m rows, eight rows each
SR	=	Skip row wheat, 0.18 m wheat rows with every third row barren, soybean planted in the barren strip 0.53 m apart, eleven rows wheat and five rows soybean
WR	=	Alternate wide rows, wheat and soybean each in 0.53 m rows, six rows wheat and five rows soybean
MW	=	Monocrop wheat, sixteen 0.18 m rows
MS	=	Monocrop soybean, eight 0.36 m rows. Soybean seeding rates were about 30 seeds per meter of row in 0.36 m rows and 36 seeds in 0.53 m rows.

Table 1: Row width, number of rows and sub-plot sample area for wheat and soybean, 1987-89

Treat-ments	Row width (m)	No. of row per plot	No. of rows 1987	No. of rows 1988-89	Area 1987 (m²)	Area 1988-89 (m²)
Wheat						
MW	0.18	16	8	8	2.84	2.84
SR	0.18-0.36	11	6	6	3.20	3.20
NR	0.36	8	4	6	2.84	4.27
WR	0.53	6	4	4	4.27	4.27
Soybean						
MS	0.36	8	6	5	4.27	3.56
WR	0.53	5	3	3	3.20	3.20
NR	0.36	8	4	4	2.84	2.84
SR	0.53	5	3	3	3.20	3.20

MW = monocrop wheat, MS = monocrop soybean, SR = plant 2 rows-skip 1 row of wheat with interplanted soybean in 0.53 m rows, NR = alternate narrow row wheat with interplanted soybean, WR = alternate wide row wheat with interplanted soybean

Treatments were arranged in a split plot with randomized complete blocks design. Spacing arrangements were main plots and serial samples were subplots randomly assigned to alternate ends of main plots.

Serial sampling of wheat and soybean, shoots only, began 3 June, 1987; 17 June, 1988 and 19 June, 1989. Samples were 2m lengths of plot from center rows, which varied in number depending on the treatment (Table 1). About 1 m of border was left between subsequent samples. Fresh weight of the wheat sample was determined in the field, and a sub sample of about 500g was weighed and then oven dried at 55 ^{0}C for 3 days and weighed in order to calculate dry matter yield of wheat shoots. The entire soybean sample was oven dried and weighed in order to calculate dry matter yield. Sub samples of 20 wheat stems and 20 soybean plants were held in an insulated box on ice until leaf area was determined in the laboratory. Wheat leaf area includes leaf blades, one side, cross sectional area of stems with intact sheaths and cylindrical area of spikes. Wheat LAI was calculated from the 20 stem area and weight values and the subplot dry matter yield. Only soybean leaf blades were measured to calculate LAI from 20 plants, total number of plants in the subplot and the subplot area. Plant area measurements were made with a photo-electric planimeter, except for wheat spike area, which was determined from length, width and thickness. Dry matter (DM) and LAI data were regressed on days after interceding soybean using linear, exponential, or quadratic models. These assumptions were in conformity with the findings of Graybill (1970), that if the improvement was significant at the 5 % probability level then the complex model explained the data significantly better than the simple model. In most instances a quadratic model was superior or equal to a linear or exponential model in maximizing the coefficient of determination (R^2). With the few exceptions where a, quadratic model was not the best fit, differences were not large enough to justify using a different model. Therefore, the quadratic model was used throughout, as a way to easily compare regression coefficients. Variance analysis was used to determine whether significantly different lines are nonparallel or are parallel at different levels. Since most parallel responses can be attributed to initial differences in plant density (or row spacing), it is more important for the current study to determine significant nonparallel responses.

Results and Discussion

Irrigation amounts are added to rainfall to provide a value for total precipitation (Table 2). Net evaporation is used as a convenient way of assessing potential moisture stress by integrating effects of temperature, wind and precipitation. There was a long drought stress period after wheat harvest during July and early August. There appeared to be some stress on the wheat before sufficient irrigation water could be applied in June and there may have been some stress on the intercropped soybean during early growth stages, also. Temperatures and evaporation were generally lower in 1989 than in the previous two seasons. Abundant rainfall in

Table 2: Precipitation (rainfall+irrigation), deviation from the long term average, net evaporation (open pan evaporation-precipitation), average daily air temperature and deviation from the long term average by 10 or 11 days increments for the wheat-soybean intercrop period in 1987-89 at Wooster, Ohio

Period	Precipitation (mm)	Deviation (mm)	Net evaporation (mm)	Temperature (°C)	Deviation (°C)
1987					
11-20 May	19	-18	34	17.4	2.7
21-31 May	16	-21	39	21.8	5.3
01-10 June	64	31	3	19.2	0.8
11-20 June	8	-27	54	22.5	2.8
12-30 June	55	21	9	21.5	0.5
01-10 July	70	33	-21	23.2	1.8
11-20 July	8	-23	54	23.1	1.0
1988					
11-20 May	12	-25	38	15.1	0.4
21-31 May	2	-35	66	18.1	1.6
01-10 June	96	63	-20	17.6	-0.8
11-20 June	38	3	42	21.7	2.0
21-30 June	40	6	52	21.4	0.4
01-10 July	93	56	-2	24.2	2.8
11-20 July	66	35	12	24.9	2.8
1989					
11-20 May	30	-7	4	13.7	-1.0
21-31 May	51	14	21	18.6	2.1
01-10 June	63	30	-6	18.9	0.5
11-20 June	84	49	-41	18.4	-1.3
21-30 June	36	2	23	22.7	1.7
01-10 July	2	-34	55	12.7	2.3
11-20 July	4	-28	53	21.3	-0.8

Fig. 1: Wheat dry matter (DM) accumulation vs days after interplanting soybean (DAIS) into wheat, 1987-89. MW = monocrop wheat, SR = plant 2 rows-skip 1 row of wheat with interplanted soybean in 0.53 m rows, NR = alternate narrow row (0.36 m) wheat with interplanted soybean and WR = alternate wide row (0.53 m) wheat with inteplanted soybean

Fig. 2: Wheat leaf area index (LAI) vs days after interplanting soybean into wheat, 1987-89

Fig. 3: Soybean dry matter (DM) accumulation vs days after planting the intercrop soybean, 1987-89. MS = monocrop soybean in 0.36 m rows; this was planted 6 days after planting intercrop soybean in 1989. Other treatments are the same as for Figs. 1 and 2

Fig. 4: Soybean LAI vs days after planting intercrop soybean, 1987-89

Fig. 5: Soybean crop growth rate (CGR) correlated with soybean LAI, 1987-89

Table 3: Comparison of regression lines by pairs of soybean treatments for dry matter (DM) accumulation, days after planting (DPA), leaf area index (LAI) and crop growth rate (CGR)

Treatment comparison	Probability > F		
	DM vs DAP	LAI vs DAP	CGR vs LAI
1987			
NR vs SR	0.00	0.23	0.00
NR vs WR	0.38	0.04	0.04
NR vs MS	0.00	0.00	0.01
SR vs WR	0.00	0.00	0.23
SR vs MS	0.00	0.00	0.41
WR vs MS	0.00	0.00	0.07
1988			
NR vs SR	0.08	0.04	0.25
NR vs WR	0.24	0.01	0.77
NR vs MS	0.00	0.00	0.00
SR vs WR	0.00	0.00	0.13
SR vs MS	0.00	0.00	0.00
WR vs MS	0.00	0.00	0.00
1989			
NR vs SR	0.00	0.00	0.00
NR vs WR	0.00	0.00	0.00
NR vs MS	0.00	0.00	0.00
SR vs WR	0.08	0.68	0.00
SR vs MS	0.00	0.00	0.29
WR vs MS	0.00	0.00	0.00

June provided sufficient soil moisture, which carried into early July. Because of conflicts with plant sampling, irrigation amounts in early July were not adequate to compensate for evaporation during a critical period for the soybean. However, there was a reserve of soil moisture and soybean plants did not seem to be stressed. With irrigation, moisture levels in late July and in August were adequate.

Winter wheat: In Northeastern Ohio wheat is often physiologically mature by 1st July, so maximum values in some of the DM curves occurring in late June (Fig. 1) is normal. Wheat was harvested for grain 71 days after interplanting soybean (DAIS) in 1987,47 DAIS in 1988, and 63 DAIS in 1989. Skip row or wider row wheat will usually grow more tillers than normal drill rows (0.18 m), and these tillers tend to mature later than main culms. The resulting tiller growth, and in some cases a lack of fit to the quadratic model, causes slightly later maxima for some of the intercrop wheat DM curves. For all three years DM curves are statistically parallel ($p = 0.05$), with expected levels following in order of row spacing; monocrop wheat (MW) had highest DM yields, wide row (WR,), the lowest, and skip row (SR) and narrow row (NR) wheat was intermediate. The lack of significant slope differences among the intercrop treatments indicates that competition by intercropped soybean is very low in most instances. Dry matter yields in 1988 were about 15 % lower than in 1987 and 1989 because of extremely hot and dry weather in May and June. The field was irrigated beginning in early June 1988, but it is evident that the wheat had already incurred some damage before adequate irrigation water could be applied.

Wheat LAI values declined during the sampling period, as would be expected (Fig. 2). An attempt was made to measure only green tissue, but with the later samples it was not possible to completely separate green from yellowing, mature tissue. So, LAI levels at the end of the sampling period probably represent an exaggerated view of photosynthetic potential. This is demonstrated by the leveling of the dry matter curves late in the sampling period in most instances. First samples were taken in 1987 and 1989 early in the heading period, and levels of 4 to 5 LAI represent maximum values. Because of the replanting of soybean in 1988, maximum wheat LAI likely occurred prior to the time of first sampling. A statistical test for parallel lines showed that essentially none of the treatment comparisons for either DMA or LAI are significantly different. This indicates that the response curves are parallel, and therefore, there was no outstanding effect of interplanted soybean on wheat. Differences in level are presumed to result from initial differences in row spacing or density of wheat. Because soybean was present in wheat through most of the rapid growth period, beginning as early as the jointing stage of wheat in 1987 and 1989, it is unlikely that interplanted soybean in any row arrangement would ever be a significant competitor with the wheat. Thus, soybean does not compete with wheat to any significant extent in this cropping system.

Soybean: Dry matter accumulation displays a competitive relationship with wheat density; intercrop soybean had highest values in alternative wide rows where wheat was thinnest, and lowest values in skip row plantings, where intercrop wheat was thickest (Fig. 3). Intercrop values lagged far behind those of monocrop soybean except in 1989 where monocrop soybean was planted six days later in order to bring the DM data into a similar scale. This is appropriate since the objective is a comparison of growth efficiency as measured by DMA rates rather than absolute DMA accumulation. Most DM and LAI accumulation rates increased during the first 70 to 90 days, as is usually the case with growth responses (Figs. 3 and 4). Statistical comparisons of growth curves (Table 3) result in significant differences (nonparallel responses) in most instances, although absolute DM values are not very large among the intercrop treatments. LAI curves tend to follow the dry matter data, an unexpected response during early growth when a large proportion of accumulated dry matter is converted to leaves, the less dense leaves of the intercrop soybean in 1988 indicate greater competition for light than in 1987 and 1989. This difference also reflects a somewhat better moisture status for soybean during the intercrop periods of June 1987 and 1989.

Evaluation of rainfall and evaporation data at the experimental sites among the three years (Table 2) suggests that transient moisture stress is a factor influencing DM response differences. The experiment was not irrigated in 1987 because of accessibility, and there was a dry period in July during the sampling period, which would have favored the monocrop soybean because of a better root system and absence of competitive water use by wheat. Again during June 1988, there was a period of unusually high atmospheric demand, not fully compensated by rainfall and irrigation, when moisture use by wheat may have stressed the intercrop soybean. In 1989, more rainfall in a climate of lower atmospheric demand probably prevented severe moisture stress on soybean during the sampling period. Among three seasons, CGR of monocrop soybean followed about the same pattern for the range of leaf area observed with the CGR levels in 1989 averaging the lowest (Fig. 5). For intercrop soybean CGR per unit LAI remained somewhat less than that for the monocrop over a range of LAI. The NR intercrop growth rate in 1987 and 1989 approached that of the monocrop at a CGR of 6 to 7g m^{-2} d^{-1} at 2 LAI. However, CGR for the WR and SR spacings all three years, did not display this 'catching up' pattern of increase, and remained divergent from the monocrop during the sample period. Over all intercrop treatments CGR was reduced about 40 % compared to monocrop over the range of 2 to 3 LAI.

In order to maximize CGR, wide row and skip row soybean requires filling of between-row space. Eventually, CGR would be expected to catch up with the monocrop as growth increased leaf area. However, CGR in these two treatments showed no trend toward the CGR of the monocrop. The 'catch up' of the NR treatment appears to be related to the better moisture in June of 1987 and 1989 as compared to June 1988. The similar behavior was noted by Parvez *et al*. (1989), where narrows CGR was larger than wide rows because soybean canopy closure in narrow rows occurred earlier compared to wide rows. This slow increase in efficiency is surprising, since CGR in the intercrop soybean was expected to approach that of the monocrop as the wheat senesced and became less competitive for moisture and light. Intercrop soybean often does not respond rapidly to the removal of competition when wheat is harvested. This has been most observed with earlier (maturity group two) soybean cultivars. These are usually flowering at the time of wheat harvest, and ultimately yield much less (on the order of 50 %) than full season (maturity group four) cultivars; whereas, differences among these cultivars in monoculture would not normally exceed 10 % (Jeffers, 1987; McBlain *et al*.,1990). In the current study these cultivars are rated as early group four in maturity, but appear to be affected by the growth inhibition in the intercrop system that has been much more evident in earlier cultivars. It is apparent that closer attention to crop moisture status would help understand the vulnerability of soybean to stress, which seems to be accentuated in an intercrop situation. Future studies should provide controlled soil moisture levels with intensive monitoring and irrigation.

Differences in crop growth rate changes between the intercrop soybean spacings among the three seasons suggest relationships with temperature and moisture stress. However, the divergence CGR between MS and the wide row soybean, WR and SR, continued even in 1989 when the moisture status was much better than the previous two seasons. In the manner of Shibles and Weber's (1965) findings with soybean, CGR should converge with increasing LAI, and be similar as the critical LAI is approached. In these findings a residual effect appears to be occurring over and above a temperature-moisture stress effect. This effect could be caused by direct inhibition from the wheat. In Mississippi studies (Hairston *et al*., 1987) wheat residue was inhibitory to double crop soybean unless the residue was burned, removed or incorporated. Inhibition was overcome by use of N fertilizer, which indicates that residue prevented uptake of soil N or inhibited symbiotic N fixation. This suggests that intercrop soybean might benefit from N fertilizer applied after the wheat is senescent, or by using methods that would accelerate early symbiotic N fixation.

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