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<https://hdl.handle.net/2324/8185>

出版情報 : BIOTRONICS. 22, pp.15-24, 1993-12. Biotron Institute, Kyushu University

バージョン :

権利関係 :

SHADING EFFECTS ON SOYBEAN AND CORN

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(Received Sept. 30, 1992; accepted Dec. 21, 1992)

Ephrath J., Wang R. F., Terashima K., Hesketh J. D., Huck M. G. and Hummel J. W. *Shading effects on soybean and corn*. BIOTRONICS 22, 15-24, 1993. Shades for reducing available irradiance were placed over field-grown plants to measure light effects on root and shoot morphology and phenology. As reported in the past the ratios of leaf and shoot biomass to leaf area decreased with shade intensity. The 20%-of-ambient treatment greatly reduced corn root growth, but the trend from 70 to 27% ambient was weak. Kernel row numbers on the corn cob were sensitive to shade level. In general soybean was more shade tolerant than corn. The treatments supplying 49 to 20%-of-ambient resulted in longer internodes in soybean, which induced severe lodging. The many measurements reported are useful for generating logic for biomass dynamics in crop stands.

Key Words: *Zea mays* L., *Glycine max* (L.) Merr., maize, shading, roots

INTRODUCTION

Logic for quantifying water, carbon and nitrogen flow in defined soil-plant-air systems is needed for predicting seasonal/location effects upon crop performance, as well as effects of changes in environmental quality, including projected climate changes (3). Carbon dioxide enrichment of the atmosphere from the burning of fossil fuels may enhance photosynthesis and plant performance. The extent of these changes is difficult to quantify; any resulting agricultural yield changes may depend upon how plant stresses affect the partitioning of photosynthate and other materials during the growing season.

Long term CO₂ enrichment studies of materials budgets with plants under varying stress are expensive and difficult to interpret; there are many other less expensive ways of manipulating photosynthate supply, such as shading, artificial

lighting, or varying plant density. From a practical standpoint, it may be advisable to first estimate plant responses to changes in photosynthate supply using these less expensive methods, before designing large-scale tests involving communities of plants growing in a CO₂ enriched atmospheres and various combinations of stress treatments.

In this experiment, we report measures of variation in partitioning of photosynthate in plants growing under different levels of artificial shade, with emphasis upon changes in root growth as measured by minirhizotron techniques.

MATERIALS AND METHODS

'Pioneer 3379' corn (*Zea mays* L.) seeds were planted 13 May 1991, 0.2 m apart in rows every 0.76 m, in a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Arguidoll) soil at the University of Illinois Agronomy South Farm. Preemergence herbicides and anhydrous ammonia (168 kg/ha) were applied 10 April; the corn plants emerged 18 May.

'Williams 82' soybean (*Glycine max* (L.) Merr.) seeds were planted 29 May, 0.05 m apart in rows every 0.76 m in the same soil treated with pre-emergence herbicides. These plants emerged 3 June.

Weather data from a nearby standard station are given in Table 1. Plots were irrigated to replace the amount of water loss measured by a standard evaporation pan, reduced by the amount of measured precipitation. Black polypropylene shade fabrics ('Lumite' brand, Gainesville Ga.)¹ were used to

Table 1. Weather data.

Dates	Daily average			Precip. (cm/period)	- Evap.
	Irradiance (MJ/m ² /d)	temperature (°C)			
		T max	T min		
13 - 22 May	17.9	26.7	15.9	14.5	-3.9
23 May - 1 Jun	22.5	31.1	20.6	1.4	-5.3
2 - 11 June	25.9	28.3	17.0	0.0	-5.9
12 - 21 June	25.5	31.5	19.2	1.7	-6.1
22 June - 1 July	24.1	31.3	19.7	0.2	-5.5
2 - 11 July	21.7	31.3	20.4	5.7	-5.2
12 - 21 July	25.8	31.0	19.2	0.0	-6.1
22 - 31 July	23.2	28.8	17.3	0.0	-5.4
1 - 9 Aug.	17.0	28.9	19.0	5.5	-3.9
10 - 19 Aug.	21.5	28.9	16.7	0.3	-15.0
20 - 29 Aug.	20.0	32.3	19.7	0.1	-14.8

cover $1.52 \times 0.9 \times 2.53$ m enclosures (width \times length \times height) for corn plants and $0.76 \times 0.9 \times 1.27$ m enclosures for soybean plants. Incident irradiance was advertised to be to 70, 49, 37, 27, 20, or 8% of ambient under these shade fabrics. The enclosures were placed over two - 0.9 m corn rows on 17 May, 1991 and over one - 0.9 m soybean row on 17 June, 1991, with three replicates at each shade level and three sets of control plots in each crop. Calibration measurements on 4 and 11 June showed light readings during leaf photosynthetic determinations to be reduced more than values given by the vendor inside the shade enclosures, with the exception of the 8% fabric (specific values were 60% for the 70% treatment, 46% for the 49% treatment, 33% for the 37% shade, 22% for the 27% shade, 16.5% for the 20% shade and 7% for the 8% treatment).

Minirhizotron tubes, consisting of 0.05 m (inside) diameter transparent polybutyrate (4), were installed to a depth of 0.75 m at an angle of 30° from the vertical in the center of a row of maize or soybeans in each shade structure before emergence of the crops. Video photographs were recorded at 0.01 m depth increments at intervals throughout the growing season to estimate root growth and spatial distribution of root biomass. A LI-COR model 6200 Portable Photosynthesis System was used to measure leaf photosynthetic CO_2 and H_2O gas exchange characteristics, temperatures and incident *PAR*. Plants were dissected for shoot phytomer and ear dimensions and mass, at anthesis and near maturity.

RESULTS

Corn shoots

Following imposition of shade treatments two days before seedling emergence (17 May), tip collar production was slowed by 5 June in the 80% and 93% treatments; this slower growth rate was maintained for the next 27 days, Table 2, attribute #'s 1-4. During the 27 day interval, 453 degree days (8°C base) were accumulated, resulting in a range of 52 to 151 degree days per collar and 59 to 122 degree days per leaf tip, for the different shade treatments (attribute #'s 5-6).

Masses and dimensions of various shoot parts, including parts of the ear, are given in Table 2 (#'s 7-18). Leaf area per plant (# 10) was the morphological character least affected by shading; this was accomplished by partitioning more of the total available photosynthate to leaves and by shifts in the ratio of leaf area to leaf mass (# 12). Leaf width (# 3) was affected less than leaf length (# 9). Plants grew taller (# 18) in the less severe shade treatments, evidently a result of increased internode length at moderate levels of shading.

Leaf photosynthetic CO_2 exchange rates (*Pn*) declined with shading, Table 2 - #13, and with leaf age, Fig. 1. The *PAR* values in Fig. 1 represent the 7 shade

¹ Proprietary data is supplied for the convenience of the reader and does not imply endorsement of a commercial product by the US Dept. of Agriculture or the University of Illinois.

Table 2. Effects of shading on corn attributes.

attributes	date	percent available light							SE
		100	70	49	37	27	20	8	
	5/6								
1. collars		5.30	5.00	5.00	5.00	5.00	4.70	4.00	0.14
2. tips		9.30	8.70	8.00	8.00	8.00	7.00	7.00	0.19
	5/6-2/7								
3. collars		8.70	8.70	8.00	7.00	7.00	5.30	3.00	0.24
4. tips		7.70	8.00	8.70	7.70	7.00	7.00	3.70	0.24
5. degree day per collar		52.00	52.00	57.00	65.00	65.00	85.00	151.00	
6. degree day per tip		59.00	57.00	52.00	59.00	65.00	65.00	122.00	
	22/7								
7. total stalk nodes		19.00	19.10	19.10	18.20	18.20	17.40	15.00	0.07
8. leaf length: node 9-16 (cm)		85.00	84.00	89.00	86.00	86.00	77.00	—	0.31
9. leaf width: node 9-16 (cm)		10.00	9.20	8.30	7.00	5.50	5.10	—	0.03
10. leaf area (dm ² /plant)		71.30	63.30	59.90	45.30	33.80	27.70	7.70	2.96
11. leaf mass (g/plant)		43.90	32.40	28.20	19.00	11.50	9.20	1.80	1.76
12. mass/area (g/dm ²)		0.60	0.50	0.50	0.40	0.30	0.30	0.30	0.01
13. mean Pn ($\mu\text{mol m}^{-2}\text{s}^{-1}$)		25.30	16.60	18.90	18.10	11.70	9.70	3.10	
14. sheath mass (g/plant)		21.60	14.50	11.30	7.60	4.40	3.10	—	0.94
15. stalk mass (g/plant)		72.60	48.10	34.80	23.00	12.80	7.20	0.90	3.90
16. total shoot mass (g/plant)		138.10	95.00	74.30	49.60	28.70	19.60	2.70	6.40
17. shoot mass/l. area (g/dm ²)		1.90	1.50	1.20	1.10	0.90	0.70	0.30	0.70
	1/9								
18. height to tassel node (cm)		202.00	205.00	225.00	229.00	220.00	157.00	39.00	1.42
19. tassel length (cm)		68.00	57.00	59.00	49.00	44.00	31.00	—	
20. ear length (cm)		19.90	16.10	14.90	14.40	8.60	1.70	—	0.30
21. ear diameter (cm)		4.20	3.90	3.90	3.70	2.60	—	—	0.07
22. kernel rows		15.00	13.20	12.70	12.00	9.90	—	—	0.34
23. kernel per rows		41.70	27.60	22.80	20.00	7.80	—	—	0.80
24. total kernel mass (g)		160.00	93.00	75.00	61.00	17.00	—	—	3.60
25. cob mass (g)		23.20	11.60	11.50	9.10	3.00	—	—	0.54
26. husk mass (g)		14.40	8.00	6.60	4.50	2.50	1.70	—	0.37
prop roots/node									
27. nodes 1-4		4.40	4.20	4.50	4.50	4.40	4.30	—	
28. node 5		9.90	8.60	6.70	7.30	7.10	5.80	—	
29. node 6		13.70	13.20	10.00	9.00	10.00	8.80	—	
30. node 7		16.50	5.80	4.70	2.20	0.00	2.40	—	
31. root intersection means									
last 5 dates:		1.30	0.50	0.50	0.40	0.20	0.10	—	

Node numbering according to the scheme of Kawara *et al.* 1966 (6)

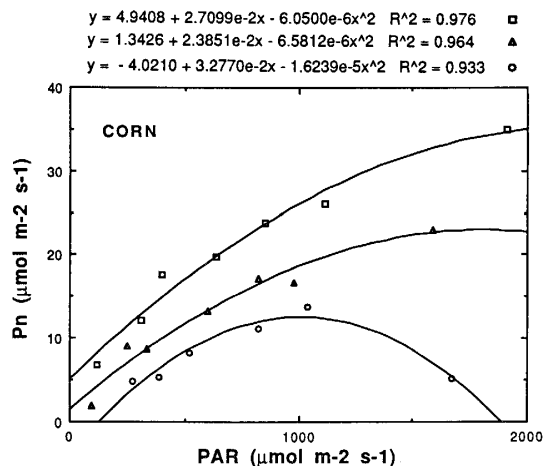


Fig. 1. Corn leaf net photosynthetic CO_2 exchange rates (P_n), with mean values for the seven shade levels for the first three dates (\triangle) and the next four sampling dates (\square) plotted with measurements taken on the final date (\circ). On the last sampling date plants were dead in the 92% shade treatment and plants in the open had begun to senesce.

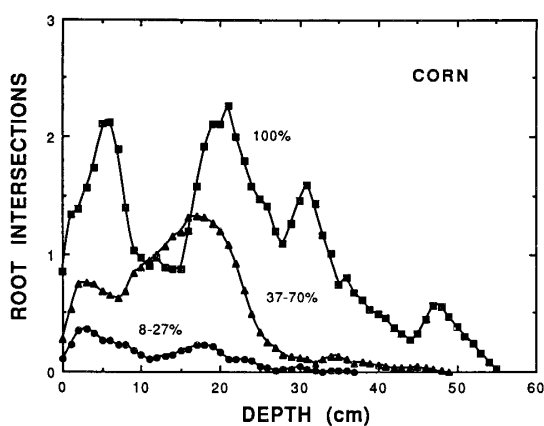


Fig. 2. Total corn root intersections encountered among all sampling dates at different depths in the soil profile.

treatments; plants in the 8% treatment were dead at the last date P_n was measured. P_n values were lower for unshaded plants on the last measurement date; these plants apparently senesced earlier than shaded plants.

Corn roots

The number of prop roots at each node was not greatly affected by shading at the lower 4 nodes (#27) but was reduced at the higher nodes (#28–30). Shading reduced the rooting depth, Fig. 2. Root numbers declined markedly at 70% available light, Fig. 3. Because of the variability among treatments, treatment \times date means that were similar as shown in Fig. 3 were combined for

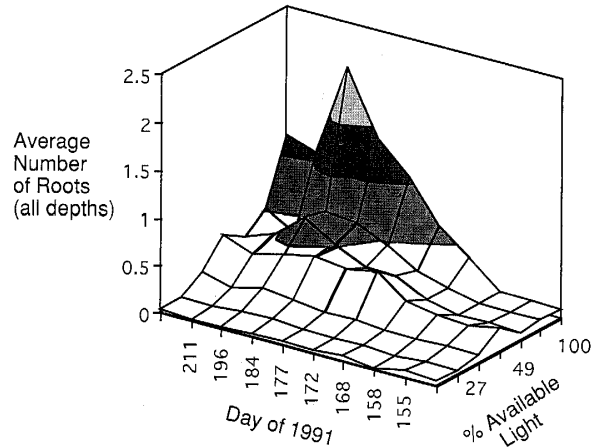


Fig. 3. Total corn root intersections encountered at all depths for different sampling dates and shade treatments.

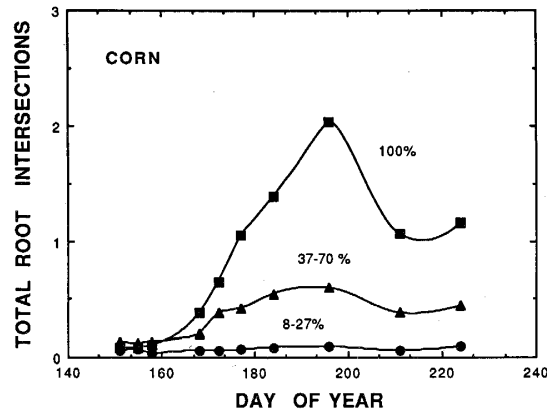


Fig. 4. Total corn root intersections encountered at all depths for different sampling dates, with data from shade treatments showing similar results combined into one mean.

subsequent comparison with soybean data, Fig. 4.

Soybean shoot

Soybean vegetative and reproductive responses to shading are given in Table 3. Shoots were much taller at 37–49% available light (attribute #13, Table 3), resulting in early lodging. Lodging induced more branch growth (#'s 6–8) and seed production (#16 vs. #19). We did not take as much data because of the lodging problem. P_n values are given for different shade levels and dates in Fig. 5 and Table 3 (#4); P_n declined as expected with shade level and canopy age.

Soybean roots

Soybean root intersections measured in the minirhizotron photographs are shown in Table 3 (#21) and in Figs. 6–7. Soybean plants produced fewer roots

Table 3. Effects of shading on soybean attributes.

attributes	date	percent available light							SE
		100	70	49	37	27	20	8	
30/7									
mainstem									
1. leaf area (dm ²)		20.80	20.50	16.60	16.20	9.10	7.50	3.00	0.64
2. leaf mass (g)		8.10	7.70	6.10	4.50	2.00	1.60	0.40	0.60
3. mass/area (g/dm ²)		0.39	0.38	0.37	0.28	0.22	0.22	0.21	0.02
4. Pn mean ($\mu\text{mol m}^{-2} \text{s}^{-1}$)		15.50	12.10	8.90	7.60	5.20	4.60	2.80	
5. petiole mass (g)		3.30	2.85	1.73	1.20	0.47	0.43	--	0.20
branch									
6. leaf area (dm ²)		4.70	3.30	1.47	1.43	2.37	5.26	2.60	0.96
7. leaf mass (g)		1.07	0.75	0.40	0.30	0.47	1.20	--	0.78
8. mass/area (g/dm ²)		0.23	0.23	0.27	0.21	0.20	0.23	0.30	0.02
9. stem mass per plant (g)		8.00	7.70	5.00	4.70	2.70	2.50	0.67	0.58
10. total shoot mass (g)		20.50	19.00	13.30	10.70	5.70	5.80	1.50	1.33
11. total shoot area (dm ²)		25.50	23.80	18.10	17.60	11.50	12.80	6.70	2.03
12. tot. shoot mass/area (g/dm ²)		0.80	0.80	0.73	0.61	0.49	0.45	0.26	
13. height (cm)		71.10	75.20	108.50	150.00	146.70	127.00	60.00	5.10
1/9									
14. height (cm)		96.40	110.00	137.00	152.00	142.00	129.00	62.00	1.80
mainstem									
15. stem mass (g)		9.20	7.00	6.80	3.10	1.80	1.00	0.40	0.20
16. seed mass (g)		11.70	10.20	9.60	2.90	1.20	0.40	0.13	0.32
17. pod mass (g)		4.90	4.10	4.00	1.20	0.43	0.23	0.10	0.15
branch									
18. stem mass (g)		0.38	0.47	0.47	0.57	0.41	0.13	0.03	0.60
19. seed mass (g)		1.10	1.90	1.70	2.16	1.13	0.28	--	0.23
20. pod mass (g)		0.43	0.78	0.74	1.00	0.56	0.15	0.02	0.11
21. mean root intersection									
1st 3 sampling dates		0.250	0.168	0.125	0.190	0.224	0.220	0.087	0.037

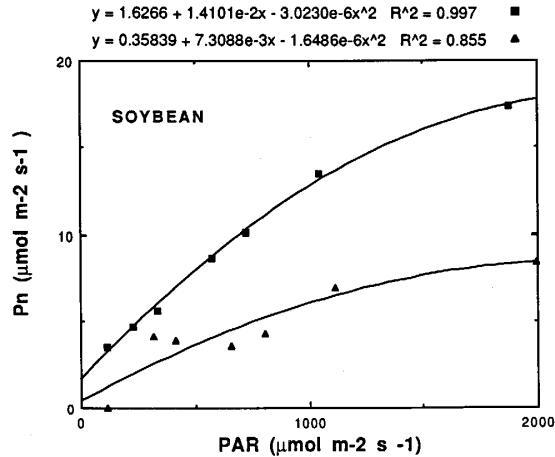


Fig. 5. Soybean leaf net photosynthetic CO_2 exchange rates (P_n), with mean values for different shade levels for the first four dates (\blacktriangle) plotted with measurements taken at the last sampling date (\blacksquare).

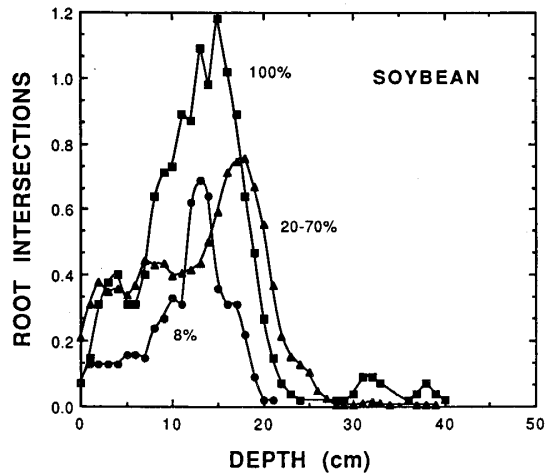


Fig. 6. Total soybean root intersections for all sampling dates at different depths in the soil profile.

than corn, Figs. 6–7 vs. Figs. 2–4, and root growth seemed to be relatively less sensitive to available light.

Reproductive organs, corn vs. soybean

Seed yields were reduced more in corn than in soybean (Table 2, #24 vs. Table 3, #'s 16 and 19). Kernel row numbers in corn were reduced by the 70% treatment, Table 2 (#22). Seed yield comparisons in soybean were complicated by the lodging that occurred under shades.

DISCUSSION

As reported many times in the past (1, 2, 5, 7, 8), partitioning is influenced

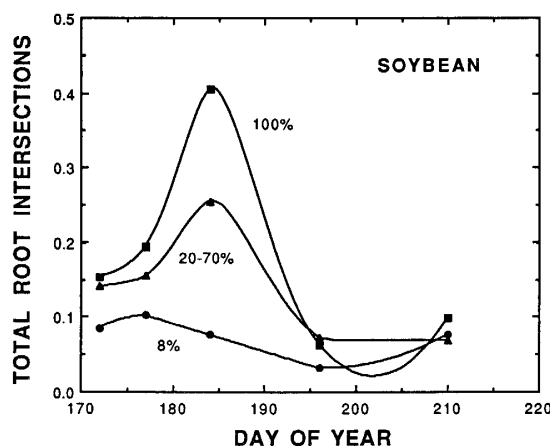


Fig. 7. Total soybean root intersections encountered at all depths in the soil profile at each sampling date. Mean values for 20 to 70% available light given.

by shading; leaf area is maintained at the expense of other organs and the mass/area ratio. This is an important point when attempting to predict shoot growth; some models in the past have assumed constant partitioning ratios as photosynthate supply varied. Cloudy weather and low *PAR* values can prevail for considerable lengths of time when a weather front stalls or moves back and forth over a location; comparison of values from the ambient (100%) and 70% ambient treatments lie in a range appropriate for accounting for these effects upon plant growth and yield. Our shade treatments remained in place over the entire growing season; shorter shade treatments at different stages of growth, such as those imposed by Schou et al. (7) would provide even more useful information. Data for plants at higher shade levels might be used for comparisons with plants grown in controlled environments under artificial lights or in greenhouses. The “viny” growth habit of soybean plants seen in these experiments (see plant heights, Table 1) are commonly observed in greenhouse-grown plants during winter months under warm temperature regimes, or warm nights.

Differences in photosynthetic carbon fixation pathways (C_4 vs. C_3) and shade tolerance are reflected in our comparisons between corn and soybean; such effects are fairly well known, except for differences in rooting behavior.

Information on root growth and development, along with materials budgets, is difficult to find in the literature, and is a weak part of any plant materials budget study. Here we report only the number of root intersections observed at different depths on a small portion of the surface of rhizotron tubes. These data give a statistical estimate from a small sample of the total root system. One can gain a qualitative sense of the dynamic changes in root growth rates resulting from the imposed shade treatments, but data on root frequency is not equivalent to root mass measurements obtained from weighing excavated root samples. It is only a very tentative guide for developing a materials budget analysis, but these data do indicate strong trends in the location of growing root tips.

One should attempt to measure similar characteristics in CO₂, environmental, pest stress and planting density experiments, so as to improve prediction of quantitative relationships between plant growth and the environment, and estimates of just how plants might be expected to respond to increasing concentrations of atmospheric CO₂. Since it is difficult to impose and study the effects of so many possible treatments in such an experiment quantitative logic for plant behavior based upon plant responses under stress at ambient CO₂ levels may be helpful in making predictions and in designing more efficient CO₂ enrichment experiments.

Cotton models in the early 1970's (3) were based upon such information, as well as results from CO₂ enrichment studies, long before the present interest in effects of increasing atmospheric CO₂ concentrations upon plant behavior; such models were useful for making predictions about response to increasing CO₂ levels, without additional research. Boll biomass yields were doubled in CO₂ enrichment experiments done at the time (3), as part of the cotton model development effort, but because of the indeterminate reproductive behavior involved, a longer growing season was required. If the growing season were long enough to take advantage of such behavior, harvesting a crop maturing over such a long time period on tall plants would be a problem. This particular system is far more complex than given here but the above information does indicate how necessary a systems approach is to predicting how plants might behave in different climates.

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