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Shade Effects on Growth and Biomass Production of Corn and Sunflower in Western Saudi Arabia

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Abstract. The effects of shade on biomass production in corn and sunflower were determined in pot culture experiments. Total (above ground) dry weight (TDW), leaf weight, stem weight, leaf area, and root weight, were significantly reduced during the reproductive growth at 60% shade in sunflower and at both 30 and 60% shade in corn. During vegetative growth, stem weight, leaf weight and TDW in sunflower and root weight in corn were also significantly reduced by shade. Growth analysis indicated that in corn growth rate, net assimilation rate and leaf area ratio at the active flowering stage, as well as relative growth rate, specific leaf area and specific leaf weight, at post-flowering stage were significantly affected by deep shade. In sunflower, none of these parameters was significantly affected by shade.

Introduction

The dependence of plant growth on photosynthesis (and hence sunlight) is well established [1]. The ability of plants to tolerate shade depends both on the efficiency of total dry matter (TDM) production [2,3] and on the growth habit [4–6]. Most plants adapt to shading or changes in radiation regimes through morphological adaptation, e.g. elongated stem and leaf size [7–12], physiological changes, e.g. reduced specific leaf weight (SLW) and increased leaf area per unit of plant weight, expressed as leaf area ratio (LAR) [12–14] and anatomical modifications such as number, shape and size of mesophyll cells [12,15].

Shading experiments in various crops have shown that yield and/or TDM production are mostly adversely affected by low light intensities [16–18]. In the tropics, reductions in yield and TDM are mostly attributed to reduced solar radiation due to dense cloud cover [18]. In arid and semi-arid regions, cloud cover is minimal, and

hence light is not a limiting factor in crop production. On the contrary, it is commonly believed that the high radiations intercepted by the crops in these regions may have detrimental effects on growth and dry matter accumulation. Investigations were, therefore, undertaken to study photosynthetic and morphological responses of corn and sunflower – with their variant growth habits – to partial and full sunlight in an arid region of western Saudi Arabia.

Materials and Methods

Corn and Sunflower were planted at King Abdulaziz University, Jeddah (21° 30′N, 39° 32′E; 11 m above sea level) in a spring climate (Table 1) from 1st March to 26 May 1984 in pots containing 10 kg of sandy loam soil each. A basal dose of NPK

Table 1. Meteorological data (temperature, relative humidity (R.H) and solar radiation at the experimental site in Jeddah (1984).

	Temp. °C		R.H. %		Solar radiation (W/m²/day)	
	Range	Mean	Range	Mean	Range	Mean
March	20.5–31.1	25.5	7–98	58.0	184–289	267.0
April	22.0–33.7	27.5	7–98	56.0	247–333	299.0
May	24.1–35.6	29.7	5–100	57.0	229–365	300.5

fertilizers was applied at the rate of 1.5, 1.5, and 0.75 g/pot, respectively. Pots were hand planted and the emerging seedlings were thinned to one plant per pot. Thereafter, the plants were separated into three groups and each group was placed under one: either full sunlight (S_0), 30% shade (S_1) or 60% shade (S_2) shading treatment in the field. Shading was imposed by placing the plants under hanging black polyethylene netting, offering the appropriate level of shade.

At 45, 60, and 80 days from full emergence, five pots from each treatment and crop were sampled and plants of each sample were separated into leaves, stems, roots and for the last sample the heads or tassel as well. Root samples were collected after washing out the soil in running tap water Samples were then oven dried at 70°C and weighed. Leaf area was estimated by photocopying and weighing. The data were analyzed as for a completely randomized design and was used to calculate growth rate (GR), relative growth rate (RGR), net assimilation rate (NAR), leaf area ratio (LAR), leaf weight ratio (LWR), and specific leaf area (SLA), as suggested by Radford [19].

Results

1 – Dry matter production and leaf area

In general, lower total above ground dry matter (TDM) was produced by plants growth in the shade than by those grown in full sunlight over the 80-day period. TDM produced in treatments S_1 and S_2 at 60 and 80 days from emergence in corn and in S_2 at 45 days and 80 days in sunflower was significantly lower than that produced at S_o (Table 2). Only in Corn, 80 days from emergence, S_2 had significantly lower TDM than S_1.

Dry matter accumulation in the stems of both corn and sunflower generally followed the same trends observed in TDM production. However, at 80 days from emergence, stem dry weight (SDW) in sunflower was significantly reduced by treatments S_1 and S_2 while in corn it was only affected by treatment S_2 (Table 2).

Table 2. Total dry weight, culm weight and leaf weight in corn and sunflower under three levels of shade

	Total dry weight (g)			Culm dry weight (g)			Leaf dry weight (g)		
No.of days from emergence	**45**	**60**	**80**	**45**	**60**	**80**	**45**	**60**	**80**
Treatment					C O R N				
(S_o)	10.2^a	34.9^a	52.3^{a*}	4.6^a	16.4^a	36.8^a	5.7^a	18.4^a	13.4^a
(S_1)	11.8^a	0.4^b	45.8^b	5.7^a	10.1^b	35.0^a	6.6^a	10.4^b	9.7^a
(S_2)	15.3^a	15.9^b	36.5^c	6.5^a	7.6^b	27.5^b	8.8^a	8.3^b	11.0^a
					S U N F L O W E R				
(S_o)	10.5^a	15.7^a	23.7^a	4.7^a	5.6^a	7.7^a	5.2^a	6.4^a	4.8^a
(S_1)	7.3^a	14.4^a	18.5^a	3.0^a	4.9^a	5.5^a	3.9^a	5.7^a	3.7^{ab}
(S_2)	4.0^b	12.0^a	16.5^b	1.5^b	4.3^a	5.3^b	2.4^b	4.8^a	2.2^b

* Figures in a column followed by the same letter are not significantly different at the $P = 0.05$ level according to Duncan's Multiple Range Test.

Leaf dry weight (LDW) in corn was significantly reduced by treatments S_1 and S_2 at 60 days from emergence (Table 2). In sunflower, significant reductions in LDW, similar to those observed in SDW, were observed at 45 and 80 days from emergence.

In corn, root dry weight (RDW), unlike the other TDM components, was significantly reduced by shading (S_1 and S_2) at all growth stages. At 45 days after emergence, reduction in RDW was more severe under S_2 than at S_1 (Table 3). In

sunflower, the effect of shading on RDW was only observed at 80 days after emergence (Table 3).

Table 3. Root dry weight, leaf area and head weight in corn and sunflower under three levels of shade

	Root dry weight (g)			Leaf area (cm^2)			Head weight** (g)
No. of days from emergence	**45**	**60**	**80**	**45**	**60**	**80**	**45**
Treatment (% shade)				C O R N			
(S_o)	3.9[a*]	10.1[a]	24.6[a]	338.7[a]	345.3[a]	123.0[a]	2.2[a]
(S_1)	2.2[b]	3.8[b]	12.4[b]	431.1[a]	160.9[b]	103.4[ab]	1.2[ab]
(S_2)	1.3[c]	2.3[b]	15.3[b]	442.1[a]	219.3[a]	72.1[b]	1.0[b]
				S U N F L O W E R			
(S_o)	1.4[a]	4.3[a]	3.3[a]	139.2[a]	158.3[a]	85.5[a]	11.1[a]
(S_1)	0.9[a]	2.9[a]	1.5[b]	140.5[a]	146.5[ab]	75.6[a]	9.3[a]
(S_2)	1.5[a]	2.5[a]	1.4[b]	115.9[a]	116.2[b]	54.7[a]	9.0[a]

* Figures in a column followed by the same letter are not significantly different at the $p = 0.05$ level according to Duncan's Multiple Range Test.

** Tassel in corn and capitulm in sunflowers.

Leaf area (LA) production in corn (Table 3) was significantly reduced by S_1 at 60 days from emergence and by S_2 at 80 days. In sunflower (Table 3) significant reduction in LA was observed in treatment S_2 only at 60 days from emergence.

Head weight (HW), in both crop species was generally reduced by shading intensity. However, only in corn, at S_2 was head weight significantly reduced by shading (Table 3).

2 – Growth analysis

In corn (Table 4), growth rate (GR) or accumulation of dry matter per day during the active flowering stage (45–60 days) was significantly reduced by shading. In sunflower, no significant change in GR during the active flowering stage was observed. In the post-flowering stage (60–80 days), GR in corn and sunflower remained the same.

Table 4. Growth rate (GR) relative growth rate (RGR) and net assimilation rate (NAR) of corn and sunflower under three levels of shade.

		GR (mg day^{-1})		RGR (mg g^{-1} day^{-1})		NAR (mg cm$^{2-1}$ day^{-1})	
Intervals (days)		**45–60**	**60–80**	**45–60**	**60–80**	**45–60**	**60–80**
Treatment							
(% shade)				C O R N			
0	(S_o)	1649.3[a*]	872.0[a]	81.8[a]	20.8[b]	4.84[a]	4.70[a]
30	(S_1)	576.0[b]	1269.0[a]	39.2[a]	41.2[ab]	2.43[a]	5.57[a]
60	(S_2)	36.0[b]	1033.0[a]	1.9[b]	44.1[a]	0.50[b]	8.60[a]
				S U N F L O W E R			
0	(S_o)	330.5[a]	401.0[a]	28.6[a]	21.7[a]	3.21[a]	3.36[a]
30	(S_1)	471.9[a]	104.0[a]	46.7[a]	5.3[a]	3.18[a]	0.96[a]
60	(S_2)	412.3[a]	224.0[a]	77.6[a]	14.7[a]	4.60[a]	1.98[a]

* Figures in a column followed by the same letter are not significantly different at the $p = 0.05$ level according to Duncan's Multiple Range Test.

Relative growth (RGR) or the rate of dry matter production per gram of total dry weight per day during the active flowering stage and its two components, viz., net assimilation rate (NAR) and leaf area ratio (LAR) in corn were significantly affected by deep shade (60%). At this shading intensity, in contrast to LAR (Table 5), RGR and NAR (Table 4) were significantly reduced. At the post flowering stage, RGR was significantly increased by 60% shade while its two components (RGR = NAR

Table 5. Leaf area ratio (LAR), specific leaf area (SLA) and leaf weight ratio of corn and sunflower under three levels of shade.

		LAR (cm^2 g^{-1})		SLA (cm^2 g^{-1})		LWR (mg g^{-1})	
Intervals (days)		**45–60**	**60–80**	**45–60**	**60–80**	**45–60**	**60–80**
Treatment							
(% shade)				C O R N			
(S_o)	0	17.08[b*]	5.00[a]	31.52[b]	26.50[a]	537.7[a]	208.9[b]
(S_1)	30	17.67[b]	4.19[a]	34.02[a]	15.53[b]	422.4[b]	276.2[b]
(S_2)	60	23.28[a]	5.24[a]	42.58[a]	14.89[b]	323.5[c]	355.5[a]
				S U N F L O W E R			
(S_o)	0	14.32[a]	6.48[a]	43.32[a]	41.24[a]	348.9[a]	237.0[a]
(S_1)	30	15.61[a]	8.32[a]	37.46[a]	42.39[a]	368.2[a]	219.8[a]
(S_2)	60	16.79[a]	5.27[a]	32.37[a]	45.71[a]	371.3[a]	160.4[a]

* Figures in a column followed by the same letter are not significantly different at the $p = 0.05$ level according to Duncan's Multiple Range Test.

× LAR) although, tended to increase with shading intensity, they were not significantly affected. In sunflower, shading had no significant effect on either RGR or its components during both of the active and the post-flowering stages (Tables 4 and 5).

It is evident from Table 5 that in corn, SLA and LWR, similar to LAR (LAR = SLA × LWR) were significantly affected by shading at the active flowering stage. However, as one component, SLA, was significantly increased, the other, LWR, was significantly reduced by shading. In contrast to this, shading, at the post-flowering stage, had significantly reduced SLA and increased LWR. In sunflower, differences between shaded and unshaded plants, with respect to SLA and LWR in the reproductive stage, similar to the other growth components were also non significant. However, as the season advanced LWR, generally tended to decrease while SLA tended to increase (Table 5).

Discussion

The mean air temperature in the spring at the experimental site ranged between 25.5 and 29.6°C, being generally regarded as normal for this part of Saudi Arabia and favorable for vegetative growth of corn and sunflower. An expected average reduction of 1°C in the mean air temperature under the shade [20] is unlikely to cause a significant reduction in TDM accumulation of corn and sunflower. In this study, accumulation of dry matter in the stems, leave, roots and the reproductive parts, as well as TDM and total leaf area production were adversely affected by shade. The extent of these effects depended on the level of shade applied, the plant type and the stage of growth. There was a general decline in TDM and its components as shade increased from 0 to 60%, however, significant reductions were mostly observed at 60% in sunflower and at both 30 and 60% shade in corn. Shading experiments with corn [21], winter wheat [16], Soybean [17,22], sweet potato [12] have shown that yield and/or TDM production were mostly adversely affected by low light intensities during early reproductive development.

In spite of contrasting trends in GR, above ground TDM in corn and its components were significantly reduced by shading at both 60 and 80 days from emergence, while in sunflower, reductions, were only observed 80 days from emergence. Reports in the literature [20] indicated that in peanut 75% reduction of light intensity reduced the growth rate of vegetative and reproductive parts and total biomass by 85% and 67% respectively. Accumulation of dry matter in roots of both corn and sunflower also was generally adversely affected by shade.

According to Blackman and Wilson [2], photosynthetic efficiency is maintained in shade if the reduction in NAR, which normally occurs, is fully compensated by

increase in LAR. In corn, both TDM production and RGR, in the active flowering stage, were significantly reduced by 60% shade. Despite the much greater decline in NAR at this shade level, its LAR increase was significantly higher than those of the other shading levels. It may thus be argued that the LAR response at this level was not adequately compensatory. The compensatory effect of LAR and NAR or RGR under deep shade was mostly attributed to the comparatively high leaf area observed at the end of the vegetative stage. With the increase in leaf area, self-shading was increased and NAR was consequently reduced. The increase in leaf area, on the other hand, resulted in higher SLA and consequently LAR was increased. In the post-flowering stage, TDM production in deep shade (60%), in spite of the significant increase in RGR, was severely restricted. This is an indication that, although, shading in corn in the post flowering stage was conductive to favorable growth, its adverse effects occurring in earlier growth stages were, however, not completely reversible. In sunflower, TDM production in both the active and the post-flowering stages, similar to that in corn, was significantly reduced in deep shade. However, differences between shaded and unshaded plants in RGR and its components in both stages were not significant.

In corn, only SLA and LWR (the two components of LAR), similar to RGR, were also significantly affected by shade throughout the reproductive growth period. This is an indication that the effect of LAR on growth under the shade as reported by Roberts-Nkrumah *et al.* [12] and Blackman and Wilson [2] was more pronounced than that of NAR. The decrease in SLA under the shade as the season advanced is an indication that corn leaves, in adapting to shade, get thicker with age. Increase in leaf thickness in response to shade has previously been reported in sweet potato [12] and was mostly attributed to changes in leaf anatomy and size of mesophyll cels [15]. The increase in LWR at S_2, on the other hand, in contrast to its decrease at S_1 and S_2, as the season advanced was an indication that proportionally higher amounts of assimilates were involved in leaf production under deep shade at the late stages of growth. Increase in LWR in response to shade was previously reported by Roberts-Nkrumah *et al.* [12], in sweet potato. In sunflower, differences between shaded and unshaded plants in SLA and LWR during the reproductive growth, similar to those in RGR and its components, were generally low and non-significant.

It is, therefore, concluded that under full sunlight, TDM produced by corn during the growing season was considerably higher than that produced by sunflower. However, under the shade TDM accumulation of corn was significantly reduced at 30 and 60% shade while that of sunflower was only reduced at 60% shade. Under deep shade, corn plants tended to adapt themselves to low level of light by maintaining a high relative growth rate, a high leaf weight ratio and a lower specific leaf area during the post-flowering stage. Such adaptive changes were not observed in sunflower.

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آثـار التـظليل على النمو وإنتاج المادة الجافة بمحصولي الذرة الشامية وعباد الشمس بالمنطقة الغربية ـ المملكة العربية السعودية

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ملخص البحث. درست آثار التظليل على إنتاج المادة الجافة بمحصولي الذرة الشامية وعباد الشمس. أحدث التظليل نقصًا معنويًّا في الوزن الجاف الكلي (الأجزاء العليا من النبات) ومكوناته: وزن الورقة ووزن الساق بالإضافة لمساحة الأوراق ووزن الجذور خلال فترة النمو الثمري. أما أثناء فترة النمو الخضري فإن التظليل أحدث نقصًا معنويًّا بوزن الساق، وزن الورقة، الوزن الكليّ الجاف بعباد الشمس ووزن الجذور للذرة الشامية. أما تحليل النمو فقد أوضح أن كلًّا من: معدل النمو، المعدل النسبي للنمو، كفاءة التمثيل الضوئي، ونسبة مساحة الأوراق لوزن النبات أثناء فترة النمو الثمري علاوة على المعدل النسبي للنمو، نسبة مساحة الأوراق لوزنها، ونسبة وزن الورقة لوزن النبات أثناء فترة ما بعد التزهير بالذرة الشامية قد تأثرت بالظل الكثيف، أما في نبات عباد الشمس فإن التظليل لم يؤثر معنويًّا على أي مكون من مكونات النمو المختلفة.