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Effect of Light Intensity and Temperature on the Photosynthesis of Shaded and Unshaded Native Sorghum

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ABSTRACT. Seed of an indigenous variety of sorghum from Jizan were grown in plastic pots. After germination and thinning half of the pots were transferred to 30% shade and the other half continued to be in the open sun. Apparent photosynthesis (*AP*) was measured at heading on both groups of plants at five light intensities (12, 22, 27, 30 and 40 K Lux) and three temperature levels (25, 35 and 45°C). Total dry weight and grain yield were higher for the open sun plants, while harvest index (*HI*) was lower than shade plants. Leaf area, however, was almost equal for both groups. *AP* declined with the increase in temperature, while it increased with the increase of light intensity. *AP* of shade plants remained always lower than open sun plants. This explains the reduction in biomass and grain yield of shade plants. Apparent photosynthesis (*AP*) could be taken as criteria for evaluating the adaptation of crop plants to environmental stresses such as temperature and light to be used for breeding adapted varieties.

Introduction

In Saudi Arabia sorghum is widely cultivated for grain and fodder, however, in the mid-western region its productivity is low due to water deficit and high temperature. This necessitate a need to develop methods to improve this crop genetically and physiologically by developing cultivars capable of withstanding environmental stress. High temperature has been known to strongly influence the different plant physiological processes envolving photosynthesis (Johnson *et al.* 1981, Woledge and

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Dennis 1982). Many studies have been made to evaluate photosynthetic activity at different temperature and light intensity in various crops (Gaastra 1959, Heskekth 1963 and Wilson 1966). Winter and Pendleton (1970) analyzed the apparent photosynthesis in corn at changing light and temperatures, and obtained a photosynthesis optima at 31°C of leaf temperature while nearly a failure in photosynthetic activity at 53°C. The optimum photosynthesis, nevertheless, was calculated by Gates (1965), and it was considerably high at leaf temperature of 51°C. The knowledge on the pattern of response is usually not based on precision control of the environments, plant development and the measurement system, implying that repeatability of results will not be accurate. Sorghum has adaptive potential for hot arid climate, but precise data on the relationships of temperature and irradiance with photosynthetic efficiency are lacking.

The first objective of this study was to measure apparent photosynthesis in sorghum under possibly precision control of the environmental and plant growth factors. The second: to demonstrate the effects of different levels of irradiance and temperature under simulated environmental conditions. The third: to measure the degree of fluctuation in photosynthesis with the change in plant growth. The fourth objective was to delineate the measurement technique for accurate screening using photosynthesis as selection criteria for breeding evolving sorghum cultivars for local aridity conditions.

Material and Methods

The work was conducted in 1985 at the King Abdulaziz University, Agricultural Experimental Station, Jeddah, Saudi Arabia. Seeds of a local adapted sorghum variety collected from Jizan were grown in black plastic pots containing 8 kg, 3:1 sand peat moss mixture with a blend of 500 g pot^{-1} organic manure. Seeds, sieved to a uniform size and carefully placed 2 cm deep in the soil. After germination, plants were thinned to one per pot. The pots were divided in two groups of twenty each. One group were left to remain in the open sun while the other was transferred to a 30 percent shade provided by black plastic mesh fitted 2.5 m above the soil surface.

Irrigation was given when required. Two weeks after emergence a side dressing of 196 mg N (as urea 46% N) (super phosphate 48% P_2O_5) and 19.6 mg K (Potassium sulphate 50% K_2O), was given to each pot.

Apparent photosynthesis and plant dry weight were measured at heading from four randomly selected plants (apparently all plants were quite uniform) from each of the shaded and open-sun grown plants at five irradiance densities, *viz.*, 12, 22, 27, 30 and 40 K lux and three temperature levels, *i.e.*, 25, 35 and 45°C. The control chamber (82 cm × 66 cm × 130 cm) was fabricated from 10 mm thick plexiglass with vents on two sides for inlet and outlets air tubing. Inside, this chamber was supplied with humidity, temperature and illumination sensors connected to strip-chart recorders for continuous monitoring. Two blower fans circulated the air in the control chamber through a precision thermo-hydro regulation system. Whole potted plant was placed inside the control chamber, but for photosynthesis measurement single leaf was enclosed in a smaller specimen chamber hermetically sealed except for regulated-air feed and exit vents.

Filtered air sample was stored in a large rubber balloon and was driven in to the specimen chamber at 1.5 / min flow rate, via, a glass tubing coil (affixed adjacent to the specimen chamber to attain the temperature of control chamber). This system has the whole plant, the leaf chamber and inlet air at the same specified environmental conditions. Infrared CO_2 analyzer (Fuji Electric, Type ZSB, adjustable to absolute mode 500 ppm CO_2 or reference mode –50 to + 50 ppm CO_2, repeatability 0.5% full scale) was used for measuring CO_2 exchange rate. A pair of three-channel strip-chart recorders were hooked with the system to plot data on, control chamber temperature, leaf temperature, humidity inside the leaf chamber, light intensity (at the leaf surface) and CO^2 intake by the leaf.

Illumination was provided from eight individually switchable 400W (Toshiba sun-type) lamps. When all lamps are switched on they emit 60 K lux of nearly solar quality visible spectrum. Light intensity could be varied by adjusting the height of lamp housing, or by switching on and off any set of lamps. The whole set up furnished a very versatile precision system for simulating a range of desired light, humidity and temperature conditions.

With least possible disturbance the potted plants were placed inside the control chamber and prior to the actual measurements, these were acclimatized for 1 hr to the chamber environment. Leaf area was taken promptly after the experiment using LI-300 (LICOR Ltd Lincoln Nebraska USA) leaf area meter.

Results and Discussion

Table 1 shows response of several productivity components in sorghum plants growing in open sun and under 30% shading. A comparison of the two light treatments indicate obvious differences between various characters. The values were generally higher in all characters measured except for leaf area and specific leaf area and harvest index (*HI*) for the open sun grown plants. The total biomass production as measured by plant dry weight was reduced 38% in the shade treatment. Grain yields however, were reduced (24%). This decrease may be attributed to the difference in partitioning of total dry matter to the grain. The harvest index (*HI*) of the shade treatment was 19% higher than that of the open sun treatment. The leaf area was nearly equal in plants of both treatments, while the specific leaf area was higher in the shade grown plants. This suggests that to a certain degree the leaf expansion in sorghum is less dependent on the light regulated process. The high values of specific leaf area in the shade grown plants indicated a decline in leaf density, which likely is due to reduced cell number, cell size and other contributing components that may be dependent on light regulated process (Wilson and Cooper 1970).

The data suggest that sorghum exhibited high sensitivity for illumination to the extent that even a 30 percent cut of sunlight in shaded plants during growth has caused a marked reduction in biomass including grain yield.

TABLE 1. Morphophysiological characters in sorghum grown in open sun and shade.

Characters	Open	Sdx***	Shade	Sdx
Total dry weight (g/plant)	61.88	1.29	38.19	0.86
Grain weight (g/plant)	28.89	0.72	22.07	0.09
Culm weight (g/plant)	18.56	0.32	11.08	0.66
Leaf weight (g/plant)	8.71	0.30	6.25	0.22
Root weight (g/plant)	9.02	0.26	6.82	0.36
Top/Root ratio	5.83	0.12	4.61	0.32
*H. I (%)	46.78	2.07	57.93	1.37
Leaf area (cm^2/plant)	720.00	15.48	731.00	15.02
Specific leaf area (cm^2/g)	255.4	7.66	412.40	14.30
**Photosynthesis ($mgCO_2/dm^{-2} h^{-1}$)	42.8	0.33	30.14	0.14

*Harvest index.
**Measured at 35°C 30 K Lux.
**Standard deviation.

In spite of the fact that leaf area in open and shade grown plants remained similar yet the high specific leaf area under shade caused the reduction in photosynthetic rate pêr unit leaf area and consequently the reduction in biomass. Shading may have caused drop in the ambient temperature, but no parallel check was set up to measure the effect during plant growth. Woledge and Dennis (1982), however, observed that the differences in net photosynthesis were much smaller in ryegrass and white clover plants grown at different temperatures. In white clover for instance the net photosynthesis was nearly the same among the plants grown at 13°C day/9°C night and 16°C day/14°C night temperature regimes, whereas the photosynthesis in ryegrass and white clover responded very similarly to growth temperature.

The rate of apparent photosynthesis at different temperatures and light intensities was measured when the heads had completely emerged. In both the open sun and shade grown plants pronounced effects for temperature and light intensity were observed (Table 2). Photosynthetic rate dropped concomitantly with the increased in temperature level from 25°C through 45°C. The photosynthetic rate increased with increase in light intensity from 12 to 40 K lux for open plants. However, in the shaded plant the photosynthetic rate increased to a plateau starting from 22 K lux with slight decrease at higher intensities. These results correspond with the trend in photosynthetic rates of single leaves from field grown sorghum plants recorded by Naylor *et al.* (1975). However, the quantum values of apparent photosynthesis in the shade grown plants always remain lower than those of open sun plants. At 25°C, seemingly the light saturation point resides at light intensities somewhere higher than 40 K lux. It seems that 45°C is threshold temperature where stress signs begins to manifest. This becomes more obvious from the photosynthesis values on shade grown plants where, at 45°C, p-max is reached at 22 K lux, then the photosynthetic activity declined to a very low level as the illumination is raised from 30-40 K lux. This implies that these plants experience a dual stress of high temperature and high irradiance, since during growth they were adjusted to relatively low light levels. In these plants a primary modification has been observed manifested in the higher specific leaf area implying concomitant decrease in the capacity of CO_2 assimilating elements (Keulen *et al.* 1975) and eventually reduced tolerance to high light intensities and temperature. Adaptive changes are common and varietal differences have been reported (Naylor *et al.* 1975, Gourdon and Planchon 1982) in different types of response of photosynthesis to illumination levels during growth.

The changes in photosynthesis from one to the next higher temperature is nearly identical among plants under the two treatments (open-sun and shade). Nevertheless, the rise in photosynthetic rate due to light increase is more pronounced between 12 to 22 and 22 to 27 K lux and then levels off, that is the saturation point is reached. These effects on photosynthetic rate may vary from almost nothing (Murata and Iyama 1963, Keys *et al.* 1977) to those similar reported here and those reported by Charles-Edwards and Ludwig 1970, Woledge and Dennis 1982. It is, of course, understandable that in a crop canopy, mutual shading by leaves reduces the total incident of light energy as well as the temperature on canopy. Thus photosynthesis will be less than that of single leaves in bright light (Watson 1958).

The response of photosynthesis to climatic factors such as irradiance and temperature raises the need to evaluate varieties for stress tolerance on the basis of their photosynthetic capacity and utilize the adjustment and adaptability characters in sorghum germplasm to be exploited in crop improvement programmes. The ambient light and temperature conditions imposed during plant growth incorporate large fluctuation in the plant characters but at the same time expression of adaptability genes having selective values may also be revealed. Such genotypes can be identified and evaluated under precision simulated environmental control during photosynthesis measurements.

TABLE 2. Apparent photosynthesis ($mgCO_2dm^{-2}h^{-1}$) in sorghum grown in open sun and shade measured at different temperatures and light intensities.

Light intensity (Lux)	25°C		35°C		45°C		Mean	
	sun	shade	sun	shade	sun	shade	sun	shade
12000	27.32	20.32	25.1	21.58	20.00	17.11	24.14	19.67
22000	37.76	30.66	32.97	32.34	36.62	29.47	35.78	30.82
27000	44.09	32.83	38.62	30.28	37.93	27.31	40.21	30.14
30000	45.03	28.33	42.1	29.71	41.18	24.00	42.77	27.35
40000	45.43	28.20	43.3	29.90	42.5	17.9	43.74	25.27
Mean	39.93	28.1	36.42	24.76	35.65	23.16		

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تأثير شدة الاضاءة ودرجات الحرارة على التمثيل الضوئى للذرة الرفيعة المحلية فى الضِّحِّ والظل

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تمت زراعة بذور ذرة رفيعة محلية من جيزان فى قصارٍ بلاستيكية وبعد الإنبات والخف تم نقل نصفها إلى ٣٠٪ ظل والنصف الآخر ترك في الضِّحّ . وقد تم قياس التمثيل الضوئى عند الازهار لكلا المجموعتين تحت اضاءات متفاوتة (١٢ ، ٢٢ ، ٢٧ ، ٤٠ كيلو لوكس) ودرجات حرارة متفاوتة (٢٥ ، ٣٥ ، ٤٥°م) . لقد كان الوزن الكلى الجاف وكمية محصول الحبوب أعلى فى نباتات الضِّحّ ودليل الحصاد أقل فيها بالمقارنة بنباتات الظل . فى حين كانت مساحة الأوراق متساوية تقريبا فى الفئتين ، أما التمثيل الضوئى فقد تناقصت قيمته بازدياد درجة الحرارة ، في حين تزايدت بتزايد الإضاءة ، غير أن التمثيل الضوئي كان دائماً أعلى في نباتات الضخ منه فى نباتات الظل ، وهذا يفسر انخفاض الوزن الجاف الكلى وكمية المحصول فى نباتات الظل .

إنه فى الإمكان اتخاذ التمثيل الضوئى معيارا لتقويم تكيف نباتات المحاصيل للإجهاد البيئى مثل الحرارة والرطوبة والإضاءة من أجل تربية أصناف متكيفة .