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Effect of Light Intensity on Snap Bean Performance

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ABSTRACT

Two snap bean (*Phaseolus vulgaris*, L.) cultivars, Strike and Carlo, were planted into a Hebbronville sandy loam soil on 24 Feb. 2000 and grown under 0, 30, and 70% of ambient daily light (shade) throughout the 65-day growing season. Leaf, air, and soil (at 10 cm depth) temperatures were reduced by increased shading. Although the yield response was linear with respect to increased shading, first harvest and season yields were not affected by a 30% reduction in incident light. Light reduction tended to decrease pod size, but increased pod dry matter content in 'Carlo'. Plant biomass was reduced by shading as was leaf greenness, but leaf area and chlorophyll content (dry wt. basis) were increased by shading. The incidence of powdery mildew occurred late in the season and was linearly increased by reduced light. Leaf transpiration and stomatal conductance were generally increased by shading. Rhizobium nodulation of 'Carlo' roots was greater under reduced light. Pod mineral nutrients varied between cultivars, but generally were not affected by light intensity. Trifoliate leaf Al, Fe, and Na levels were linearly increased, and B and Cu levels reduced by reduced light intensity.

RESUMEN

Dos cultivares de ejote (*Phaseolus vulgaris*, L.), Srike y Carlo, se sembraron en suelo arenoso limoso tipo Hebbronville el 24 de febrero del 2000 y se cultivaron bajo regímenes de sombra de 0, 30, y 70% durante una estación de crecimiento que duró 65 días. Las temperaturas de la hoja, del aire y del suelo a 10 cm de profundidad se redujeron con el incremento de la sombra. Aunque el incremento en el rendimiento fue linear con respecto al incremento en sombreado, la primera cosecha y el rendimiento de la estación no fueron afectados por una reducción del 30% en la luz incidente. La reducción de la luz tendió a disminuir el tamaño de la vaina, pero incrementó el contenido de materia muerta en 'Carlo'. La biomasa de la planta y la intensidad del color verde de la hoja se redujeron con el sombreado, pero el área de la hoja y el contenido de clorofila (en base a peso seco) se incrementaron bajo condiciones de sombra. La incidencia de cenicilla polvorienta se presentó tarde en la estación y se incrementó linealmente con la reducción de la luz. La transpiración de la hoja y la conductancia estomática fueron en general incrementadas por el sombreado. La nondulación por Rhizobium de las raíces de 'Carlo' fue mayor bajo el tratamiento de menor luz. Los nutrientes minerales de la vaina variaron entre los cultivares pero en general no fueron afectados por la intensidad de la luz. Los niveles de Na, Fe y Al en las hojas trifoliadas se incrementaron linealmente y los niveles de B y Cu se redujeron con la reducción de la intensidad luminosa.

Additional index words: Shading, global warming, mineral nutrition, Rhizobia

Shading has been reported to modulate leaf nutrients, such a K, P, Mg, and Fe (Cruz, 1997; Dorenstaouter, et al, 1985; Rodriguez and Cibes, 1977), increase leaf area and stomatal conductance in cucumber (Smith and Mills, 1984), increase leaf chlorophyll, per unit leaf area, in several tropical root crops (Johnston and Onwueme, 1998), and increase plant susceptibility to disease (Pennypacker et al, 1994; Sealy et al, 1990). The effect of light intensity on snap bean pod nutrition and plant performance has not been well documented. In previous work, I have observed that amaranth leaf nutrients and total protein-N appear to be enhanced by periods of reduced light (Makus, 2001). Asparagus grown during periods of high light, and consequently higher temperatures, are greener, higher in ascorbic acid, and lower in soluble solids (Makus, 1992). In this study, my objectives were to determine if plant performance was effected and if mineral nutrient concentrations were altered in snap bean pods and leaves when plants were grown under reduced levels of light.

MATERIAL AND METHODS

Snap bean (*Phaseolus vulgaris*, L.) cultivars Carlo and Strike (Asgrow, Kalamazoo, MI) were sown in a quanset-framed screen house enclosure located near Weslaco, TX (lat. 26º 8'), capable of intercepting 0, 30, and 70% cosine incident light. The 8 x 10 m shade fabrics used for light reduction were

Table 1. Effect of light intensity on snap bean performance, Spring 2000.

	Yield at 1st Harvest[z]	Sieve Size Distribution (%)					Season Yield[z]	Powdery Mildew Rating[y]
		<No. 1	No. 2	No. 3	No. 4	≥No. 5		
	(kg)						(kg)	
Cultivars:								
Carlo (C)	0.95	6	13	45a	36	0b	1.06b	19a
Strike (S)	0.95	7	15	41b	35	1a	1.24a	2b
	NS[x]	NS	NS	*	NS	0.09[w]	*	**
Light Reduction:								
0%	1.01a	6	18a	38b	37a	1	1.27a	0b
30%	1.09a	6	12b	41b	40a	1	1.25a	9ab
70%	0.78b	8	12b	50a	29b	1	0.94b	23a
	0.07	NS	0.11	**	*	NS	*	
Polynomial fit:	Q*	-	L*	Q**[v]	Q*	–	L**	L**
Interaction:								
C x 0	1.01	6b	16	38b	40	0	1.16	0c
C x 30	1.06	7b	11	46a	36	0	1.15	16b
C x 70	0.77	6b	12	52a	30	0	0.89	40a
S x 0	1.01	6b	21	39b	33	1	1.39	0c
S x 30	1.12	6b	13	36b	44	1	1.34	1c
S x 70	0.78	10a	12	48a	28	1	1.00	5bc
	NS	*	NS	*	NS	NS	NS	0.08

[z]Based on 2 m of row. Harvested on 4/14 and 4/27. Size distribution determined on 4/14.

[y]Rated on 4/28. Observations normalized with arcsin=sq root transformation; actual means shown.

[x]NS, *, ** = Not significant or significant at P=0.05, P=0.01, respectively. L, Q = linear or quadratic, respectively.

[w]Probability of a greater 'F' value.

[v]'Carlo only.

Table 2. Effect of cultivar and light intensity on leaf greenness, chlorophyll, and area.

	Leaf Greenness		Trifoliate Leaf	Leaf Area	
	Primary	Trifoliate	Chlorophyll	Primary	Trifoliate
	SPAD		mg/g	cm^2	
Cultivars:					
Carlo (C)	39.5a	41.2a	11.6	40.6b	216b
Strike (S)	34.6b	38.9b	11.5	49.5a	265a
	**	**	NS	**	**
Light Reduction:					
0%	39.0a	42.6a	9.2b	40.2b	212b
30%	37.6b	40.8a	12.1a	46.0ab	248ab
70%	34.6c	36.8b	13.3a	49.0a	262a
	**	**	**	*	*
Polynomial fit:	L**[x]	L**	Q*	L*[w]	L**
Interaction:					
C x 0	42.1a	44.2	9.0	38.2b	188
C x 30	40.2b	41.8	11.9	41.9b	226
C x 70	36.2c	37.8	13.8	41.7b	235
S x 0	35.9c	41.2	9.5	42.2b	237
S x 30	34.8c	39.8	12.2	50.2a	269
S x 70	33.0d	35.8	12.7	56.2a	288
	*	NS	NS	0.08[y]	NS

[z]NS, *, ** = Not significant or significant at P=0.05, P=0.01, respectively. L, Q = linear or quadratic, respectively.

[y]Probability of a greater 'F' value.

[x]'Carlo' only.

[w]'Strike' only.

randomized throughout the structure and then secured 2.4 m above the soil surface. Seeds of each cultivar were planted in 3 m long single row plots on 24 Feb. 2000 into a Hebbronville (course-loamy, mixed, hyperthermic Aridic Haplustalfls) soil. The experimental design was a RCB with four replications, three light levels (main plots), and two cultivars (sub-plots). Light (as PAR), air (at canopy height), and soil (at 10 cm) temperatures were monitored in the second replication from 24 Feb. to 30 Apr., inclusive.

No pest control was used. Water soluble fertilizer was applied through the trickle irrigation on a Monday-Wednesday-Friday schedule with approx. 6 mm per watering. A complete N-P-K (1:1:1) granular fertilizer was side-dressed on 20 Mar. at a rate of 20 kg N per Ha. Total fertilizer applied over the growing season was approx. 60-60-60 kg (N-P-K) / ha. Leaf greenness was determined with a Minolta 502 Chlorophyll Meter (Minolta Corp., Ramsey, NJ), and was measured in primary leaves on 10 Mar. and in trifoliate leaves on 6 Apr. Leaf area was determined on primary leaves on 17 Mar. and on trifoliate leaves on 7 Apr. The trifoliate leaves used for area determination were frozen, lyophilized, ground, and then used for chlorophyll and leaf nutrient (N, K, Ca, P, Mg, S, NO_3, Fe, Na, Al, Mn, Zn, B, and Cu) analysis (Plank, 1992; Welburn and Lichtenthaler, 1984). The pods harvested from 2 m of row on 14 Apr. were used for determination of yield and sieve size distribution. Sieve size No. 3 pods were frozen to -20ºC, lyophilized, and used for percent dry matter and nutrient analysis. Leaf porometry was determined on 4 Apr., 1 day prior to a scheduled irrigation, and on 5 Apr., within 6 hours after an irrigation. A second and final harvest was made on 27 Apr. and leaf powdery mildew readings were determined the following day. Two meters of row were sampled for plant biomass on 1 May and 10 roots per plot were removed on 2 May for rhizobium nodule counts (g dry wt. root basis).

RESULTS AND DISCUSSION

Avg. soil temperatures (at 10 cm) during the growing season were 23.2, 22.9, and 20.7ºC for 0, 30, and 70% light reduction treatments, respectively. Season average air temperatures at plant canopy height were 23.6, 23.1, and 22.8, respectively; and cumulative average hourly photosynthetically active radiation (PAR) was 591, 377, and 164 mM/s/m^2, respectively, representing a 0, 36, and 72% reduction in measured PAR, respectively, over the growing season. Total solar radiation at the site was 192 kW/m^2 or 691 MJ/m^2 for the same 24 Feb. to 27 Apr. period.

Plant stand was not affected by shade treatment (data not shown). ‘Carlo’ and ‘Strike’ yielded 89 and 78%, respectively, of their total crop at first picking. For the cultivar Carlo, the percentage of sieve size no. 3 pods were increased by reduced light, whereas the percentage of sieve size no. 4 pods were decreased by 70% shading (Table 1). The shift to smaller sieve sizes caused by shading suggests a tendency for both cultivars

Table 3. Leaf porometric response to treatments before (Apr. 4) and after (Apr. 5) an irrigation[z].

	PAR	Leaf Temp.	Stomatal Conductance	Transpiration
	$\mu Mol \cdot m^{-2} \cdot s^{-1}$	ºC	$cm \cdot s^{-1}$	$\mu g \cdot cm^{-2} \cdot s^{-1}$
April 4				
Cultivars:				
Carlo (C)	1466	26.5	0.66 a	11.1 a
Strike (S)	1475	26.6	0.53 b	9.5 b
	NS[y]	NS	0.14[x]	0.14
Light Reduction:				
0%	2079 a	27.6 a	0.65	11.5 b
30%	1492 b	27.2 a	0.53	9.8 b
70%	632 c	24.3 b	0.61	9.3 b
	**	**	NS	0.11
Polynomial fit:	Q**	Q**	Q**	L*
April 5				
Cultivars:				
Carlo (C)	1372	29.6	0.83 a	13.2
Strike (S)	1373	29.7	0.72 b	12.3
	NS	NS	0.16	NS
Light Reduction:				
0%	2044 a	31.5 a	0.59 b	11.6
30%	1465 b	29.7 b	0.84 a	13.8
70%	610 c	27.8 c	0.89 a	12.9
	**	**	**	NS
Polynomial fit:	Q**	L**	L*	–

[z]There were no Cultivar x Light reduction interactions.
[y]NS, *., ** = Not significant or significant at P=0.05, P=0.01, respectively.
L, Q = linear or quadratic, respectively.
[x]Probability of a greater ‘F’ value.

to delay maturation in the absence of full sun. Decreasing light intensity quadratically (Q) reduced pod yield at the first harvest and linearly (L) over the total season yield; however, differences between 0 and 30% light reduction were not significant at the first or combined harvests. The incidence of powdery mildew on leaves recorded after the last harvest increased linearly with increased shading, particularly in ‘Carlo’ (P=0.08).

There was an inverse relationship between SPAD readings and leaf area as shading increased (Table 2). Increasing the level of shading decreased SPAD readings and increased leaf area L in both primary and trifoliate leaves. Leaf chlorophyll was increased Q by shading. ‘Carlo’ leaves had higher greenness or SPAD values but less leaf area than ‘Strike’ leaves. Both cultivars compensated for the reduced light by increasing their leaf area by up to 25% more than those of leaves growing under ambient light. Leaf chlorophyll (dry wt. basis) was similar between cultivars. Pod (sieve size no. 3) total chlorophyll and carotenoid contents were not effected by shade level, but ‘Strike’ total chlorophyll (P<0.10) and carotenoid (P<0.12) concentrations appeared to increase with increased shade (data not shown).

Immediately following an irrigation, when soil moisture was high, leaf stomatal conductance was enhanced, transpiration rates were similar, and leaf temperatures were decreased under reduced light (Table 3). However, toward the end of an irrigation cycle when soil moisture was depleted, stomatal conductance was similar and transpiration rates and leaf temperatures increased as plants were exposed to full sun.

Table 4. Effect of cultivar and light reduction on sieve size No. 3 pod dry matter (%), top plant dry weight, and rhizobium nudulation of the roots.

	Pod Dry Matter	Top Dry Wt.	Rhizobium Root Nodules
	%	g•2 m row^{-1}	No.•g root d.w.$^{-1}$
Cultivars:			
Carlo (C)	9.2 a	232	755
Strike (S)	8.1 b	223	890
	**^{z}	NS	NS
Light Reduction:			
0%	8.6	252 a	698
30%	8.7	251 a	841
70%	8.8	180 b	928
	NS	**	NS
Polynomial fit:	–	Q*	L*^{x}
Interaction:			
C x 0	9.0 a	254	468 b
C x 30	9.2 ab	267	708 ab
C x 70	9.6 a	176	1090 a
S x 0	8.2 c	251	929 a
S x 30	8.1 c	235	976 a
S x 70	8.1 c	183	766 ab
	0.06^{y}	NS	0.06^{y}

^{z}NS, *, ** = Not significant or significant at P=0.05, P=0.01, respectively. L, Q = linear or quadratic, respectively.
^{y} Probability of a greater ‘F’ value.
^{x} ‘Carlo’ only.

Table 5. Effect of cultivar and light reduction on trifoliate leaf nutrients collected 22 Apr.

	Total N	Ca	K	Mg	Al	Fe	NO_3	Na	Mn	B	Cu	Total^{z}
	-------------- % --------------				---------------------------- µg•g^{-1} ----------------------------							%
Cultivars:												
Carlo (C)	2.94 b	3.14	2.12 b	.312 b	799	494	384 b	159 a	117	36 b	13	6.14 b
Strike (S)	3.27 a	3.30	2.49 a	.358 a	710	475	482 a	131 b	120	41 a	13	6.73 a
	**^{y}	NS	**	**	NS	NS	**	**	NS	**	NS	**
Light Reduction:												
0%	2.98	3.33 a	2.35	.330	649 b	421 b	450	118 a	98	42 a	15	6.56
30%	3.17	3.34 a	2.13	.352	800 ab	468 ab	414	151 ab	147	41 a	13	6.40
70%	3.16	2.99 b	2.41	.323	904 a	565 a	434	167 a	110	34 b	12	6.34
	NS	0.12^{x}	NS	NS	0.10	0.20	NS	0.06	NS	**	NS	NS
Polynomial fit:	–	Q*	Q*^{w}	Q*^{w}	L**	L*	L*^{v}	L**	Q*	L**	L*	–
Interaction:												
C x 0	2.72	3.36	2.11 b	.309 b	694	463	433 b	129	102	37	15	6.33
C x 30	3.02	3.02	2.14 b	.304 b	731	430	391 bc	175	151	39	13	6.02
C x 70	3.08	3.04	2.13 b	.312 b	969	591	327 c	173	97	31	12	6.08
S x 0	3.25	3.31	2.59 a	.350 b	604	380	468 ab	106	94	46	14	6.79
S x 30	3.32	3.64	2.13 b	.400 a	867	507	437 b	126	143	43	13	6.78
S x 70	3.24	2.94	2.76 a	.325 b	837	539	542 a	161	122	36	12	6.61
	NS	**	*	0.11	NS	NS	*	NS	NS	NS	NS	NS

^{z}Sum of all mineral nutrients. P, S, and Zn were 0.205%, 0.208%, and 23µg•g^{-1} and were not effected by treatments.
^{y}NS, *, ** =Not significant or significant at P=0.05, P=0.01, respectively. L, Q=linear or quadratic, respectively.
^{x}Probability of a greater ‘F’ value.
^{w}‘Strike’ only.
^{v}‘Carlo’ only.

The dry matter (%) in sieve size no. 3 pods was increased (L) in 'Carlo' when plants were grown under reduced light intensity (Table 4). However, plant biomass or top dry wt. was decreased (Q) by shading in both cultivars. The number of rhizobium nodules found in 'Carlo' roots (dry wt. basis) were increased (L) by shading. Cooler soil temperature appeared to enhanced the symbiotic rhizobial relationship, at least with 'Carlo' roots. Root dry weights were higher in 0 and 30% shade compared to 70% shade (data not shown). 'Carlo' sieve size no. 3 pods were higher in dry matter (%) (Table 4), P, Ca, Mg, and B, but lower in NO_3 and Fe than 'Strike' pods (data not shown). As shading increased, pod Mn levels increased (L) and Fe levels decreased ('Carlo', only); however, total-N and the other pod mineral nutrients were not influenced by shade (data not shown).

'Strike' trifoliate leaves had higher concentrations of total-N, K, Mg, NO_3, and B, but less Na than 'Carlo' leaves (Table 5). Total leaf cations were higher in 'Strike'. Reduced light intensity increased (L) leaf Al, Fe, and Na, but decreased (L) leaf NO_3 ('Carlo', only), B, and Cu. Light intensity affected (Q) Ca, K ('Strike', only), Mg ('Strike', only), and Mn. Leaves of *Amaranthus tricolor* (L.), a C-4 photosynthetic plant, responded similarly to reduced levels of light (Makus, 2001) as did the C-3 photosynthetic plant used in this study.

CONCLUSIONS

Snap bean cultivars Carlo and Strike tolerated at least a 30% reduction in cumulative incident seasonal solar radiation without loss of yield and were capable of compensating for reduced light by increasing leaf area and chlorophyll content (dry wt. basis). Pod (sieve size no. 3) mineral nutrient and total nitrogen concentrations and pod chlorophyll content were generally not affected when plants were grown at reduced light levels of up to 70% intercepted light. Leaf temperature and transpiration prior to irrigation were reduced by shading. 'Strike' had higher yield, lighter green leaves, more leaf area, higher leaf mineral nutrient levels, but lower leaf transpiration rates and incidence of powder mildew than 'Carlo'. Transpiration rates per leaf and leaf chlorophyll content in both cultivars were similar.

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