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Research notes

Optimal light for greenhouse culture of American ginseng seedlings

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ABSTRACT

Three greenhouse experiments with American ginseng seedlings growing under light levels from 4.8% to 68% showed a quadratic response for root dry weight, giving an optimal root dry weight of 239 mg (range 160–415 mg) at an optimal light level of 35.6% (range 30.6–43.2%).

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Growing of ginseng under artificial shade is practiced worldwide [1–8]. Optimal light required for growing Asian and American ginseng (*Panax ginseng* Meyer and *Panax quinquefolius* L., respectively) is characterized as follows: too little light, which reduces root yield [6]; and too much light, which leads to photoinhibition of photosynthesis, photobleaching, and leaf death [7,9–11]. Generally, optimal light intensity for Asian ginseng ranged from 5% to 20% [6,12–14]. However, Parmenter and Littlejohn [7], working with Asian ginseng in New Zealand, found similar root growth with 8–36% light intensity.

We were unable to find research reports addressing optimal light requirements for growing American ginseng in Canada. Present practices attempt to imitate the understory of the deciduous forests in eastern North America, which is the native environment for the growth of American ginseng [1,15]. This forest canopy attenuates incoming solar radiation (light) to 10–30% of full sunlight, conserves soil moisture during the growing season, and protects roots from low soil temperatures in winter. Fournier et al. [11], working with 2-y-old forest-grown American ginseng, showed that during the development of the forest canopy when light levels were high, the understory ginseng plants acclimated and there was no photodamage to the photosynthetic apparatus.

Proctor et al. [4] reported that the major shade material used for the field culture of ginseng in Ontario, Canada, was woven black polypropylene that permits light penetration of about 28%. According to the production recommendations for Ontario ginseng

growers [16], the various weaves of polypropylene permit 18–26% light penetration.

Given that there are no definitive research reports on optimal light for American ginseng culture in North America, the objective of this work was to determine, for the first time, the optimal light requirements for ginseng seedlings grown in greenhouses.

A first pot experiment (Expt. 1) was carried out in 1989 (March–August) at the Institute of Horticultural Research, East Malling, England (51° 18' N, 0° 26' E). Some of the data have been presented previously, (see Table 1, Expt. 4 in [17]) and are further analyzed here. Two additional pot experiments (Expts. 2 and 3) were carried out in 2006 and 2008 in a greenhouse at the University of Guelph, Guelph, Ontario, Canada (43° 32' N, 80° 15' W). For all experiments, mature stratified ginseng seeds were purchased from a local Ontario grower in October. These seeds were mixed with moistened mortar sand (1 seed/3 sand, v/v) and put in plastic containers, which were placed in a controlled environment room (4 ± 1°C, 50 ± 5% relative humidity) until the experiments were started in January–March.

For all pot experiments, 10 seeds were planted equidistant within each wide (21 cm diameter) and deep (21 cm) pot, at a seeding depth of 30 mm [18]. The germination and growing medium for the seedlings in England was a peat moss/sand (3:1, v/v) mixture. In Guelph, a general-purpose growing medium, ProMix BX (Les Tourbieres Premier LTEE, Riviere du Loup, QC, Canada), was used. The pots were filled with the medium to within 3 cm of the top.

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Table 1

Effects of different light levels in three greenhouse experiments on root dry weight, leaf area and weight, and stem length and weight of ginseng seedlings at final harvest

Expt. no.	Light level (%)	Root dry weight (mg)	Leaf		Stem	
			Area (cm ²)	Dry weight (mg)	Length (mm)	Dry weight (mg)
1	4.8	193	23.3	67	81	17
	10.2	234	25	74	86	21
	20.4	339	22.2	92	79	22
	68	318	16.6	109	67	21
		Q (0.01)*	L (0.04)	L (0.07)	L (0.06)	NS
2	5	99	19.9	57	80	16
	10	92	16.7	63	76	20
	15	158	17.4	59	74	18
	22	181	21.3	79	81	21
	30	220	16	68	77	19
	40	180	12.2	60	63	17
		L (0.05)	NS	NS	NS	NS
		Q (0.05)				
3	5	115	17.1	41	91	12
	10	130	19.7	52	104	19
	15	145	19.7	63	92	13
	22	155	20.1	66	91	16
	30	160	19.1	59	80	14
	40	155	17.2	52	72	12
	60	135	15.5	50	82	10
	70	110	12	47	76	8
		Q (0.0001)	L (0.01)	NS	L (0.04)	NS
		Q (0.03)		Q (0.06)		
1, 2, and 3	NS	L (0.003)	NS	L (0.03)	NS	
		Q (0.01)				
2 and 3	Q (0.001)	L (0.007)	Q (0.06)			
		Q (0.02)				

* Significant linear (L) and quadratic (Q) values are shown with their *p* levels (within parenthesis); *p* values > 0.05 are sometimes shown to aid with discussion in the text.
Expt., experiment; NS, not significant.

Light transmission of the greenhouses was measured using a quantum, or line quantum, sensor (LI-COR Inc., Lincoln, NE, USA). For each greenhouse experiment, the required incident light at the top of the seedlings was established by suspending knitted black polypropylene shade cloths of different thickness above the plants. For each experiment, repeated at least twice, there was a minimum of four pots per treatment in a completely randomized design. Pest control was carried out following the guidelines in production recommendations for ginseng [16].

In these pot experiments, seedling emergence was recorded every 5–10 d to obtain seedling survival rate. Seedlings were harvested at the end of the growing season of about 100 d after seeding. Plant health was assessed visually [16,19]. Stem length was measured, and then leaf area of each seedling was determined using an LI-3100 leaf area meter (LI-COR Inc.). Each seedling was then separated into leaves with petioles, stem, and root, and dried at 80°C to constant weight.

Where appropriate, data were analyzed using SAS Version 9.1 (SAS Institute Inc., Cary, NC, USA). Optimal values for light and their respective maxima were determined by differentiation of best-fit quadratic functions. Significance levels at >5% are shown in Table 1 and discussed in the text, because American ginseng is essentially an unimproved land race and therefore genetically highly variable [20,21].

The final seedling population in all experiments was about 70%, similar to that reported previously [18], and did not differ between

Table 2

Quadratic relationship between ginseng seedling root dry weight (Y) and light received (X) in three greenhouse experiments

Expt. no.	Equation	Optimal value		<i>R</i> ² (<i>p</i>)
		Root weight (mg)	Light (%)	
1	$Y = 126.2 + 13.4X - 0.15X^2$	415	43.2	0.98 (0.01)
2	$Y = 29.5 + 10.9X - 0.17X^2$	200	31.4	0.87 (0.047)
3	$Y = 95.5 + 4.2X - 0.07X^2$	160	30.6	0.99 (0.0001)
2 + 3	$Y = 77.9 + 5.5X - 0.07X^2$	181	37.4	0.70 (0.001)
Overall means		239	35.6	0.88
Means for Expts. 2 and 3 and their combination (2 + 3)		180	33.1	

The optimal root weight (mg) and light (%) are calculated from the quadratic equation.
Expt., experiment.

experiments. Similarly, plant health was excellent in all experiments.

The seedling root dry weight (economic yield) response to increasing light was similar in the three experiments (Tables 1 and 2). Generally, there was a rapid increase in root dry weight as light was increased from about 5% to a maximum (optimal) at around 30%. Thereafter, there was a rapid decline in root weight with increasing light to about 70%, except in the experiment carried out in England (Expt. 1), where the decline was more gradual. There was a strong quadratic relationship between the ginseng seedling root dry weight and the light reaching the plants (Table 2, $R^2 = 0.70–0.99$). This quadratic relationship is similar to that of Kim [12] and Cheon et al. [6] working with Asian ginseng of various ages, although their optimal light values were lower.

The highest optimal value of 415 mg root dry weight at 43.2% light was obtained in England (Table 2, Expt. 1). This high root weight may be due to more favorable climatic growing conditions in England, such as lower growing-season temperatures than in Canada [22] and lower solar radiation, and suggests further evaluation of ginseng as a crop in England. For the three growing-season months (June, July, and August), the mean solar radiation in England was 15.2 MJ/m², whereas in southern Ontario it was 21.1 MJ/m², i.e., 38.8% higher [23,24]. The high optimal light value of 43.2% is surprising, because maximum optimal values for American ginseng, although unknown, are likely to be below 36%, as Fournier et al. [11] found that with 2-y-old plants, leaf bleaching and premature leaf death occurred above 36% light. Maximum optimal values for Asian ginseng are usually in the range of 5–20%, although Parmenter and Littlejohn [7] found maximum light values of 36%, similar to that reported by Fournier et al. [11] for American ginseng. Leaf bleaching was not observed at the highest light level (68%) in Expt. 1, suggesting adaptation to this growing environment.

There was a strong quadratic relationship between ginseng seedling root dry weight and light reaching the plants in Expts. 2 and 3 and their combination (Table 2, $R^2 = 0.70–0.99$). The optimal light value for Expts. 2 and 3 and their combination was 33.1% and ranged from 30.6% to 37.4% (Table 2). These values are mostly below the 36% light threshold for leaf bleaching and premature leaf death in American ginseng [11]. Some leaf bleaching was observed in 60% and 70% light treatments (Table 1, Expt. 3) toward the end of the experiment. The quadratic relationships reported in Tables 1 and 2 are similar to those of Kim [12] and Cheon et al. [6] working with Asian ginseng of various ages, although their optimal light values were lower. The optimal root weights for Expts. 2 and 3 and their combination was 181 mg and ranged from 160 mg to 200 mg (Table 2).

Leaf area in the three experiments was always lowest at the highest light level (Table 1). With the exception of Expt. 2, there was

a linear decline in leaf area with increasing light ($R^2 = -0.66$ to -0.93 ; Table 1). When the data for the three experiments were combined, the linear regression equation was $Y = 21.2 - 0.11X$, with $R^2 = 0.43$ and $p = 0.003$. The reduction in leaf area between 4.8% and 68% light (Table 1, Expt. 1) was 28.7%. These data complement those of Proctor [25] who showed that approximately 90% of the variation in seedling root dry weight was accounted for by leaf area once the canopy was established. In addition, Parmenter [26] reported a leaf area reduction of 30% with increasing irradiance. There was a relationship between leaf area and stem length decline (see below) with increasing light ($R^2 = 0.23$, $p = 0.04$) when data from the three experiments were combined.

The response of leaf dry weight to increasing light tended to be quadratic (Table 1, Expts. 1 and 3), somewhat similar to the response of root dry weight to increasing light.

Stem length decreased with increasing light, with an R^2 of -0.26 ($p = 0.03$, $n = 18$) for the combined data from the three experiments (Table 1).

Determination of optimal light for ginseng culture is complex and needs to include consideration of the numerous factors influencing crop growing under the required shade. For instance, Cheon et al. (see Table 7 in [6]), growing Asian ginseng in Korea, reported that the highest root weight for 6-y-old plants was 148 g at 20% light (real light transmittance rate (RLTR) of 22.4%). At 30% light (RLTR of 31.7%) root weight was 144 g. Quadratic regression of their root weight data gave an optimal root weight of 146 g at 26.2% light. However, their recommendation for optimal light was 10% (RLTR of 14.4%) based on root yield (kg/kan^2), which included consideration of factors other than light such as early leaf defoliation, missing plant rate, leakage rate of shade, and *Alternaria* blight. This indicates the complexity of determining optimal light values. A different result for Asian ginseng was obtained by Parmenter and Littlejohn [7] working in New Zealand. They found similar root growth in 8–36% light. This may be related to local environmental conditions of relatively low growing-season temperatures, low rainfall during the growing season, and a low incidence of diseases [19]. In related work with Asian ginseng, Jang et al. [14] determined that the optimal light for cultivation in greenhouses in Korea was in the range of 13–17%.

In summary, the optimal light level for growing ginseng is determined by a combination of plant responses to light, and the associated specific environmental and plant health issues at that location.

Conflicts of interest

Both authors have no conflicts of interest to declare.

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