SOME ASPECTS OF THE CANADIAN CULTURE OF GINSENG (*PANAX QUINQUEFOLIUS* L.), PARTICULARLY THE GROWING ENVIRONMENT[1]

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Abstract

The harvesting and export of Canadian ginseng from the cool, shady hardwood forests of southern Canada can be traced to 1796. Because of its high dollar value and diminishing woodland supplies it was decided in 1896 that it should be cultivated under wood lath screens. Present day economics dictate changes in production techniques to allow for a decreasing supply of expensive labour.

Traditional wooden lath screens have a surface area of wood of 70 per cent and permit light penetration of only about 18 per cent. Experimental woven black polypropylene shade has an estimated surface area of 72 per cent and permits light pentration of about 28 per cent. While differences in air and leaf temperatures under the two shade structures can be measured it is doubtful if these are great enough to cause differences in plant growth under the two structures. Shade grown ginseng had a low fresh and dry weight and total chlorophyll content (ratio of a to b was 3 to 1) comparable to other shade species. There was no differences in fresh and dry weight and chlorophyll content of leaves from plants grown under the two shade structures. Maximum net photosynthesis of leaves was 0.175 g CO_2 m^{-2} hr^{-1} and light saturation level was about 200 μ E m^{-2} s^{-1}, or about 10 per cent of full sunlight.

Introduction

American ginseng, *Panax quinquefolius* L., (Bailey, L.H., Hortorium Staff, 1976) is a fleshly rooted perennial herbaceous plant which is native to the cool, shady hardwood forests of southern Canada. In the past its commercial value has been limited because of a dependence on the export trade to China and Korea where the roots have a high medicinal value.

The value of Canadian ginseng in international trade can be traced to 1716 and a Jesuit Priest, Father Lafitau (Staba and Kim, 1971). Lafitau has spent some time in China and was familiar with ginseng's medicinal qualities as used by the Chinese. He discovered it near Montreal where he was a missionary among the Iroquois. The French quickly realised the value of ginseng and large quantities were collected in the hardwood forests around Montreal and throughout Quebec. It was then exported to China from Montreal. In 1890 exported Canadian ginseng had a value of $100,000 (Panton, 1891). The price realised was $6–$8 per

[1]Research work reported in this paper was carried out over several years and is based, in part, on another manuscript which has been submitted to Scientia Horticultural for consideration for publication.

kg for dry roots. Because of this high value it was thought that it would pay to cultivate it rather than collect it in the woods.

Ginseng has been cultivated under wooden lath screens in southern Ontario since 1896. While there are no statistics on crop production and values it is estimated that the present annual Canadian output is about 36,360 kg of crude dry root valued about $100 per kg to the grower. While it is a high value crop and in demand on both the export and domestic markets, production techniques will have to change to allow for a decreasing supply of expensive labour. Investigations on different shade materials to replace the traditional wooden lath screens have been started. The research work reported here is concerned with the Canadian culture of ginseng emphasizing the environmental variables associated with production.

Materials and Methods

The field study was conducted at the Hellyer farm at Oakland, Ontario, during the months of June, July and August 1977 and parts of 1978.

For the determination of fresh and dry weights and chlorophyll content leaves were collected from plants growing under the two shade structures, placed in plastic bags, removed to the laboratory and immediately weighed. Dry weight was obtained by drying to constant weight at 85° C. Chlorophyll content was determined on a minimum of 4 samples for each location each containing 10 discs cut with a cork borer (1.77 cm^2) which were weighed and extracted for 48 h in darkness in 5 ml of 85% acetone. The absorbance of the extracted solutions was measured at 645 nm and the concentration of chlorophyll calculated using the equations given by MacLachlan and Zalik (1963).

Stomatal conductance of the abaxial surface of exposed ginseng leaves was measured with a diffusion resistance promoter, Kanemasu et al., (1969). (Lambda Instruments Corporation, Nebraska).

Net photosynthetic rates were determined in the laboratory on intact leaves of potted plants following the method used by Herath and Ormrod (1979). Leaf temperature during photosynthesis measurements was 25 ± 2° C. Light was supplied to the entire plant by a General Electric high pressure sodium lamp. Irradiation levels at the surface of the leaf were measured with a Lambda meter (Model LI-185, Lambda Instruments Corporation, Nebraska) fitted with a quantum sensor. Different leaf light intensities were obtained by inserting screens of cheese cloth between the light and the leaves.

Two adjacent plots (each of 2 ha) of 3 year old ginseng plants were identically instrumented. One plot had wooden lath screen shade and the other had woven black polypropylene shade suspended 2 m above the crop (see Fig. 1). Dry-bulb temperatures were measured at 1 m above the shade material and at 1 m above the crop with five-junction copper-constantan thermopile units (shielded and ventilated) similar to that described by Pruitt and Lourence (1969). Similar thermopile units but unshielded and non-ventilated were used to measure leaf temperature. Global and diffuse solar radiation were measured 1 m above the crop with Kipp and Zonen pyranometers (Kipp and Zonen, Delft, The Netherlands). The shade rings for measuring diffuse solar radiation were constructed following Horowitz (1969). Incoming global and diffuse solar radiation were measured above an instrument trailer adjacent to the plots. Polyethylene-shielded radiometers (Type S-1, Swissteco Pty., Ltd., Australia) mounted 1 m above the crop measured net radiation directly. The Kipp and Zonen pyranometers were calibrated by the Canadian Radiation Laboratory, and the recent calibrations of the net ratiometers by the manufacturer were accepted.

All signals were recorded continuously on multi-point electronic recorders. Raw data were extracted manually from the recorder charts and half hourly means determined.

Results and Discussion

Basic climatic requirements for ginseng production. Essentially, ginseng production may be regarded as the conversion of solar energy, water and soil nutrients into a root which has considerable economic importance. The following basic climatic requirements may be suggested for ginseng production:

(a) energy in the form of solar radiation for the processes of photosynthesis and transpiration;
(b) water, either rainfall or irrigation, for the solution and uptake of plant nutrients from the soil;
(c) freedom from climatic hazards producing physical damage, e.g. gales and tornadoes;
(d) freedom from climatic hazards conducive to the spread of insects and diseases.

While it is impossible to define the above requirements precisely they will serve as a useful base for a discussion of the atmospheric environment for two ginseng growing areas, Korea and Canada, and for the research which is reported below.

Standard climatic data. Selected data for two ginseng producing areas on two continents have been summarized (Table 1).)Data for Seoul, Korea have been taken as representative of a major producing area, Kyonggi province, and compared with the Lake Erie Counties of Ontario, Canada where most of Canada's ginseng is cultivated.

Table 1. Climate data for two ginseng producing areas-Seoul, Korea and the Lake Erie Counties of Ontario, Canada.

	Seoul[y]	Lake Erie Counties[z]
Latitude	37°35′N	42°51′N
Mean Annual Temperature °C	11.1	8.3
Mean Daily Maximum Temperature °C		
—January	−0.4	−0.6
—April	16.5	11.7
—July	29.2	27.2
—October	19.9	16.1
Extreme Low Temperature °C	−23.1	−36.7
Mean Date of Last Frost in Spring	April 21	May 12
Mean Date of First Frost in Fall	Oct. 16	Oct. 10
Mean Annual Frost Free Period (Days)	177	150
Mean Annual Precipitation (mm)	1259	864

[y]Data from Chen (1970)
[z]Data from Brown, *et al* (1968).

The differences between the two producing areas are small but consistent in most parameters reported (Table 1). The growing season is longer in Seoul than in the Lake Erie Counties and the mean daily maximum temperatures are a few degrees higher. Probably the greatest differences lie in the amount and distribution of the rainfall. Seoul receives about 400 mm more rain than the Lake Erie Counties and in Ontario, Canada there is remarkably little seasonal variation. Seoul has a rainy season from June to September, about 60 per cent of the total rain being received in this period (Chen, 1970). In July the summer monsoon predominates with strong southerly winds and cloudy, rainy weather. This accounts for the drop in the number of hours of bright sunshine in Seoul in July (Table 2). Another difference is that Seoul can experience typhoons.

The above differences probably relate to item (d) of the basic climatic requirements. Cultivated ginseng is susceptible to a number of diseases, some of them severe. Their development could be re lated to lack of adequate ventilation and excessive soil moisture among others. Because of the warmer, wet growing season in Seoul disease control is probably more difficult.

Sunshine and solar radiation. Seoul, Korea, receives more hours of bright sunshine than Guelph, Canada (Table 2). The monthly distribution

Table 2. Mean number of hours of bright sunshine for Seoul, Korea, and Guelph, Canada (a), and average daily solar radiation received on a horizontal surface (cal. cm^{-2}) at Guelph.

Location	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
(a) Hours of bright sunshine													
Seoul[y]	180	182	207	228	257	214	179	202	206	231	180	161	2427
Guelph[z]	66	89	121	159	211	250	290	247	170	139	77	61	1880
(b) Average daily solar radiation (cal. cm^{-2})													
Guelph[z]	145	216	317	372	479	536	543	447	352	237	129	107	

[y]Data from Chen (1970)
[z]Data from Brown, *et al* (1968)

in the two countries is very different with May and October being the sunniest in Korea and July the sunniest in Canada. The dullest month in both locations is December with about five hours per day of bright sunshine in Seoul but only two hours per day in Guelph.

The seasonal variation in solar energy received at Guelph, Canada is closely related to the elevation of the sun (Table 2). Most energy is received in June and July. The mean monthly hours of bright sunshine are well correlated ($r = 0.96$) with average daily solar radiation.

The Plant. *Chlorophyll content, fresh and dry weight of leaves of ginseng grown under two shade structures.* Shade grown ginseng had a low fresh weight and total chlorophyll content per leaf area which was comparable to data cited for shade species and which was much less than cited data for sun species (Table 3). Chlorophyll expressed on a weight basis was more comparable to sun than shade species. Shade plants often contain a higher proportion of chlorophyll b than chlorophyll a (Boardman 1977). The ratio of chlorophyll a to be was 3:1 in ginseng and was comparable to most sun species.

Dry weight per leaf area was low in ginseng (Table 3) and was similar to the rain forest shade species, *Alocasia macrorrhiza* (Boardman 1977). The average value for the three species cited was 0.52 g dm^{-2} with a range of 0.23 to 0.78 g dm^{-2}.

There were no differences in dry and fresh weight and chlorophyll content of leaves from plants grown under the two shade structures (Table 3).

The Plant Environment. The necessary shade for the commercial Canadian culture of ginseng has been obtained with wooden lath screen (Fig. 1A, left). These wooden screens are 1.21 m × 1.21m and are supported on wires with retaining hooks. The surface area of wood is 70% and allows light penetration of 17.8% (Fig. 1D). The experimental woven black polypropylene (Fig. 1A right) is made up of threads in 1.8 cm wide bands and 0.7 cm wide spaces with cross threads. An estimate of the woven area is 72%. Mean light penetration data of 27.6% agree with this (Fig. 1D). Light measured immediately under the two shade structures showed that there was more uniform light penetration across the woven black polypropylene than across the wooden lath shade (Fig. 1C). This is also evident in Fig. 1B, at plant level.

Radiation. The disposition of the incoming solar and atmospheric radiation under the shade structures will establish an unique microclimate which will manifest itself in the growth and production of the crop. Therefore, an analysis of the partitioning of radiation is central in this research. Incoming radiation at the top of the shade and over the crop is composed of three major components - direct solar, diffuse solar, and atmospheric radiation. The first two are mainly short-wave, while the last is

Table 3. Chlorophyll content, fresh and dry weight of leaves of 3 year old ginseng (*Panax quinquefolius* L.) grown under wooden lath screens and woven black polypropylene. Data from published sources included for comparison.

Species	Structure	Dry wt. per leaf area (g dm^{-2})	Fresh wt. per leaf area (g dm^{-2})	Chlorophyll a and b per fresh wt. (mg/g^{-1})	Chlorophyll a and b perleaf area (mg dm^{-2})
Ginseng-Panax[x]	1. Wooden lath screens	0.34	1.06	1.85	1.96
	2. Woven black polypropylene	0.35	1.13	1.84	2.08
Shade species	Redwood Forest				
Mean values for 5 species[y]		0.23[z]	0.96	3.1	3.0
Sun species					
Mean values for 5 species[z]			2.5	1.9	4.7

[x]Leaves collected and determinations made August 4, 1977.
[y]Data from Boardman (1977)
[z]Value for *Alocasia macrorrhiza*, a Queensland rainforest shade species.

longwave. Partitioning of the radiation is summarized in Table 4.

The woven black polypropylene shade permitted greater penetration of total and diffuse solar radiation than did the wooden lath shade (Table 4) - see also Fig. 1. Above the shades diffuse radiation was an average 33.6% of total short-wave radiation and increased to just over 40% of the total under both shades. The diffuse radiation component is important in photosynthesis and in these studies was usually adequate (from 100 to 200 $\mu mol\ m^{-2} s^{-1}$) to ensure saturated ginseng leaf photosynthesis - compare with Fig. 4. More studies are needed to resolve the inter-relationship between parts of the ginseng leaf when different parts are simultaneously exposed to full sun and shade.

Daytime net radiation was greater above the woven black polypropylene shade than above the wooden lath (Table 4). This is due to the greater emission of radiation by the black polypropylene than by the wood. Under the shades the amount of net radiation was similar. Linear correlations were obtained for short-wave and for net radiation for all available data. All correlation co-efficients were high, 0.95 to 0.98, but some comparisons were more highly correlated than others. For instance, the solar radiation above the shades was better correlated with that received under polypropylene than under wood. This may be due to the more consistent radiation regime under the polypropylene (Fig. 1).

Table 4. Partitioning of short-wave and daytime net radiation on 7 days in July and August, 1977 by the wooden lath shade and the black polypropylene shade expressed as a percentage of the radiation above the shades[z]

	LOCATION		
	above the shade	Under wooden lath shade	Under woven black polypropylene shade
Short-wave radiation			
(1) Total solar	100	16.4	26.6
(2) Diffuse solar	33.6	6.6	11.4
Net radiation			
polypropylene Wood			
	100 77.2	21.9	23.2

[z]Net radiation was not the same above the two shades

Air and leaf temperatures

During the day temperatures under the shade structures were slightly higher than those above the shades. For a 48 h period at the end of July 1977 (Table 5) mean temperature differences were 0.22° C for the woven black polypropylene and 0.34°C for the wooden lath screens respectively. At night it was much cooler under the shade structures than above them, differences of 3.5°C being measured. For the nights for the 48 h period shown in Table 5 the mean temperature differences were 1.17°C for woven black polypropylene and 0.83°C for wooden lath screen.

Leaf temperatures

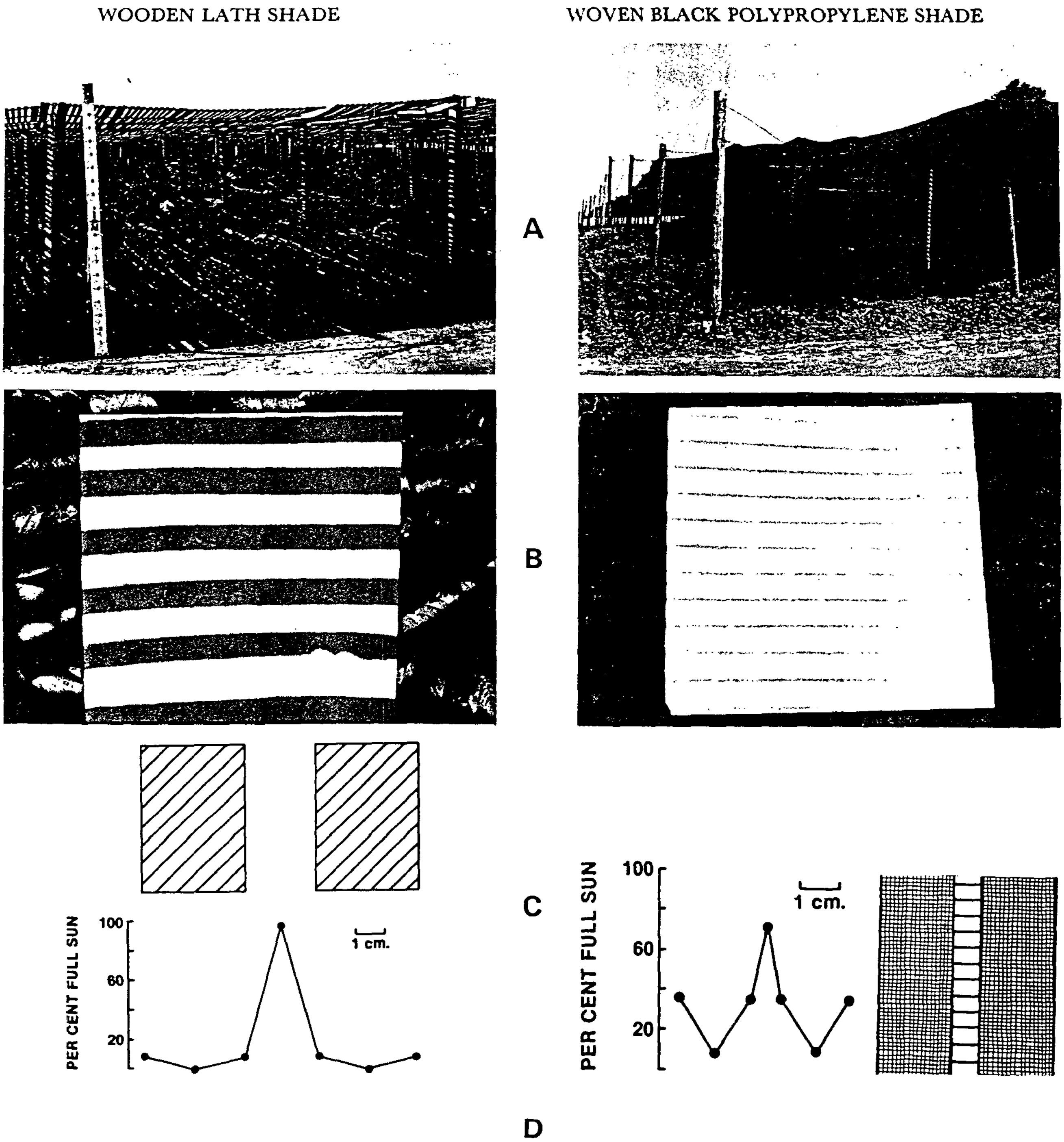
During the day mean leaf temperatures under the woven black polypropylene were higher than air temperatures above or below this shade (Table 5). Under wooden lath screens mean leaf temperature was the same as air temperature above the shade and lower than air temperature below this shade (Table 5). At certain times during the day leaf temperatures were several degrees higher than the temperatures under the two shade structures.

At night mean leaf temperature under the woven black polypropylene was lower than air temperatures above or below this shade (Table 5). Under the wooden lath shade at night mean leaf temperature was similar to air temperature under the shade (Table 5).

While portions of the radiant energy in the daytime were used to heat the air, the crop and the soil, the measurable temperature differences were

Table 5. Mean air and leaf temperatures (°C) above and below two shade structures for days (0800 to 1900) and nights (1900 to 0800) for the period 1630 on 27 July, 1977 to 1530 on 29 July, 1977.

		Mean temperatures (°C)			
		Day		Night	
Shade Structure	Location	Air	Leaf	Air	Leaf
Woven black polypropylene	Above	23.11	—	14.00	—
	Below	23.33	24.17	12.83	12.56
Wooden lath screen	Above	23.72	—	13.44	—
	Below	24.06	23.72	12.61	13.44



Per cent light penetration to the top of the crop canopy

(i) Spot measurements

19.2	28.6

(ii) Continuous measurements

16.4	26.6

Fig. 1. Comparison of the two shade materials used in the Canadian culture of ginseng. A-General view of the two materials in a commercial planting. B-Shade pattern on a 0.3 m × 0.3 m card and on the crop. C-Light penetration through the two shades measured immediately under the shade. D-Percent of the available light reaching the crop canopy under the two shade materials.

not large. At night radiation loss led to lower temperature but again these differences were small. Although differences between air and leaf temperatures exist under the two shade structures it is doubtful that these differences are great enough to cause differential growth and yield of the plants.

Stomatal Conductance. Stomatal (leaf) conductance, the reciprocal of the widely used parameter, stomatal resistance, for mature leaves increased with increasing photon flux density, reaching a saturation level at about 950 μmol m^{-2} s^{-1} (Fig. 2). Considerable variation was found in the data and the relationship indicated can only be taken as showing the general trend. However, Turner (1974) has shown a similar relationship for several crops and tree species. Data presented by Turner for sorghum, maize, beech and yellow poplar, are of comparable magnitude to those given here for ginseng.

Data given in Fig. 2 corroborate findings presented earlier. Exposed leaves growing under wooden lath screens were in 2 light regimes (and 2 stomatal conductance regimes)-one in low light (<200 μmol m^{-2} s^{-1}), and the other in high light (700–1800 μmol m^{-2} s^{-1}). Exposed leaves growing under black polypropylene were mainly in an intermediate light regime of 300 to 600

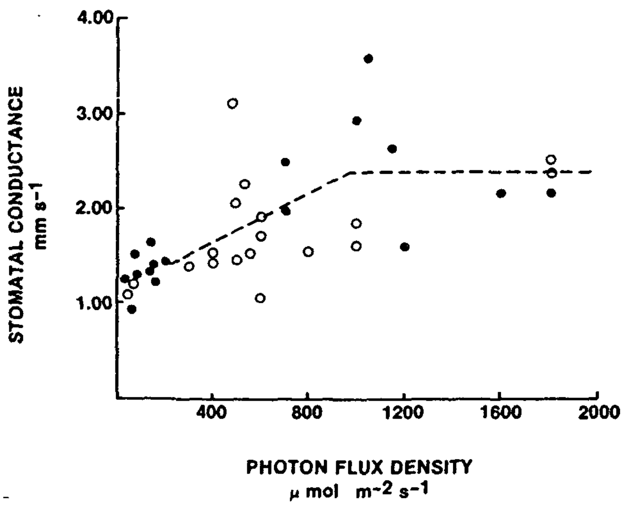


Fig. 2. The relation between stomatal conductance and photon flux density of 3 year old ginseng growing under wooden lath shade (●), and under woven black polypropylene (○). The lines are fitted by eye.

μmol m^{-2} s^{-1}. Data given for other light regimes under black polypropylene were obtained in breaks in the shade structure and leaves within the canopy.

Measurements of photon flux density and stomatal conductance were made on the same leaves at the same time. However, it is reasonable to assume that the stomata were responding to radiation received in the previous half hour or so. Because of the changing light regime and the response to this (see below), precise relationships between photon flux density and stomatal conductance are difficult to establish. Further studies are needed, preferably in a leaf cuvette, to clarify not only the above relationship but also the relationship between stomatal conductance and other environmental variables such as leaf temperature, vapour pressure deficit and carbon dioxide concentration.

Cuticular Conductance. This was measured by applying the porometer to the adaxial surface of the leaf which has no stomata. Mean cuticular conductance was about 0.10 mm s^{-1} which is about 5 to 10% of stomatal conductance.

Stomatal closing in response to a change from light (250 μmol m^{-2} s^{-1}) to dark and to light. The light intensity at which ginseng stomata open and close and respond to changing light intensity is important because of the natural changes in light intensity experienced in culture under shade. Changes could be from 2000 (full sunlight) to about 200 μmol m^{-2} s^{-1} under the shades. The capacity to respond to rapidly changing light conditions is probably inherent in ginseng because it is a natural shade species. Ginseng stomata were slow to respond to darkness relative to species studied by Davies and Kozlowski (1974). Their green species took 17 to 31 minutes to reach equilibrium whereas ginseng took about an hour (Fig. 3). Once the lights were switched on stomatal conductance increased rapidly reaching a peak in about 17 minutes and declining to the original level about 15 minutes later (Fig. 3). This is a fast response. At the ginseng leaf light conditions will change because of the changing light penetra-

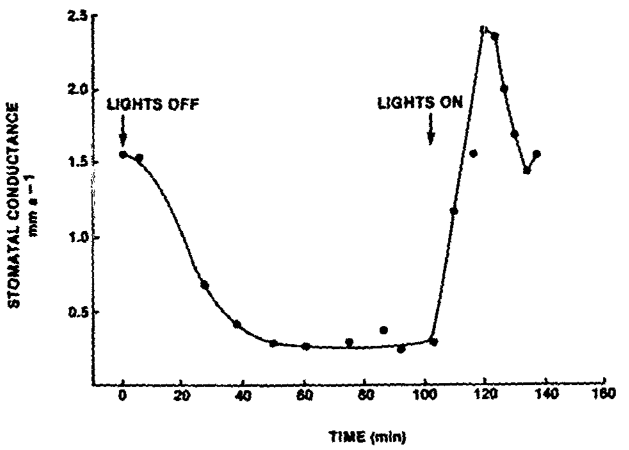


Fig. 3. Changes, with time, in stomatal conductance of ginseng leaves to darkness and to light.

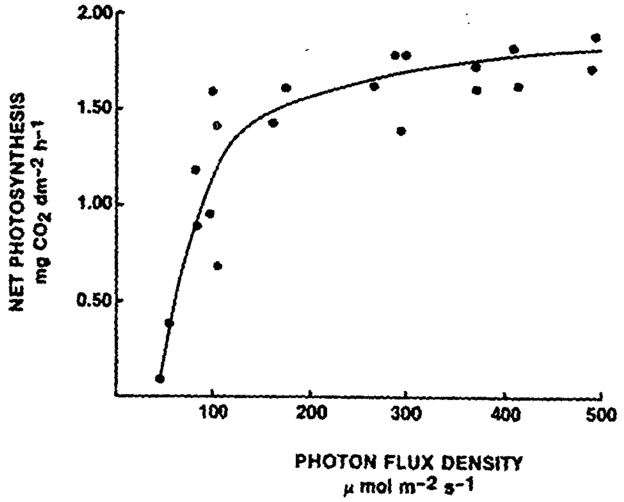


Fig. 4. The response of photosynthesis in ginseng leaves to photon flux density. The curve is fitted by eye.

tion through the shade. In this situation the capacity of the guard cells to respond to changing light conditions in important since it will allow it to survive. Ginseng exhibits relatively slow stomatal closure when light intensity decreases and fast response when exposed to light (Fig. 3).

The unexpected peak in stomatal conductance after the lights were switched on (Fig. 3) could be related to a CO_2 "gulp" associated with a preceding post-illumination CO_2 burst and photorespiration. However, no such burst was observed so this stomatal response remains to be resolved.

Photosynthesis of attached ginseng leaves. This was measured to establish the maximum photosynthetic rate, the saturating photon flux density and to see if inhibition of net photosynthesis could be achieved at high light intensities.

The maximum photosynthetic rate was about 1.70 mg CO_2 dm^{-2} h^{-1} and the saturating photon flux density about 200 μmol m^{-2} s^{-1} (Fig. 4). These figures are comparable to those given by Böhning and Burnside (1956) for a representative sample of shade plants.

The maximum photon flux density that could be obtained in the laboratory was 500 μmol m^{-2} s^{-1} (about one quarter of full sunlight) and no inhibition of photosynthesis was obtained. However, the plants were exposed only for a short time (up to 30 minutes) at this level. Further studies of leaf photosynthesis are needed and must include measurements at full sunlight levels for extended periods, measurements made at light levels mimicking those under woven black polypropylene shade, and measurements under fluctuating full sunlight and shade conditions.

Conclusions

Ginseng has been cultivated for only about a centry in Canada under wooden lath shades. This is a short history relative to Korea. Dramatic changes in the microclimate under the shade have been measured and are given in this report. Solar radiation penetration through the shade varies with the shade structure and can be from 18 to 28%. Shade induced differences in air and leaf temperatures were slight compared to the radiation differences and probably not adequate to evoke responses in plants. While the shade approximates the native habitat of the forest canopy it differs from it in that it is not a major source and sink of heat.

As changes in production techniques for ginseng are made they must be based on a knowledge of the physiology of the plant. These first Canadian reports of stomatal conductance and photosynthesis in relation to photon flux density must be extended to provide the necessary base for advancement.

Chairman: Now the time is open to discussion.

Park: The saturation light intensity is about 10% of the total all sunlight. Then why do you use about the 30% of the sunlight, usually, you put about 30% sunlight. What do you think about it?

Proctor: That is correct observation from the data that I showed. We are trying to understand the physiological significance of this. I showed you the experimental woven black polypropylene shade which permits about 30% of sunlight as opposed to wooden shade which permits 18 or 20%. Our growers who are evaluating this shade are not satisfied. They think their light level is too high at 30%. But we would like to confirm in the photosynthesis study and this is one of the reasons for doing it, what is the optimum light level. Is it the minimum 10% and where is the maximum. We find that where the shade is removed either purposely or accidentally that we get least marginal leaf nicrosis and if the shade is removed for a several days, we get complete death of the plant. So we would like to know just where the optimum light level is, because this will determine what we thought the new shade structure is. We would like to know if it is 10% or if it is 25% or 30. We think it is somewhere between 10% or 25%.

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