J. Amer. Soc. Hort. Sci. 106(2):163–167. 1981.

Economics of Harvest Timing for Once-over Harvesting of Cucumbers[1]

H. T. M. Colwell
Agriculture Canada, Research Station, Harrow, Ontario, Canada N0R 1G0
John O'Sullivan
Horticultural Experiment Station, Simcoe, Ontario, Canada N3Y 4N5

Additional index words. *Cucumis sativus*, chlorflurenol

Abstract. **An economic model involving simulation methodology was used, in conjunction with data from field experiments, to examine the economic effects of delayed or premature harvest of pickling cucumbers (*Cucumis sativa* L.) on yield and several measures of size grade distribution. It was shown that, for once-over harvesting of cucumbers, profitability of cucumber production was extremely sensitive to untimely harvesting. Profitability/ha was reduced on average by $1091 and $722 respectively for harvesting 3 days earlier or later than optimum. Harvest criteria which maximized profit were identified for both conventional cucumber production and production based on gynoecious cultivars and treatment with chlorflurenol. Substantial differences in the effect of harvest timing on profitability/ha and in optimum harvest criteria occurred between these production systems. Maximum margins occurred in production methods involving gynoecious cultivars and chlorflurenol when 54.6% of the fruit were classified as grade 1. The comparable value for conventional production methods was 27.3%.**

Harvest timing is of great importance in the production of cucumbers for once-over mechanical harvesting because of the use of a single harvest rather than multiple sequential harvests which are used in hand harvesting. Production information available to the grower using mechanized harvesting should include details to permit identification of the optimum time to harvest his crops. In a previous study, the economically optimal harvest time for a once-over harvest occurred 9 days after the first fruit developed (2). This criterion is unlikely to be of wide industry applicability because it is based on an assumed rate of fruit maturation. Since fruit maturation rates are closely related to growing conditions and climatic factors after fruit set, a harvest criterion based on the current status of fruit maturity for each potential harvest date would be more applicable. Economically optimal harvest criteria will also be different for new production technology involving gynoecious cultivars and growth regulators which alter the pattern of fruit set.

This paper reports results of research which examined the economic importance of timely harvesting and quantified physical and financial measures which could be used as time of harvest decision criteria.

Materials and Methods

Input data was obtained from a series of 11 experiments conducted between 1976 and 1979 at the Horticultural Experiment Station, Simcoe, Ontario. 'Greenstar' and 'Femcap' cucumber were precision seeded into a sandy loam as previously described (6). Chlorflurenol was applied to 'Femcap' at 2 liters per ha when 6–8 flowers reached anthesis. Cucumbers were harvested once-over by hand at 1-day intervals for periods of from 6 to 11 days. In 1978 and 1979, plots were also harvested with a commercial once-over cucumber harvester. At harvest, values for yield ($/ha and MT/ha) and the proportion of the crop in each of 5 grades on consecutive days, were obtained. The grades, based on maximum diameter and dollar values/MT used in Ontario, are: No. 1, less than 25 mm, $382.02 Canadian; No. 2, 25 to 32 mm, $275.83; No. 3, 32 to 41 mm, $154.57; No. 4, 41 to 51 mm, $65.97; No. 5, greater than 51 mm, no value. (These grades are related to P.C.I.C. grades which are as follows: No. 1, < 27 mm; No. 2, 27–38.1 mm; No. 3, 38.1–51 mm; No. 4, > 51 mm).

For the purpose of these analyses it is assumed that profit or margin (M) is related to yield per hectare (Y); sale price/MT of crop (Q); method of production (T) and costs of production (C) (equation 1).

$$M = f(Y, Q, T, C) \quad [1]$$

Delayed or premature harvest of a specific crop will cause changes in values of Y, Q and C when the method of production does not change.

$$M_t = f(Y_t, Q_t, C_t) \quad [2]$$

where subscript t = a specific harvest date.
The economic effects of untimely harvesting are calculated using equation 3.

$$U_t = M_{to} - M_t \quad [3]$$

where U_t = cost ($/ha) of untimely harvesting
and M_{to} = margin ($/ha) at the optimum harvest date.
The optimum harvest date occurs at the point of maximum profitability, i.e. when marginal cost equals marginal revenue (equation 4).

$$\frac{\partial M}{\partial t} = 0 \quad [4]$$

As cucumber harvest is delayed a few days, marginal revenue measured as crop sales per hectare will change because of increased yield of larger fruit and declining crop value/MT. Harvest delays of a few days will have a small influence on crop costs/ha which will increase because weight increases result in greater trucking costs. Where cost increases are insignificant in relation to changes in marginal revenue i.e. crop sales

$$M_t \simeq Y_t \times Q_t \quad [5]$$

where Y_t = yield per hectare and Q_t = crop value/MT at a specific harvest date and

$$Q_t = \Sigma D_t P_D Y_t \qquad D = 1 \text{ to } 5 \quad [6]$$

[1]Received for publication July 15, 1980.
The cost of publishing this paper was deferred in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-07-08 via Open Access. This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/). https://creativecommons.org/licenses/by-nc-nd/4.0/

where D_t = proportion of the crop in each of 5 specified grade classifications for a specific harvest date

and $\quad P_D$ = price (\$/MT) for a specified crop grade

but
$$Y_t = a + b\,Q_t \tag{7}$$

Substituting 7 into 5 gives equation 8.

$$M_t = (a + bQ_t)Q_t \tag{8}$$

Optimum crop value Q_{to} and yield/ha Y_{to} are calculated using equation 9.

$$\frac{\partial M}{\partial t} = a + 2\,bQ_{to} = 0 \tag{9}$$

The optimum yield level Y_o is calculated as in equation 10.

$$Y_o = a + 2bQ_{to} \tag{10}$$

The optimal levels of D_t for any of 5 grades are calculated as follows:

$$Y_o = k + nD_{to} \tag{11}$$

or

$$a + 2bQ_{to} = k + nD_{to} \tag{12}$$

where the coefficients k and n were established using linear regression analysis of the original data and Y_o is obtained from equation 10.

Values of margin per ha for different harvest dates were calculated using a general purpose crop mechanization computer model (3) which incorporated a benchmark production system based on the likely production system for southern Ontario. The computer algorithm is summarized in Fig. 1. The benchmark production system assumed that 60 ha of cucumbers was produced annually using the machine operations and rates outlined in Table 1. Each machine operation was classified as either operation dependent or operation independent. The rate at which dependent operations can be completed was assumed to be directly influenced by the rate of completion of an earlier operation. Independent operations were not directly influenced by other operations within the production system. Independent operations were divided into 2 subclasses. Time critical operations must be completed within a specified time period. The algorithm calculated the maximum output based on specified machine work rates, work day length, and maximum days available to complete the operation. Areas in excess of this maximum could be completed by purchasing more machines, using custom services, completing the operation in an untimely fashion with a yield or quality loss, or not completing the operation. Independent operations which are not time critical are assumed to be completed with the specified machine capacity.

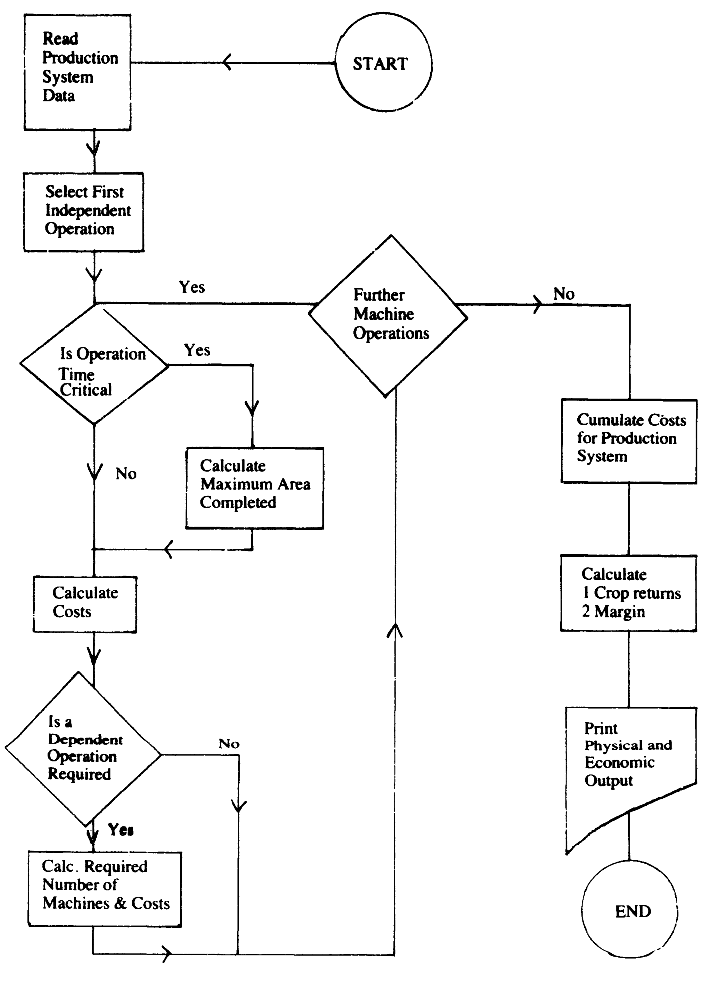

Fig. 1. Summary flowchart for algorithm.

The algorithm, on completion of the cost analysis of all individual machine operations, cumulates costs and calculates crop returns and margin per unit area. Crop returns are the cumulative value of the products of yield and price of each of 5 cucumber grades. Margin represents the return to the grower of his investment risk and management skills and is defined as total cucumber sales less variable, labor, machinery, land, and miscellaneous costs.

The benchmark production system was based on the use of commonly available machines such as a tractor, plow, cultivating and spraying equipment (Table 1). A precision seeder and a pickling cucumber harvester were assumed to be purchased as new equipment to be used specifically in pickling cucumber production. The remaining machinery was assumed to be 3 years old on average. Machine performance characteristics, fertilizer, seed and spray application rates were based on discussions with research and extension personnel and on published extension information (4, 5, 7).

The transport operation was classified as a machine dependent operation. The number of trucks required was dependent upon the harvester work rate and the harvested yield per hectare. The trucks had a capacity of 5.4 MT and were assumed to travel 160 km to and from the processing plant at a speed of 56 km/hr with a combined loading and unloading time of 1.5 hr. A harvester work rate of 0.3 ha/hr and a daily harvesting period of 10 hrs were assumed in the benchmark system. All labor used in the production system was valued at \$3/hr and annual land costs consisted of an opportunity cost of 9% of the land value estimated at \$6000/ha.

Combinations of yield per hectare and percentage by weight of grades 1 to 4 for each harvest date were used as input to the computer model. Since crop prices for the various grades were kept constant for all experiments, differences in margin reflect differences in physical output and harvesting and transport costs rather than differences in crop prices over time. Previous regression analysis studies indicated that the explanatory power for linear relationships between yield (MT/ha) and average crop value (\$/MT) and between yield and grade 1 or grade 5 cucumbers (percent by number) was sufficiently high ($R^2 > 0.68$) to enable these parameters to be used in equation 7 for quantification of optimum harvest criteria (6). Values of each parameter which maximized margin per hectare for each experiment were identified by solving Q_{to} in equation 9 and, by substitution, solving equation 11 to establish D_{to}. The constants a, b, k and n were established during the previous regression phase of the study (6).

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-07-08 via Open Access. This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/). https://creativecommons.org/licenses/by-nc-nd/4.0/

Table 1. Machine operations in the benchmark production system.

Operation	Machine(s) used	Work rate (ha/hr)	Machine cost—salvage value ($ Canadian)
Plowing	6 furrow + 82 kW tractor	1.2	3 900 20 000
Primary cultivation	Cultivator + 82 kW tractor	4	1 500 20 000
Secondary cultivation	Cultivator + harrow + packer + 82 kW tractor	4	4 500 20 000
Fertilizer	Application completed by custom operator	N/A	N/A
Seeding	Precision seeder + 37 kW tractor	0.61	3 700 7 500
Spraying	Sprayer + 60 kW tractor	3.25	1 [illegible] 12 000
Row cultivation	Cultivator + 60 kW tractor	1.2	12 000
Harvesting	Harvester + 82 kW tractor	0.30	33 000
Transporting	Trucks (used)	Dependent on harvester work rate	5 000

N/A Not applicable

Results and Discussion

Economic importance of untimely harvest. Timeliness is of major economic importance in once-over harvesting of pickling cucumbers (Table 2). For pooled data with 2 cultivars and 2 methods of production, harvesting 3 days earlier or later than the optimum date reduced maximum profitability/ha by $1091 and $722, respectively. Increasing income reductions occur as harvest date moves further from the optimum. The predominantly gynoecious 'Greenstar' was used in 6 experiments. The gynoecious 'Femcap' treated with chlorflurenol (a growth regulator used to promote parthenocarpic fruit set) was used for 5 experiments. The use of a gynoecious cultivar in combination with chlorflurenol results in a more concentrated fruit set (1). Differences are evident between these alternative methods of cucumber production. In general, harvesting before the optimum date was less financially crucial with 'Femcap' than with 'Greenstar'. This may occur because

Table 2. Influence of cucumber production method and harvest timing on net margin reduction for pickling cucumbers harvested once-over.

	Greenstar		Femcap (+chlorflurenol)	
Harvest date	Margin reduction from optimum date ($/ha)	% of margin at optimum date	Margin reduction from optimum date ($/ha)	% of margin at optimum date
9 days early	1930 (1)[z]	82		
8 days early	1110 (1)	47		
7 days early	1981 (3)	84		
6 days early	1587 (3)	67	1470 (1)	69
5 days early	1572 (4)	67	1328 (1)	62
4 days early	1366 (5)	58	44 (1)	2
3 days early	1236 (6)	52	657 (2)	31
2 days early	893 (6)	38	600 (2)	28
1 day early	740 (6)	31	795 (4)	37
Optimum	0 (6)	0	0 (5)	0
1 day late	522 (6)	22	667 (5)	31
2 days late	923 (5)	39	739 (5)	34
3 days late	513 (3)	22	931 (3)	43
4 days late	141 (1)	6	1285 (2)	60
5 days late			289 (1)	13
6 days late			1290 (1)	60
7 days late			1423 (1)	66
8 days late			1235 (1)	58

[z]Within each cultivar, data are pooled for a number of experiments. Values in parentheses refer to the number of experiments. Each treatment (harvest date) within an experiment had 4 replications.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-07-08 via Open Access. This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/). https://creativecommons.org/licenses/by-nc-nd/4.0/

Table 3. Harvesting criteria for maximum profits/ha for chlorflurenol treated 'Femcap' cucumbers harvested once-over.

Type of harvest	Avg crop value ($/MT)	Grade 1 (% by wt)	Grade 1 (% by no.)	Grade 4 (% by wt)	Grade 5 (% by wt)	Grade 5 (% by no.)
Simulated						
1978	227	32.3	69.7	4.6	4.7	0.8
1978	213	25.1	57.5	6.1	3.7	0.9
Actual						
1979	217	–[z]	36.6	5.4	–	–
1979	184	–	–	–	1.6	–
Mean	211	28.7	54.6	5.4	3.3	0.9

[z]The linear equation relating yield to the harvest criteria had a coefficient of determination less than 0.68.

Table 4. Harvesting criteria for maximum profits/ha for "Greenstar" cucumbers harvested once-over.

Type of machine harvest	Avg crop value ($/MT)	Grade 1 (% by wt)	Grade 1 (% by no.)	Grade 4 (% by no.)	Grade 5 (% by wt)	Grade 5 (% by no.)
Simulated						
1976	121	7.0	48.5	16.2	19.9	6.5
1976	138	7.8	34.2	15.5	14.0	5.4
1976	143	7.1	34.0	16.2	9.3	3.4
1978	139	6.6	28.4	11.6	19.7	7.5
1979	145	–[z]	6.6	26.7	20.7	–
Actual						
1978	128	2.4	12.2	16.9	14.1	5.8
1979	130	–	–	10.5	5.8	–
Mean	135	6.2	27.3	16.2	14.8	5.7

[z]The linear equation relating yield to the harvest parameter had a coefficient of determination less than 0.68.

when 'Femcap' is harvested early, the concentrated fruit set results in a high proportion of small high-value cucumbers. Therefore, although yield/ha is low it is partially counteracted by a high value/MT. Harvesting 'Femcap' up to 3 days earlier than optimum resulted in an income loss of 28% to 37%. Comparable figures for 'Greenstar' are 31% to 52%.

A converse situation is apparent for late harvesting. Harvesting 'Greenstar' up to 3 days later than optimum resulted in income losses ranging from 22% to 39%. Similar harvest delays with 'Femcap' produced margin reductions from 31% to 43%. The increased loss with 'Femcap' probably occurs because rapid sizing of the cucumbers results in an increasing proportion of larger, less valuable, cucumbers.

Harvest criteria for maximum profit. Values for 6 physical and financial parameters which maximized margin per hectare were calculated for all data in which the linear relationship between yield/ha (dependent variable) and the specific parameter had a coefficient of determination greater than 0.68 (Tables 3 and 4).

Differences between methods of cucumber production are evident. Cucumber production based on gynoecious cultivars and chlorflurenol will be most profitable if once-over harvesting is carried out when a much higher proportion of the fruit are in the high-priced grades, than for conventional production systems. Maximum margins/ha occurred when 28.7% by weight of the 'Femcap' cucumbers were in the high-priced grade 1 category (Table 3). This compares with a corresponding value of 6.2% for 'Greenstar' (Table 4). Maximum margins/ha occurred if 'Femcap' was harvested when the crop value was $211/MT compared with a value of $135/MT for 'Greenstar'. This effect is due to differences in the yield and grade distribution of the fruit since unit prices for each grade of cucumbers were held constant for all data in this study. An economic implication of concentrated fruit set in cucumber production based on gynoecious cultivars and chlorflurenol is a more rapid daily decline in average crop value. In 7 experiments with 'Greenstar' the mean daily decline in average crop value/MT over the 6–10 day period of delayed harvest was $23.97 which can be compared with a value of $33.27 for 4 experiments using 'Femcap' and chlorflurenol (Table 5).

Table 5. Average daily change in crop value for 'Femcap' and 'Greenstar' cucumbers.

Greenstar Year	Greenstar Avg crop value change ($/MT—day)	Femcap Year	Femcap Avg crop value change ($/MT—day)
1976	15.44	1978	26.32
1976	16.91	1978	33.15
1976	17.51	1979	38.09
1978	24.09	1979	35.51
1979	38.68		
1978	26.40		
1979	28.75		
Mean	23.97		33.27

Conclusions

The timing of harvest is a critical factor in the profitable production of cucumbers for once-over harvesting. Returns can be reduced by several hundred dollars per ha by harvesting even 1 day too early or too late. Distinct differences were found in the optimum harvest criteria for conventional cucumber production and production based on gynoecious cultivars and chlorflurenol. The

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-07-08 via Open Access. This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/). https://creativecommons.org/licenses/by-nc-nd/4.0/

altered fruit-set pattern due to chlorflurenol treatment requires that a much higher proportion of the fruit, than for conventional cucumber production, be in small-grade sizes at optimum harvest. Returns were maximum for conventional cucumber production if cucumbers were harvested when 6.2% of the fruit by weight was in size grade 1. For production based on gynoecious cultivars and chlorflurenol, the corresponding value was 28.7%. For field evaluations, it is of more practical value to use harvest criteria based on larger cucumbers, which are easier to count or weigh. Maximum margins per ha occur for 'Femcap' when approximately 5.5% by weight (1% by number) of the cucumbers are classified as grade 4 (41–51 mm in diameter). For 'Greenstar', the most suitable criteria to indicate optimum time of harvest is when approximately 15% by weight (6% by number) of the fruit are classified as size grade 5 (> 51 mm in diameter).

Literature Cited

1. Baker, L. R. and B. B. Dean. 1978. Perking pickle production. Amer. Veg. Grower 26(6): 12–13.
2. Chen, L. H., C. H. Miller, and R. S. Sowell. 1975. Simulation models for harvesting of pickling cucumbers. J. Amer. Soc. Hort. Sci. 100:176–179.
3. Colwell, H. T. M. 1979. Crop mechanization budgeting model — user's manual. Agriculture Canada, Policy, Planning and Economics Branch, Mimeograph.
4. Motes, J. E. 1977. Pickling cucumber production — harvesting. Mich. Agr. Ext. Serv. Bul. E–837.
5. O'Sullivan, J. 1978. Mechanical harvesting of cucumbers. Ont. Min. of Agr. Food, Factsheet, Agdex 256/51.
6. O'Sullivan, J. and H. T. M. Colwell. 1980. Effect of harvest date on yield and grade distribution relationships for pickling cucumbers harvested once-over. J. Amer. Soc. Hort. Sci. 105:408–412.
7. Thompson, J. L. 1966. Agricultural machinery costs. Can. Dept. Agr. Publ. 1291.

Downloaded from https://prime-pdf-watermark.prime-prod.pubfactory.com/ at 2025-07-08 via Open Access. This is an open access article distributed under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0/). https://creativecommons.org/licenses/by-nc-nd/4.0/

J. Amer. Soc. Hort. Sci. 106(2):167–170. 1981.

Estimation of Leaflet, Leaf, and Total Leaf Area of *Panax quinquefolius* L. Using Linear Measurements[1]

Becky R. Hughes[2] and J. T. A. Proctor
Department of Horticultural Science, University of Guelph, Guelph, Ontario, Canada N1G 2W1

Additional index words. ginseng

Abstract. **Leaflet length and width were used to calculate leaflet area, leaf area and total leaf area per plant for 3-year-old American ginseng, *Panax quinquefolius* L. grown in growth chambers. On the basis of correlation and regression analyses the product of leaflet length and width (LW) was chosen as the independent variable, but leaflet width squared (W^2) also proved satisfactory. Although leaflet shape varied somewhat with position, one regression equation was found suitable. Assuming that the Y-intercept was equal to zero had little effect on the coefficient of determination (R^2) or the standard error of estimation so the following equations were chosen to determine leaflet, leaf and total leaf area, respectively: A = 0.66 LW (R^2 = 98.92%, ± 0.75 cm^2); A = Σ0.67 LW (R^2 = 98.36%, ± 2.49 cm^2); A = Σ 0.67 LW (R^2 = 97.36%, ± 7.83 cm^2). The relationship between leaflet LW and total leaf area per plant was used to determine leaf area per plant and LAI for commercial ginseng crops 1, 2, 3, and 4 years old.**

American ginseng is a fleshy-rooted herbaceous perennial native to the eastern hardwood forests of North America. The root of this crop is used as a medicinal herb. Wild and cultivated ginseng produce an annual crop in the United States and Canada valued in excess of $25 million (7) yet there is essentially no research information on this crop. Leaf area measurements are needed in studies of the growth and development of this crop (11), which is allowed to grow 4 to 7 years before harvesting. However, due to the high value of the crop and its perennial nature, destructive sampling is restricted. To those researchers who do not have an automatic area integrating meter such as the LI-3000 (Li-Cor), non-destructive methods for determining leaf area are restricted to using leaf and geometric shapes, grids, dot counting, light interception and those based on linear measurements (6, 9). The problem is further complicated by the growth habit of the crop. During the first year of growth a ginseng plant has 1 leaf with 3 leaflets. The second year it usually has 5 leaflets, and in subsequent years 2, 3, or 4 leaves with 3 to 5 leaflets each (7). The palmately compound leaves form in a single terminal whorl. Mature plants usually have 5 leaflets per leaf (Fig. 1). The two outer smaller leaflets (1 and 5) are oval to suborbicular in shape with a round base and an acuminate apex. The three larger leaves (2, 3, and 4) are obovate-oblong to obovate with a round to acute base and an acuminate apex. Both leaflet types have serrated margins. As a crop matures it forms a canopy containing all ages of plants due to self-seeding.

Linear measurements have been used to estimate the area of compound leaves (6). Although methods based on linear measurements of leaves often require destructive subsampling from time to time, relatively few plants are destroyed. Leaf length (L) and width (W) are the most frequently measured leaf characteristics to be related to leaf area.

Materials and Methods

Three-year- old ginseng roots were planted in 12 cm pots containing a peat-perlite-vermiculite medium (Promix) on November 1, 1979, and placed in cold storage (7°C ± 2) to break dormancy. The plants were removed from storage on May 1, 1980, as they were beginning to sprout. Thirty plants were selected and placed in a growth chamber with a radiant flux density from 46.0 to 57.0 $\mu E\ m^{-2}s^{-1}$ with a 12 hr photoperiod. Night and day temperatures were 16 and 20°C, respectively. The relative humidity was set at 57%. The plants were watered as needed, alternately with deionized water and half strength Hoaglands solution. Ten plants with fully expanded leaves were selected on May 13. The number of leaves per plant varied from 3 to 4 with the number of leaflets per

[1]Received for publication July 22, 1980. This research was supported by the Natural Sciences and Engineering Research Council of Canada, Grant No. A6697. We are indebted to Mr. Walter Hellyer for supplying the ginseng roots and also for allowing access to his ginseng plantings.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[2]Present address: New Liskeard College of Agricultural Technology, New Liskeard, Ontario, Canada P0J 1P0.