

2. Bradfield, E. G. 1977. Extraction of calcium fractions from plant material. *Comm. Soil Sci. and Plant Anal.* 8:563-572.
3. Epstein, E. 1972. Mineral nutrition of plants: Principles and perspectives. Wiley, New York.
4. Hartmann, H. T., A. Tombesi, and J. Whisler. 1970. Promotion of ethylene evolution and fruit abscission in the olive by 2-chloroethanephosphonic acid and cycloheximide. *J. Amer. Soc. Hort. Sci.* 95:635-640.
5. Hoagland, D. R. and D. I. Arnon. 1950. The water culture method for growing plants without soil. *Univ. of Calif. Cir.* 347.
6. Klein, I., E. Epstein, S. Lavee, and Y. Ben-Tal. 1978. Environmental factors affecting ethephon release in olive. *Scientia Hort.* 9:21-30.
7. Poovaiah, B. W. and A. C. Leopold. 1973. Inhibition of abscission by calcium. *Plant Physiol.* 51:848-851.
8. Shaw, R. 1969. The influence of 2-chloroethane phosphonic acid (Ethrel) on maturation, ethylene production, and perianth dehiscence. *Proc. Assoc. Southern Agr. Workers Conf.* 66:203.
9. Sterry, J. R. 1973. The uses and potential of CEPA in fruit crops. *Acta Hort.* 34:489-495.

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## A Computer Simulation to Maximize Asparagus Yield<sup>1</sup>

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**Abstract.** A computer simulation of asparagus growth is developed and used to evaluate the effects of various harvest strategies on short and long term commercial yield of asparagus (*Asparagus officinalis* L.). At present asparagus is harvested until the canners stop buying, usually in the 3rd or 4th week of June in southern Michigan, purchase generally being terminated by the reduction of spear diameter (whips), increase in fiber content of the spears or opening of the bracts. The simulation shows that this strategy is economically optimal for any single year; however, if the grower terminates the harvest every year on June 1, then the average yearly yields are significantly greater than those derived from the previous strategy. Skipping strategies, in which the grower skips a harvest every n<sup>th</sup> year (2nd, 3rd, or 4th), produced significantly lower 15 year average yields than either of the other 2 strategies, but produced significantly greater yields per plant.

### Methods

Asparagus growth is dependent on light, temperature, nutrients, water and other biotic and abiotic factors (12, 13, 16, 4, 2, 15, 20, 10, 3, and 18). In addition, age and sex are important factors in determining the yield of a single plant (21, 7, 15, and 11), but lack of consistent information prevents their incorporation into the model at this time. Because of these constraints, the model was constructed and used to evaluate the qualitative rather than the quantitative effects of harvest strategies on plant yield. Consequently, the model simulates the growth of a typical 7 year old plant of indeterminate sex having 7 bud sites.

The structure of the model can be broken down into 3 periods: preharvest, harvest and postharvest (Fig. 1).

**Preharvest.** During this portion of the simulation, the user has the option to change default parameter values, to select a harvest strategy and to determine the number of plants to simulate and the length of simulation in years (Fig. 2). The subroutine WEATHER is called here and when executed reads in the current years maximum and minimum daily temperature, calculates average daily temperature and constructs arrays of minimum daily temperature and average daily temperature for use by the rest of the subroutines.

**Harvest.** This portion of the model is composed of the subroutine HARVEST, which carries out all harvest activity from spear emergence to termination of harvest (Fig. 2).

Although the first emergence of spears is of primary importance when calculating asparagus yield, due to the loss in yield

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<sup>3</sup>Rajzer, C. J. 1975. A study of asparagus buds: dominance and influence on spear size. A special class report for Horticulture 330, Michigan State University.

<sup>4</sup>Silver Mills. Shelby, Michigan. 1975 Asparagus Grade Guide.

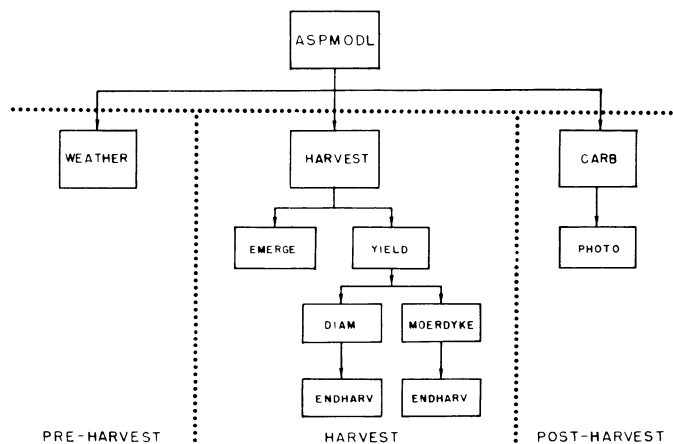


Fig. 1. Functional block diagram of asparagus simulation.

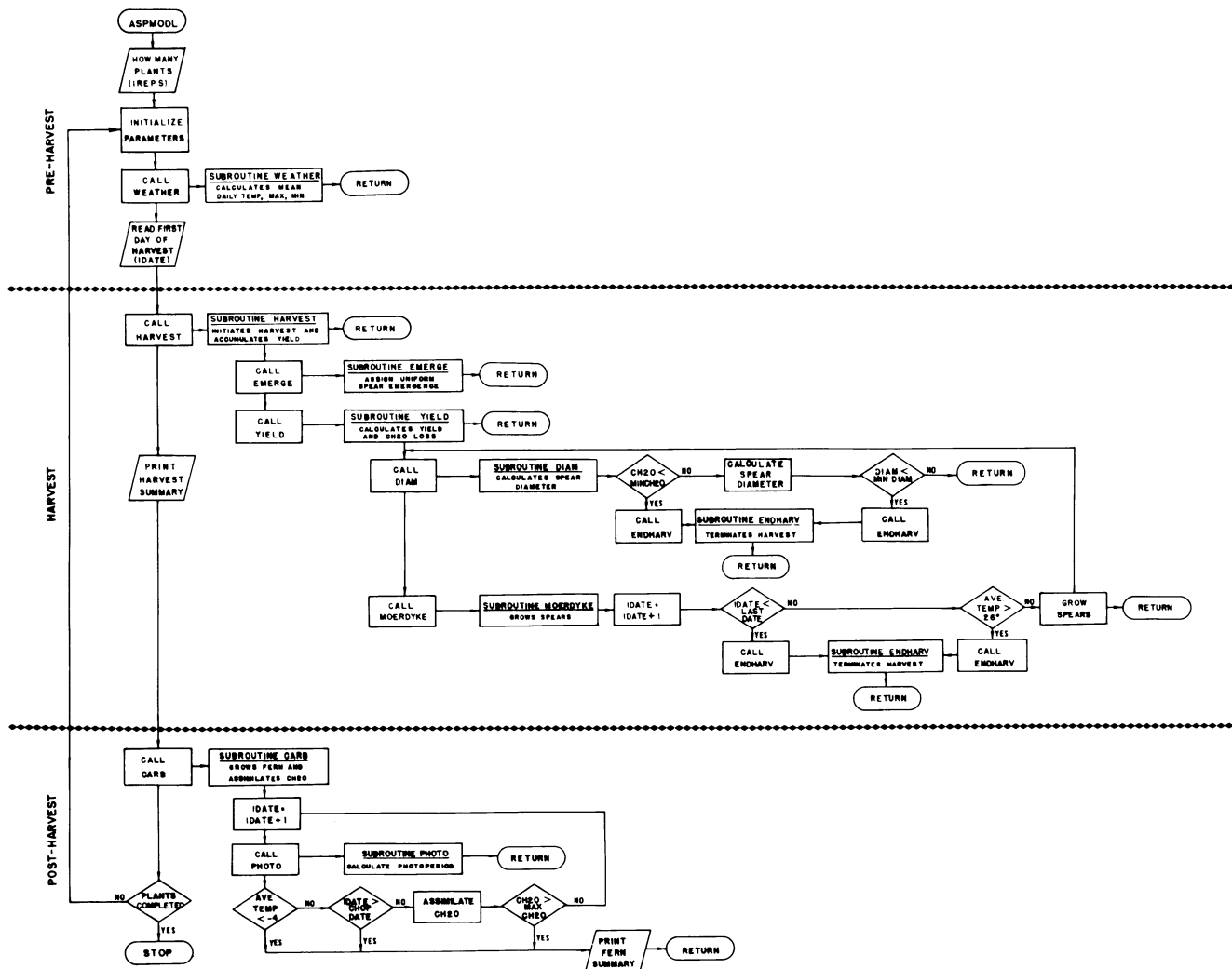


Fig. 2. Flow chart of asparagus simulation.

from freezing, little work has addressed this problem. LeCompte and Blumenfield (8) found increases in predictability of first spear emergence using degree days (1) over calendar date but reported "considerable error" even using degree days. Since this was the case, first spear emergence in our simulation begins on a user defined date (May 1 was used as default first emergence). After the emergence of the first spear, the distribution of primary spear growth activity from the other bud sites greatly influences yield. Data by Rajzer<sup>3</sup> indicate no dominance or significant order of spear initiation between the bud sites. Further, his data indicated a uniform distribution of primary spear growth activity over about a 12 day period. Therefore, in our simulation a random number generator was used to generate a uniform distribution of primary spear growth activity over a 12 day period (subroutine EMERGE). Since replicate runs differ in these initial dates of primary spear growth activity, they represent to some degree the observed variability among individual plants.

After initialization of primary bud growth at the 7 bud sites, the subroutine YIELD is accessed. This subroutine is responsible for growth and harvest of spears. When executed, YIELD calls the subroutine DIAM and spear diam is calculated.

Energy for growth of spears must come directly from the carbohydrates stored in the root. Tiedjens (22) states that spear production and size are dependent on these stored carbo-

hydrates. Also, Norton (14) found highly significant positive correlations between total cross sectional area of ferns in the fall and total cross sectional area of spears the following spring, while Ellison and Scheer (4) found similar correlations as well as a significant correlation between stalk index per plant in the fall and spear diam the following spring. These results indicate a relationship between spear diam and carbohydrate reserves. Since no data were available on spear diam through a season and carbohydrates, we were forced to look at % marketable spears. This was a decreasing sigmoid curve (H. Price, personal communication). We assumed that a Michaelis-Menten relationship existed between spear diam (D) and carbohydrate reserves above a minimum level ( $C_m$ ), and found the following equation to be sufficiently descriptive:

$$D = D_m(C - C_m)/(D_k + C - C_m), \quad [1]$$

where

- $D_m$  = maximum spear diameter,
- $C$  = current carbohydrate reserves,
- $C_m$  = minimum level of carbohydrate reserves for spear production, and
- $D_k$  = Michaelis-Menten parameter controlling form of equation.

Table 1. Default or initial parameter values for equations in text.

Parameter	Equation number	Initial/default value	Source
C	1	282.2 g	Scott, et al. (16) Table 14, p. 30.
C <sub>m</sub>	1	168.5 g	Scott, et al. (16) Table 14, p. 30.
D <sub>k</sub>	1	28.0 cm	Curve fitting to data from Dr. Hugh Price.
D <sub>m</sub>	1	2.8	Field observations.
d	3	.906	Laboratory measurements.
L <sub>r</sub>	3	7.62 cm	Segerlind (17), and field observations.
d <sub>c</sub>	4	.043 g/cm <sup>-3</sup>	Scott, et al. (16) p. 29.
L <sub>u</sub>	4	22.86 cm	7.62 cm suprasurface remains and 5.24 cm sub-soil remains. Takatori, et al. (20).
f <sub>e</sub> = f <sub>l</sub>	5	.20	Curve fitting to field observation.
K <sub>w</sub>	5	81.0 cm	Curve fitting to field observation.
R	6	.45 g/day	Curve fitting to field observation.
I	7	.40 cal cm <sup>-2</sup> min <sup>-1</sup>	Extrapolation of data by Downton and Törökfalvy (3).
P <sub>i</sub>	7	.898	Integrated proportion of day where Intensity > .40 cal cm <sup>-2</sup> min <sup>-1</sup> .
a	8	82.903	Multiple regression to data by Sawada, et al., (15), Table 1.
b <sub>1</sub>	8	8.140	Same as above.
b <sub>2</sub>	8	.064	Same as above.
f <sub>t</sub>	8	.0073	Curve fitting to field observation.

Default or initial values for these parameters and their source can be found in Table 1.

If the spears are not whips (diameter < .5 cm) or the carbohydrate reserves are above the minimal amount required for spear production, then harvest continues and spears are grown (Fig. 2).

Within the subroutine MOERDYKE, Julian date (IDATE) is incremented and spears are grown. Spear growth, a function of temperature and spear height, is calculated by the following equation as presented by Moerdyke (10):

$$G = 3.9092 + .3162 H + .6379 T, \quad [2]$$

where

- G = spear growth in cm/day,
- H = spear height in cm, and
- T = temperature in °C.

If Julian date is less than the user defined last date of harvest or branching has not occurred, then the spears are grown and yield calculated by the subroutine YIELD. Working (23) has shown that branching is a function of temperature. He found when average daily temperature was 24° or 40°C, branching occurred from 20 to 25 cm and 6 to 8 cm, respectively. Interpolating his data to a minimum harvest height of 11 cm, an average daily temperature of 26° caused branching in our simulation and terminated harvest.

The subroutine YIELD calculates both the asparagus yield to the grower and the loss of carbohydrates to the storage root. For a spear to be harvested, it must be greater than 18.6 cm in length. Any spear shorter than 18.6 cm can safely be allowed

to grow for another day. In Michigan, asparagus is harvested either by hand or with a sled. Segerlind (17) has shown a sharp reduction in force required to cut a spear as you go from 2.5 to 10 cm from the spear base, also the cutting blades in sleds are generally 6 to 8 cm above ground. Therefore, in our model a 7.6 cm portion of the spear remains after harvest. For a given spear of harvestable length, its wt (Y<sub>g</sub>) can be calculated by:

$$Y_g = (D/2)^2 \pi(L - L_r) (f) (d), \quad [3]$$

where

- D = spear diameter (cm),
- L = spear length above ground (cm),
- L<sub>r</sub> = remaining spear portion after harvest (cm),
- f = correction factor = spear volume/cylinder volume, and
- d = density of spear (g/cm<sup>3</sup>).

Default or initial values for these parameters and their source can be found in Table 1. After each harvest, the carbohydrate content in the harvested spear is computed and subtracted from the carbohydrate reserves. Either harvest or freezing terminate spear growth and contribute to carbohydrate depletion. The loss of carbohydrates (C<sub>1</sub>) from the root reserves used in production of the spear is calculated by:

$$C_1 = (D/2)^2 \pi[(L - L_r) (f) + L_u] (d) (d_c), \quad [4]$$

where

- C<sub>1</sub> = loss of carbohydrates,
- L<sub>u</sub> = unharvested length of spear, and
- d<sub>c</sub> = density of carbohydrates in g/g spear fresh wt.

Default or initial values for these parameters and their source can be found in Table 1. It is assumed there is no resorption of carbohydrates by the storage root.

*Postharvest.* Since the yield of asparagus is a function of carbohydrate reserves (14, 22, 4, and 15) and these reserves are produced by the previous years ferns, it is important in a simulation to include postharvest activity. In our simulation, the subroutine CARB models this activity.

When executed, CARB increments the Julian date, calculates daily photoperiod, grows the asparagus fern and assimilates carbohydrates. The amount of carbohydrates produced and stored in the root depends on spear diameter at the end of the season (14 and 4), light intensity (cal cm<sup>-2</sup> min<sup>-1</sup>), photoperiod, temperature and weight of photosynthetically active tissue (15).

In the simulation, the basal diameter of the spear is used as the diameter for the fern, which in turn is used to calculate max leaf weight. By weighing all leaves on 6 year old plants, Sawada et al. (15) found an average fresh weight of leaves of 630 g and 497 g for staminate and pistillate plants, respectively. These were averaged for our simulation and the following equation used to predict max leaf wt per fern:

$$W_m = f_1 D / (K_w + D), \quad [5]$$

where

- f<sub>1</sub> = parameter controlling maximum value of equation,
- D = spear diameter (cm), and
- K<sub>w</sub> = Michaelis-Menten parameter controlling the form of the equation.

Due to the lack of data, these parameters and the exact equation form could not be determined. Therefore, a Michaelis-Menten relationship was assumed and the 2 parameters adjusted to produce the desired range of output. Default or initial values for these parameters are listed in Table 1.

Leaf weight growth is assumed to behave logistically (9) as a function of leaf weight and time and described by:

$$\frac{dw}{dt} = RW (W_m - W)/W_m, \quad [6]$$

where

R = intrinsic rate of growth, and  
W = current weight of fern leaves.

The default value for R is listed in Table 1. Scott et al. (16) observed a reduction in carbohydrates of 100 g per plant as a result of fern production over a 28 day period. In our simulation, no attempt was made to represent this decline. Instead, each plants' carbohydrate reserve is depleted by 100 g over a 28 day period to account for the loss due to fern production.

Data by Downton and Törökfalvy (3) indicates that as irradiance increases the rate of increase in the photosynthetic activity decreases. This implies that photosynthesis becomes light saturated. Since photosynthesis was still increasing in the range of their experiment, we selected .40 cal cm<sup>2</sup> min<sup>-1</sup> as the irradiance at which photosynthesis saturates (2.75 times reported range). Therefore, total cal (K) available for photosynthesis were calculated by:

$$K = PIp_i, \quad [7]$$

where

P = daily photoperiod in minutes,  
I = light saturation irradiance (cal cm<sup>-2</sup> min<sup>-1</sup>), and  
p<sub>i</sub> = proportion of area under normal solar intensity curve where value > I.

Default values of I and p<sub>i</sub> are shown in Table 1. The amount of carbohydrates assimilated (C) is in turn calculated from the following equation:

$$C(t+1) = [f_T T(a + b_1P + b_2 K)(W)] + C(t) \quad [8]$$

where

f<sub>T</sub> = curve parameter,  
T = Degree days > 5.6°C,  
a+b<sub>1</sub>P+b<sub>2</sub>K = multiple regression for CH<sub>2</sub>O assimilation per 5 g leaf weight, and  
W = weight of fern leaves.

See Table 1 for values and sources of parameters.

Carbohydrates continued to be assimilated by the ferns until death or until the storage roots capacity for carbohydrates is reached. There are 2 causes of fern death in our simulation: 1) an average daily temperature below -1.1°C will freeze the fern, or 2) the grower chops the fern. In Michigan, growers frequently chop the asparagus ferns in the fall to prevent excess accumulation of snow which retards spring field access. Since asparagus root growth from year to year is not well documented, it was necessary to set an upper limit to the amount of carbohydrates stored in the roots. Morse (12) reported that up to 56% of the asparagus roots' dry weight was carbohydrates and Scott et al. (16) found from 36% to 43% in a variety of treatments. Shelton (18) examining the storage of soluble storage carbohydrates in 3 year old plants in Michigan, found a range of % from 20% to 74% under a variety of lengths of harvest. Due to this variety in %, we allowed a max storage level of 350 g/plant; which allowed for a 25% increase in storage (16). In multiple year runs, overwinter carbohydrate losses due to respiration must be examined. The model accounts for overwintering respiration loss of carbohydrates by multiplying the final fall carbohydrate reserves by 0.932, this allows for 6.8% of the reserves to be used for overwinter survival. Although no actual data on asparagus was found, the value of 0.932 came from unpublished data on winter loss in another perennial, common goldenrod (P. A. Werner, personal communication).

Certain other factors that may be important to asparagus

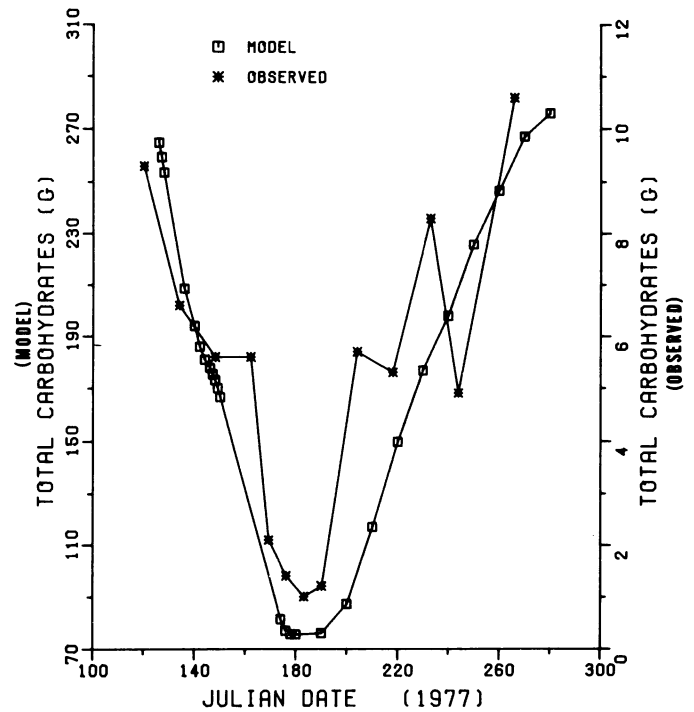


Fig. 3. Comparison of total carbohydrates in the asparagus crown. Observed results (Shelton 18) are oven dry weight of 2 year old crown. Model results represent fresh weight of 7 year old crown.

growth and yield include herbivory, disease, nutrients and certain other cultural practices. However, due to the lack of data, the desire to keep the model simple, and the qualitative rather than quantitative nature of the model, we felt omission of these factors would have little effect on the harvest strategies.

## Results and Discussion

After a simulation model has been constructed, one is confronted with the task of validation of results. This is generally very difficult since most of the available data has gone into the simulation's construction. We were fortunate in that an independent data set was made available for validation for several of the intermediate model results (18).

Since the level of carbohydrates in the storage root was a very important variable in our model, it was an essential parameter to validate. In Fig. 3, the total carbohydrate reserves

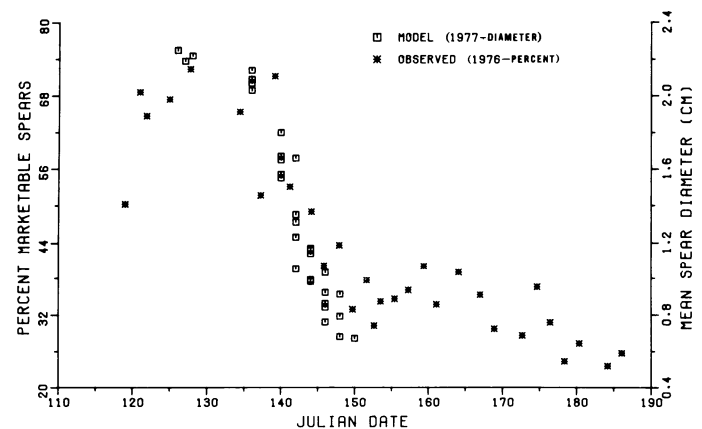


Fig. 4. Comparison of spear diameter (model) with percent marketable spear (Shelton 18).

from our simulation are compared to data by Shelton (18). Since the data were collected at the Michigan State University, Horticulture Research Farm in 1977, 1977 East Lansing weather information was used for the simulation. The differences in magnitude of the curves are of little concern since the observed values are oven dry weight of 2 year old crowns, whereas the model's output represents fresh weight of 7 year old crowns. Rather, what should be considered is the overall similarity in the shape of the curves. In this respect there is close agreement between the simulation and the observed values.

Another important consideration is the size of the spears. Since the length of the harvested spears is limited by the range of acceptability of the buyers<sup>4</sup>, the only other variable to determine spear size is diameter. No data could be found on the average spear diameter throughout a season -only on % marketable spears. In Fig. 4, the observed % marketable spears/harvest (18) is compared to the mean spear diameter as calculated in the simulation. Here validation can only be made through deductive reasoning. Since the % of marketable spears refers to the % of spears >0.5 cm, it is therefore a function of spear diameter. As this % decreases, the average spear diameter must also decrease. Since the curves are approximately similar, one can conclude an adequate fit.

Weight/spear and number of spears/plant must also be examined. The average weight/spear from the simulation, using the 1977 East Lansing weather, varied from 35.4 (± 4.97 SE) to 41.3 (± 5.35 SE) g/spear for the 5 plants simulated. Takatori et al. (19) reported 44.0 (± 1.26 SE) and 44.4 (± 1.35 SE) g/spear from 4 year old crowns at 2 nitrogen levels. This is in close agreement with our simulation results. From these simulations, the average of 25.6 (± .87 SE) spears/plant is well within the range reported by Ellison and Schermerhorn (5) of 20 to 28 and 18 to 32 for 4 and 5 year old crowns, respectively.

To evaluate the long term effects of harvest strategies on yield, several multi-year simulations were run using various harvest strategies. Weather information for East Lansing, Michigan from 1959 to 1973 was used for these simulations. Each strategy was replicated 5 times to represent 5 plants. These replications will differ somewhat because each replicate has a unique random emergence of spears which will attain harvestable size at different dates and may suffer greater or lesser freezing losses.

Fig. 5 represents the average yearly yield of 5 plants simulated over this 15 year period harvested every year until June 10. This illustrates the variation in yield between years and the range of output for the model, which is in agreement with other authors (6, 5, 4, and 11).

According to this 15 year simulation, the greatest average yield/year is obtained by harvesting every year but terminating harvest on June 1 (Table 2). If harvest is terminated either too early (May 21) or too late (June 10), then the average yearly yield is much less. With the exception of harvesting every year until June 10, skipping strategies produced significantly lower average yearly yield than harvesting every year (Fig. 6). Skipping strategies, however, did produce greater yield/plant, especially when harvested past June 1 (Table 2). The cause of the reduction of average yearly yield through skipping strategies is generally due to the lower number of harvests (up to harvest only 50% of the time). The increased yield/plant is due to the resting, which allows buildup of carbohydrate reserves. Analysis of variance for yield/plant indicated highly significant effects on yield due to harvest strategy ( $F_{3,48} = 25.35, P < 1\%$ ) and last date of harvest ( $F_{2,48} = 123.49, P < 1\%$ ). Highly significant effects on yield/year were also observed with harvest strategy ( $F_{3,48} = 702.83, P < 1\%$ ) and last date of harvest ( $F_{2,48} = 481.18, P < 1\%$ ).

Through careful choice of harvesting strategies, i.e. skipping

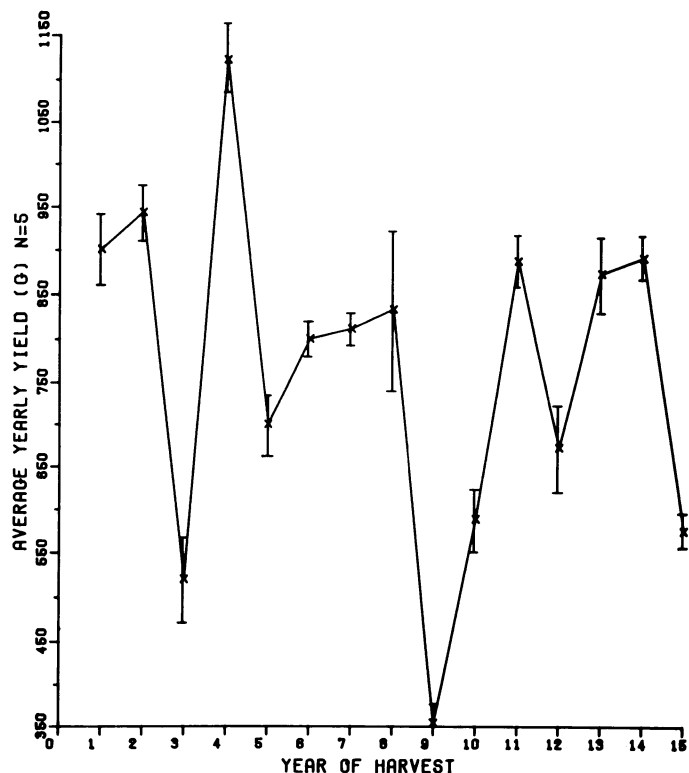


Fig. 5. A 15 year simulation of average yearly yield of 5 asparagus plants harvested every year until June 10 (mean ± 1 SE).

years of terminating harvest early, a grower should be able to maximize asparagus yield. The simulation suggests that ending harvest on June 1 (2 or 3 weeks before buying stops) provides a greater long term yield than allowing the plants to produce spears until the canners terminate their purchases. One factor that may have significant impact on the strategy used over many years is the price the growers receive for their crop. Losing much of a crop to severe weather (e.g. spring freezes) may tempt the grower to continue harvesting past June 1. The economics of asparagus production could readily be incorporated into the model by inserting alternative strategies dependent upon data describing the economic situation of a particular year.

Table 2. Effects of various harvest strategies on mean yield per plant and mean yield per year from 15 year simulations.

Last harvest date	Harvest strategy	Mean yield per plant (g)	Mean yield per year (g)
May 21 (141)	Every year	822.718 DE <sup>z</sup>	822.718 H
May 21 (141)	1 out of 2 years	626.184 G	360.560 A
May 21 (141)	2 out of 3 years	858.094 D	570.148 B
May 21 (141)	3 out of 4 years	722.880 F	608.774 C
June 1 (151)	Every year	1008.834 BC	1008.834 I
June 1 (151)	1 out of 2 years	935.726 C	582.344 B
June 1 (151)	2 out of 3 years	1098.852 A	754.240 G
June 1 (151)	3 out of 4 years	982.382 BC	781.088 G
June 10 (161)	Every year	766.432 EF	766.432 G
June 10 (161)	1 out of 2 years	1037.276 AB	677.416 E
June 10 (161)	2 out of 3 years	1003.298 BC	713.694 F
June 10 (161)	3 out of 4 years	817.972 DE	642.692 D

<sup>z</sup>Mean separation within columns by Student-Newman-Kuels, 5% level.

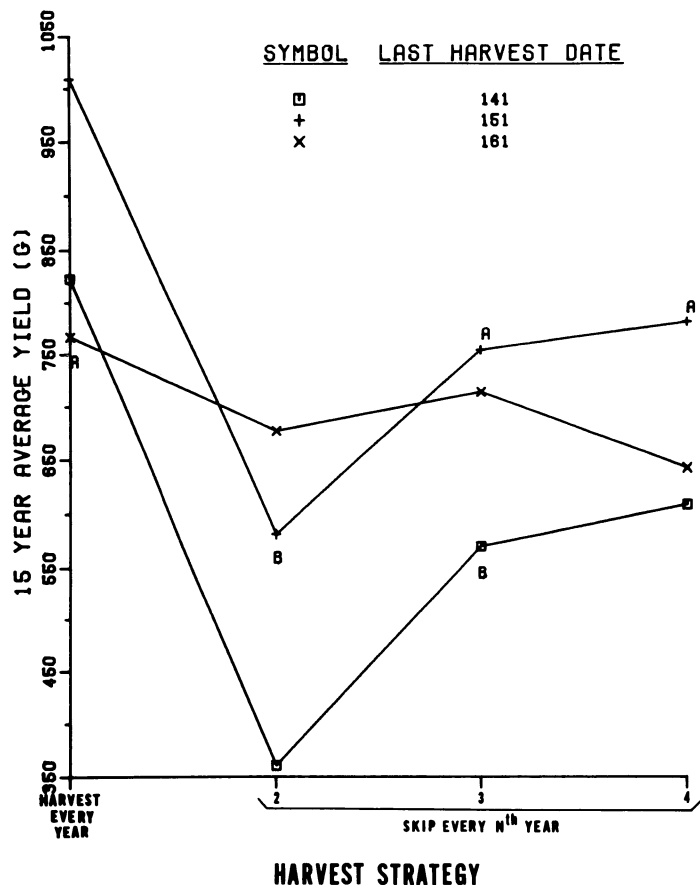


Fig. 6. The effects of various harvest strategies on average yearly yield for a 15 year simulation of 5 plants. Points followed by same letter are not indistinguishable by Student-Newman-Kuels, 5% level.

### Conclusions

The model predicts yields of spears which are quite close to field values (16, 5, 4, and 11). However, the purpose of the output is not so much absolute yield prediction as harvest strategy evaluation. A limitation of the latter is that this is a maximal yield model, and not concerned with catastrophe-avoidance which a farmer might wisely prefer to minimize his risk of crop failure at the cost of returning sub-optimal yields.

More research is needed to clarify biological mechanisms and make validation of this or any other asparagus model possible. The only across-seasons state variable at present is storage root carbohydrate level. This needs to be understood as a composite function of available water and nutrients, insects, disease and so forth, instead of merely calendar date and harvesting strategy as at present. Storage root growth, bud site proliferation, pre-emergent growth of spears through the harvest season, and fern growth need more adequate formulations. More research is needed to describe the functional relationships among root weight, root age, and fern photosynthetic potential as affected by light intensity, photoperiod, developmental

threshold and leaf weight. Finally, much historical data is needed from long-term validation plots, monitored under different controlled inputs.

Although the model at present is far from the level of completeness that would be readily useful to the farmer, it does serve to point towards needed research, and it suggests the testable hypothesis that shorter harvesting periods may maximize long-term yield.

### Literature Cited

- Baskerville, G. L. and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperature. *Ecology* 50:514-517.
- Blumenfield, D., K. W. Meiden, and S. B. LeCompte. 1961. A field study of asparagus growth. *Amer. Soc. Hort. Sci.* 77:386-392.
- Downton, W. J. S. and E. Törökfalvy. 1975. Photosynthesis in developing asparagus plants. *Austral. J. Plant Physiol.* 2:367-375.
- Ellison, J. H. and D. F. Scheer. 1959. Yield related to brush vigor in asparagus. *Proc. Amer. Soc. Hort. Sci.* 73:339-344.
- \_\_\_\_\_ and L. G. Schermerhorn. 1958. Selecting superior asparagus plants on basis of earliness. *Proc. Amer. Soc. Hort. Sci.* 72:353-359.
- Haber, E. S. 1932. Effects of size of crown and length of cutting season on yields of asparagus. *Iowa J. Agric. Res.* 45:101-109.
- Jones, H. A. 1932. Effects of extending cutting season on asparagus. *Calif. Agric. Expt. Sta. Bul.* 535:1-15.
- LeCompte, S. B. and D. Blumenfield. 1958. Degree-days used to predict time of asparagus heavy cut. *N. J. Agr.* 40:12-13.
- Milthorpe, F. L. and J. Moorby. 1974. An introduction to crop physiology. Cambridge Univ. Press, New York.
- Moerdyke, D. 1972. A growth model for asparagus. MS Thesis, Michigan State Univ. East Lansing.
- Moon, D. M. 1976. Yield potential of *Asparagus officinalis* L. *N. J. J. Agric. Res.* 19:435-438.
- Morse, F. W. 1916. A chemical study of the asparagus plant. *Mass. Agr. Expt. Bul.* 171:265-296.
- Nightingale, G. T. and L. C. Schermerhorn. 1928. Nitrate assimilation by asparagus in the absence of light. *N. J. Agric. Expt. Sta. Bul.* 476:1-24.
- Norton, J. B. 1913. Methods used in breeding asparagus for rust resistance. *Bul. U.S. Dept. Agr. Bur. Plant Ind.* 263.
- Sawada, E., T. Yakowa, and S. Imakawa. 1962. On the assimilation of asparagus ferns. Proc. XVI Intern. Hort. Congress. Vol. II p. 479-483.
- Scott, L. E., J. Mitchell, and R. McGinty. 1939. Effects of certain treatments on the carbohydrate reserves of asparagus crowns. *S. C. Agr. Expt. Sta. Bul.* 321:5-37.
- Segerlind, L. 1973. Physical measurements of toughness. Mich. State Univ. Agr. Expt. Sta. Res. Rpt. 217:12-13.
- Shelton, D. R. 1978. Effects of stresses on growth and yield of asparagus (*Asparagus officinalis* L.) MS Thesis, Mich. State Univ. East Lansing.
- Takatori, F. H., G. W. Cannell, and G. W. Asbell. 1970. Effects of soil moisture conditions on asparagus at two nitrogen levels. *Cal. Agr.* 24(2):10-12.
- \_\_\_\_\_, J. Stillman, and F. Souther. 1974. Influence of planting depth on production of green asparagus. *Cal. Agr.* 28(1):4-5.
- Tiedjens, V. A. 1924. Some physiological aspects of *Asparagus officinalis*. *Proc. Amer. Soc. Hort. Sci.* 21:129-140.
- \_\_\_\_\_ 1926. Some observations on root and crown formation in *Asparagus officinalis*. *Proc. Amer. Soc. Hort. Sci.* 23:189-196.
- Working, E. B. 1924. Physical and chemical factors in the growth of asparagus. *Ariz. Agr. Expt. Sta. Tech. Bul.* 5:86-124.