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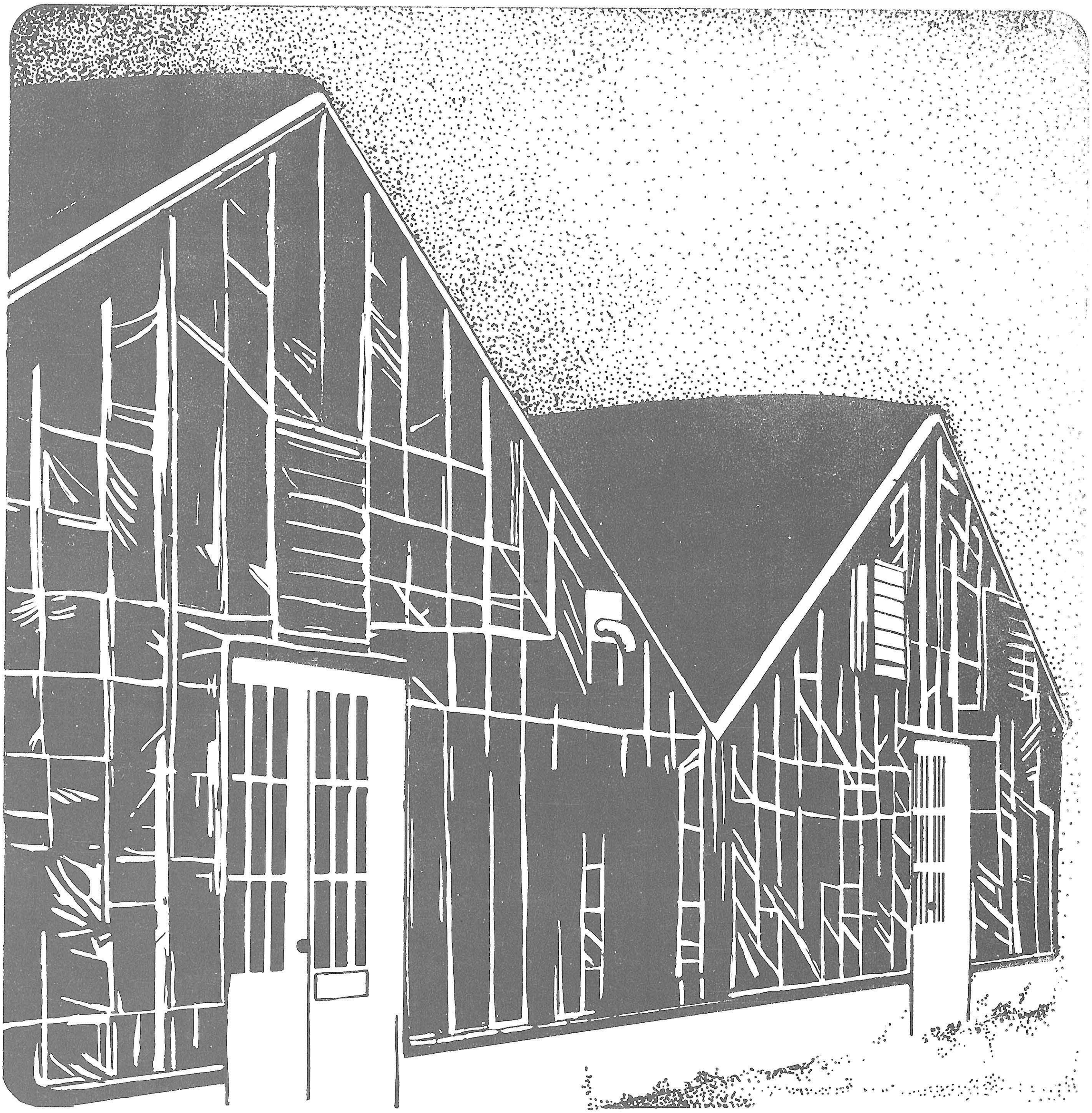
MANAGEMENT PRACTICES TO CONSERVE ENERGY IN OHIO GREENHOUSES



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management practices to reduce energy usage per crop

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Energy management in greenhouse operations is using the least possible fuel in the structure and producing the most salable product per unit of energy. For most operations, the major emphasis should be to minimize energy losses and consumption through a sound maintenance program and greenhouse modifications.

Many of these recommendations appear in "Conserving Energy in Ohio Greenhouses" by Phillip C. Badger and Hugh A. Poole (OARDC Special Circular 102 and OCES Bulletin 651, November 1979).

The intent of this publication is to explain changes in management practices that can increase greenhouse production and energy efficiency. These techniques can decrease energy costs in relation to the total costs of production and increase the operation's profits.

The authors, Hugh A. Poole, former assistant professor, horticulture; and Phillip C. Badger, former research associate, agricultural engineering, express appreciation to Priscilla Gresser, technical assistant, Department of Horticulture, and to James D. Farley and Charles Powell, associate professors, plant pathology, Ohio Agricultural Research and Development Center, and The Ohio State University, for their assistance in the preparation of this manuscript. The authors also thank Ted H. Short, associate professor, agricultural engineering; Harry K. Tayama, professor, William M. Brooks, professor, William L. Bauerle, associate professor, and John C. Peterson, assistant professor, horticulture, for their reviews of the manuscript and comments. Special thanks are extended to Robert G. Hill, Jr., professor and associate chairman of the Department of Horticulture for his patience and encouragement.

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1 management practices to reduce total greenhouse energy use

Several management practices can reduce the total greenhouse energy use (Table 1). Generally they require matching favorable plant responses with minimum acceptable temperatures at plant level. In some instances, production schedules will have to be altered and new crops or cultivars grown in this changed environment. Most recommendations provide a range of temperatures for optimum growth of specific crops (Example: 56°-60°F). A savings can be achieved by growing plants at the lower but acceptable range, but the margin for error is greatly reduced. Heat distribution has to be uniform over the cropping area and thermostat location.

Likewise, there are alternatives for live steam sterilization of soil if done thoroughly and properly. Where markets exist for them, growers may switch to crops that require cooler growing temperatures. Many older greenhouses that cannot economically be made energy efficient may either be closed during the winter or renovated for other purposes such as holding areas or sales areas that do not require year-round high temperatures. Management practices will offer only limited energy savings but are easily incorporated into most production programs. However, recommendations will not necessarily be feasible for all greenhouse-grown crops.

TABLE 1. Management Practices to Reduce Greenhouse Energy Usage.

Management Practice	Annual Energy Savings for Greenhouse: Average	Range
Lower night temperature	10%	5-25%
Alter growing schedules	5%	0-15%
Split night temperatures	10%	5-15%
Separate propagation area	5%	0-15%
Soil heating	5%	0-15%
Raised beds or benches	10%	0-20%
Disinfestation of soil		
—Chemicals or sterile pre-mix	4%	2-10%
—Aerated steam	2%	1-5%
Alternative cool crops	25%	15-40%
Production area converted to holding or sales area	30%	0-50%
Close greenhouse for part of winter	30%	0-50%

Lower Day/Night Temperatures

Possible Annual Savings — 5 to 25% (10% Average)

If a uniform temperature already exists throughout the greenhouse, and the optimum day/night temperatures for the crop are being maintained, little is gained by lowering the night temperature. But if the night temperatures are higher than necessary, fuel savings are possible. A 3°F reduction can reduce annual fuel requirements by approximately 9 percent in Ohio.

Decreasing night temperatures will reduce annual fuel consumption by approximately 3 percent for each 1°F (Table 2). A grower should not reduce night temperatures without checking the heating system for accuracy and reviewing crop recommendations (Fig. 1). Providing less than optimum temperatures may actually increase fuel consumption for the crop by lengthening the cropping time and/or reducing total yields.

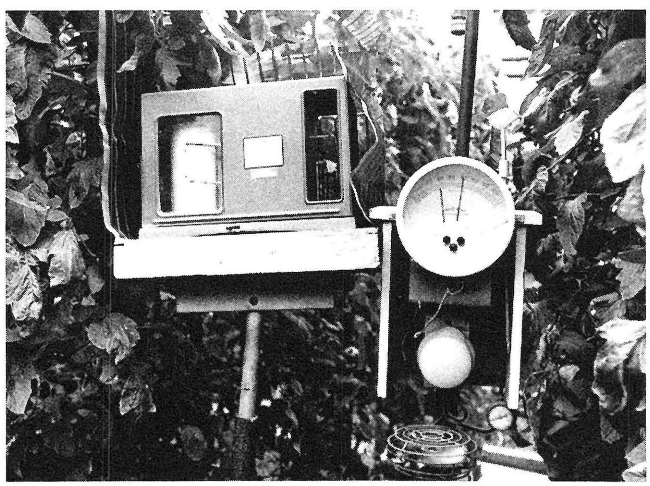

Figure 1. All temperature sensors and controllers should be sheltered from direct sunlight and fan aspirated. Recommended night temperatures should always be maintained at crop level for optimum response. The equipment should be checked periodically for accuracy.

Critical periods occur during seed germination, propagation, floral initiation and development, and fruit set and fruit maturation. At these times plants are very sensitive to night temperature. Temperatures above or below the optimum will inhibit development and reduce quality. At other physiological stages of development, plants are less

TABLE 2. Predicted Annual Dollar Savings from Lowering Operating Temperatures for a Year-round Greenhouse Operation.

	Temperature (°F) Reduction					
Heating Cost $ per Year	1°	2°	3°	4°	6°	8°
$ 10,000	$ 300	$ 600	$ 900	$ 1,200	$ 1,800	$ 2,400
$ 25,000	750	1,500	2,250	3,000	4,500	6,000
$ 50,000	1,500	3,000	4,500	6,000	9,000	12,000
$100,000	3,000	6,000	9,000	12,000	18,000	24,000
$250,000	7,500	15,000	22,500	30,000	45,000	60,000

* Based upon a 3% fuel savings for each 1°F reduction in temperature (24 hours).

TABLE 3. Typical Northern Ohio Bedding, Floral Plant Schedules[1]

Plant	Seeding Date	Germinating (Emergence) Days	Germinating (Emergence) Temp. °F.	Growing-on Days	Growing-on Temp. °F.	Hardening Days	Hardening Temp. °F.	Transplanting Date	Transplanting Temp. °F.	Selling Period
Ageratum	1/7	6	60	10	60	10	50	2/7	60	4/10-20
	4/30	5	75	8	65+	8	65+	5/22	65+	6/5-15
Alyssum	1/26	4	75	10*	60	5	50	2/14	60	4/10-20
	4/29	4	75	5	65	10	50	5/19	60	6/10-20
Aster	2/22	4	75	10	60	—	—	3/10	60	4/15-20
	5/6	4	75	10	60	—	—	5/22	65	6/10-15
Begonia	12/12	21	75	21	60	—	—	2/14	60	4/12-5/1
Coleus	1/5	8	75	20	60	7	55	2/11	62	4/15-25
	4/30	5	75	12	65	—	—	5/17	62+	6/10-20
Dusty Miller	12/15	18	75	21	60	—	—	1/28	60	4/5-20
Geranium, seed	1/2	6	75	21	60	—	—	2/4	60	4/12-30
Impatiens	1/3	6	80	21	60	—	—	2/4	62	4/12-30
Marigold										
Dwarf	1/5	8	70	10	60	12	50	2/8	60	4/10-20
Moonshot	1/5	8	70	10	60	12	50	2/8	60	4/15-25
Dwarf	5/1	6	70	6	60	10	60	5/23	60	6/10-25
Pansy	10/16	10	75	15	55	12	45	11/23	50	3/20-4/20
	11/6	10	75	15	55	12	45	12/15	50	3/20-4/25
	1/14	7	75	7	55	12	50	2/15	58	4/15-5/1
Petunia & Snapdragon	11/20	6	75	10	60	16	45	12/26	50	3/25-4/5
	12/3	5	75	7	55	16	45	1/20	50	4/10-20
	12/12	5	75	7	55	16	45	1/30	50	4/20-30
	2/7	5	75	5	55	12	45	3/2	55	4/30-5/5
	2/25	5	75	5	55	12	55	3/18	55	5/5-12
	3/15	5	75	5	55	12	55	4/10	55	5/15-20
	4/1	5	75	5	55	12	55	4/22	60	5/25-30
	4/7	5	75	5	55	12	60	4/30	60	5/25-6/5
Phlox	12/21	12	65	21	55	—	—	2/15	55	4/15-5/5
Portulaca	1/23	4	75	14*	60	12	50	2/25	60	4/20-30
	4/30	4	75	8	60	—	—	5/12	65	6/10-15
Salvia	1/24	6	75	6	55	6	50	2/12	60	4/10-20
	5/2	6	75	8	60	—	—	5/17	65	6/15-20
Snapdragon (see Petunia)										
Vinca	12/15	12	75	3	55	14	55	2/15	60+	5/1-6/1
Verbena	12/29	7	75	21	55	14	55	2/15	55	4/15-5/1

* Crops are often direct-seeded into final container to reduce transplanting delays and costs.

[1] Adapted from Brooks, W.M. *et al*. 1979. *Tips on Growing Bedding Plants.* Ohio Coop. Ext. Serv. Bul. No. MM-265.

sensitive to reduced temperatures. For instance, temperatures are commonly reduced to harden off seedlings after germination is complete. Many greenhouse crops can have a cool finish without delaying harvest. In many cases, crop quality and/or post-harvest characteristics are improved.

Schedules for commonly grown floral and vegetable bedding plants are given in Tables 3 and 4 as examples. If good growth conditions exist, the lower range in most recommendations can be used effectively.

TABLE 4. Typical Northern Ohio Bedding, Vegetable Plant Schedules[1]

Plant	Seeding Date	Germinating (Emergence) Days	Germinating (Emergence) Temp. °F.	Growing-on Days	Growing-on Temp. °F.	Transplanting Date	Transplanting Temp. °F.	Selling Period
Broccoli	2/7	5	75	10	55	2/21	55	4/1-10
	2/28	5	75	10	55	3/14	55	4/15-5/1
Brussel Sprouts	2/7	5	75	10	55	2/21	55	4/1-10
	2/28	5	75	10	55	3/14	55	4/15-5/1
Cabbage	2/7	5	75	10	55	2/21	55	4/1-10
	3/7	5	75	10	55	3/21	55	4/15-5/1
Cauliflower	2/7	5	75	10	55	2/21	55	4/1-10
	2/28	5	75	10	55	3/14	55	4/15-5/1
Celery	1/10	10	70	12	55	2/1	55	4/5-20
	2/10	10	70	12	55	3/1	55	5/1-15
Cucumber	4/25	7	80	*		5/1	65	5/15-25
	5/20	7	80			5/26	65	6/5-15
Eggplant	2/4	7	80	10	60	2/21	60	4/5-20
	3/4	7	80	10	60	3/21	60	5/1-15
Lettuce, head	2/10	6	70	8	55	2/25	55	4/5-15
	3/1	6	70	8	55	3/15	55	4/25-5/5
Muskmelon (Cantaloupe)	4/25	5	80	*		5/1	65	5/15-25
	5/20	5	80			5/25	65	6/5-15
Onion	2/4	10	70	*		2/20	55	4/5-15
	3/4	10	70			3/10	55	4/25-5/5
Parsley	1/10	14	70	10	55	2/1	55	4/5-20
	2/10	14	70	10	55	3/1	55	5/1-15
Pepper	2/4	7	80	10	60	2/21	60	4/5-20
	3/4	7	80	10	60	3/21	60	5/1-15
Tomato	3/28	7	80	7	60	4/11	60	5/15-30
	4/11	7	80	7	60	4/25	60	5/20-6/5
Tomato, hybrid	3/7	7	80	7	60	3/21	60	5/15-30
	4/8	7	80	7	60	4/18	60	5/20-6/5
Watermelon	4/25	5	80	*		5/1	65	5/15-25
	5/20	5	80			5/25	65	6/5-15

* Crops are often direct-seeded into final container to reduce transplanting delays and costs.
[1] Adapted from Brooks, W.M. *et al*. 1980. *Tips on Growing Bedding Plants.* Ohio Coop. Ext. Serv. Bul. No. MM-265.

Examples of recommended night temperature ranges for several crops during different development phases are the following:

1. Poinsettias:
   a. 70 to 75°F, propagation in August (two to three weeks)
   b. 65 to 68°F, vegetative growth in September (two to four weeks)
   c. 60 to 62°F, flower initiation in late September and early October (10 to 14 days)
   d. 65 to 68°F, flower and bract development in October and early November (four to six weeks)
   e. 60 to 62°F, finishing and color development in November (one to three weeks)
   f. 56 to 58°F, holding the crop for late or delayed sales.

2. Chrysanthemum:
   a. 68 to 75°F, propagation (10 to 14 days)
   b. 65 to 68°F, vegetative growth (10 to 14 days)

c. 60 to 62°F, floral initiation and development (four to six weeks after short days begin)
d. 56 to 58°F, cool finish for most cultivars will often improve quality (last two to four weeks)

3. Bedding Plants:

a. 70 to 75°F, germination (three to 21 days)
b. 60 to 62°F, hardening-off before transplanting
c. 58 to 65°F, vegetative growth dependent upon species
d. 45 to 55°F, hardening-off prior to sale

Caution: Do not reduce night temperatures until you have checked the accuracy of your heating system and are familiar with the specific crop requirements and recommendations.

Alter Growing Schedules

Possible Annual Savings—0 to 15% (5% Average)

Shifting the growing schedule to take advantage of the plentiful sunlight of early spring or fall can reduce fuel requirements. Earlier fall plantings, although increasing total production time of greenhouse crops, require less fuel during both the early stages of the crop, when higher temperatures are necessary, and the latter stages of development when cooler temperatures can be tolerated. In general, a better quality product can be produced.

To overcome the late start when planting later in the spring, a crop may have to be grown at higher night temperatures. However, warmer outdoor temperatures, higher light intensities, and longer spring days should reduce the total fuel requirement for these crops by increasing plant growth rates.

A grower should investigate other cultivars that may be more adaptable to these altered crop schedules or that reach maturity in a shorter time.

Caution: Some pot crops (such as poinsettia) started earlier than recommended in the fall may become too tall if not properly controlled by recommended growth regulators or other cultural factors including fertilization, watering and light intensity.

Split Night Temperatures

Possible Annual Savings—5 to 15% (10% Average)

Several research institutions in the United States (University of Connecticut, Colorado State University and North Carolina State University) and Europe (England and Holland) are investigating "split night temperatures." Instead of lowering the thermostat to a constant setting throughout the night, a relatively high temperature (60 to 65°F) is maintained for four to eight hours, then dropped to a much cooler (40 to 50°F) "holding" level until dawn. Crops grown during the summer require only eight to 10 hours of darkness to sustain metabolic processes necessary for growth. However, growers provide 14 to 16 hours of warm night temperatures in the winter to accomplish the same objective.

The major advantage of this system is a modest fuel savings with only a few days delay in crop harvest. Since most of the metabolic processes necessary for growth are achieved during the warm period, plant metabolism can be retarded during the cooler period without slowing growth.

Another variation being evaluated in England is to reduce the night temperature drastically (40 to 45°F) for only one night of each week and delaying harvest slightly. The maximum fuel savings would be dependent upon the grower's ability to predict the coldest night of each week.

Caution: Most of the research on split-night temperatures has centered upon scheduling with specific crops. In most year-round crops, such as chrysanthemums, roses and tomatoes, many varied physiological activities occur continuously in the same greenhouse. The effects of split-night temperatures on floral initiation, fruit set and early stages of flower or fruit development have not been fully studied.

Separate Propagation Area

Possible Annual Savings — 0 to 15% (5%) Average)

When propagation and seed germination took place on a few benches in the open greenhouse, success was often variable and depended upon raising soil temperature to the desired level. However, with higher fuel costs and more intensive production requirements, propagation and seed germination require an area that can be controlled separately from the production range. The first few weeks of a plant's life will often determine the final product's quality and yield.

The propagation area should have heat under the bench, separate controls and misting capabilities. Since propagation requires a comparatively small area, money invested in supplemental lighting and CO_2 will provide great dividends at minimal cost. Some growers have built elaborate growth rooms to germinate seeds of many crops and to provide a product uniformity year round that is unobtainable in the greenhouse.

The major advantages of this technique are: 1) a more uniform product, 2) reduced crop time during winter, 3) fuel savings due to lower temperatures in the rest of the range, or 4) use of the range for alternative production.

Caution: The economics of this system is dependent upon maximum space used and adherence to a well-programmed schedule.

Use Soil Heating

Possible Annual Savings — 0 to 15% (5% Average)

Root temperature is often more critical than air temperature for good crop production. As the objective of a soil heating system is to provide for temperature control in the root zone of crops grown directly in greenhouse beds, soil heating can be used on such crops as chrysanthemums, roses, tomatoes, cucumbers and lettuce. If the soil can be levelled, pot crops and bedding plants can also benefit from soil heating (Fig. 2).

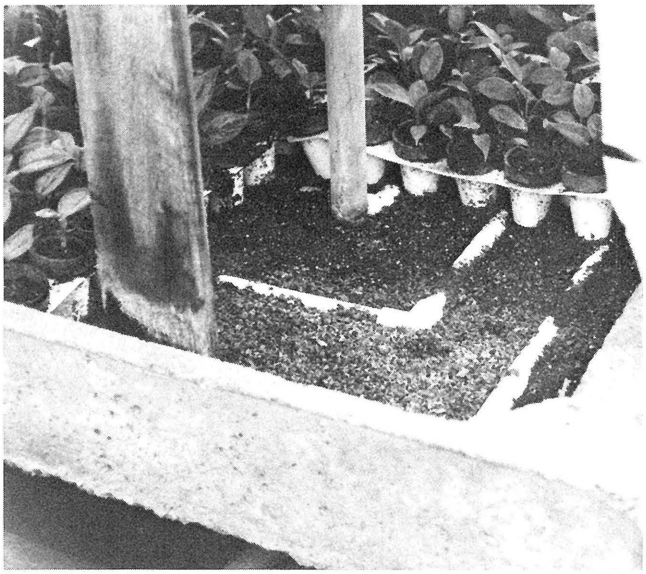

Figure 2. These foliage plants are being propagated on raised benches that are heated by warm water in plastic pipes.

Heating lines of one-inch diameter, heat-resistant plastic are placed at a depth of 12 inches and on 12-inch centers. Europeans use 18 to 24-inch depths and 18 to 24-inch centers with milder climatic conditions. The water temperature in the tubes should not exceed 104°F after the soil surface has reached 70°F.

Electrical heating cables are often used in hot frames and propagation beds for soil heating. Approximately 12 to 15-watt output should be provided for every square foot of area at a maximum depth of four to six inches. Waterproof propagation mats can also be used where cables are not appropriate or convenient. Thermostats should be provided to assure optimum temperature control.

A major objective is to distribute the heat uniformly within the soil to achieve optimal crop production conditions. Soil heating is difficult to regulate in a short period, as the soil temperature reacts very slowly to an increased heat supply. Heating pipes should not become too warm, for the soil around the pipes may either get too warm or dry out and act as an insulation layer.

The initial capital cost of such a system can be relatively high and its capacity to heat the greenhouse is relatively limited. During severely cold weather, soil heating may contribute only 5 to 10 percent of the heat requirements of the greenhouse, yet under milder conditions, 25 to 30 percent of the heat requirements may be met by soil heating. Considerably more fuel can be saved by coupling soil heating with reduced air temperatures. Therefore, if air temperatures are not lowered, soil heating can be justified by the commercial operator only on the basis of improved crop yield.

Caution: If using soil heating, be sure that heat lines are below the level where soil is tilled during ground preparation. Plastic piping may restrict or prohibit normal steaming operations. Beware of a high ground water table that will carry the heat away.

Raise Beds or Benches

Possible Annual Savings—0 to 20% (10% Average)

Because of their location and mass, ground beds stay colder than raised beds and so require more fuel for optimum growth. Large volumes of soil stabilize at temperatures near nighttime levels with little daytime fluctuation in the winter. However, the temperature of smaller volumes of soil follow air temperatures. Thus, container-grown crops on raised benches are more fuel-conserving than raised-bench crops, and greater savings can be achieved over ground-benched crops.

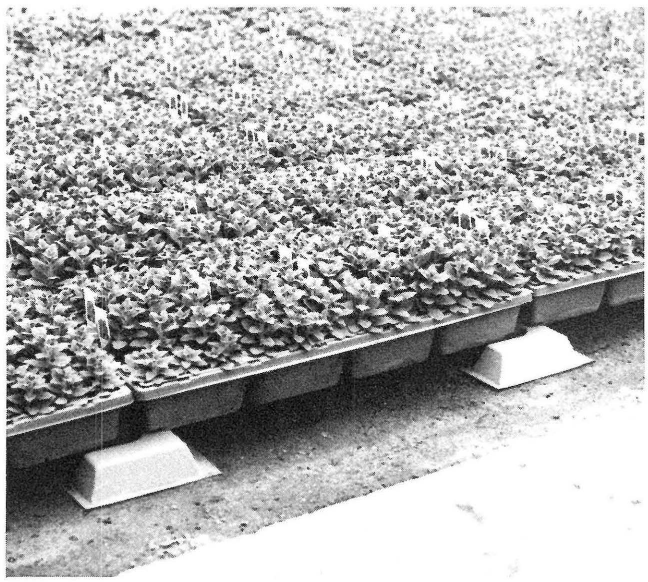

Figure 3. Plastic risers for bedding plant flats effectively keep plants off the cold ground but also promote better aeration and ventilation around the plants.

Bedding plants benefit by placing flats on small risers (Fig. 3), although they raise the flats only one to two inches above the cold ground. Such cut flowers as chrysanthemums, carnations, snapdragons, tulips and even roses have been successfully grown in containers, often on raised benches. The peat bags (Fig. 4) and the nutrient film technique (Fig. 5) used for growing tomatoes and cucumbers are variations of this concept being researched and developed in Ohio and elsewhere.

Disinfest Soil

Possible Annual Savings—2 to 10% (4% Average)

By James D. Farley and Charles C. Powell*

Growers realize that many pest problems begin with the use of pest-contaminated growth media. To correct these problems, most growers sterilize the growing media by either heat or chemicals. In temperate regions, growers have traditionally treated media with steam at 212°F. Because of increasing costs of fuel and other limitations of steam sterilizing, growers and university researchers are attempting to develop alternative methods of soil treatment and plant growing systems.

Alternatives include treating soil with aerated steam or chemicals or growing crops in soil-free media not requiring sanitation. The relative costs, merits and methods of application of each technique will be discussed in this section. Examples of ground bed, bench, and batch treatments will be given.

Steam Sterilization of Ground Beds or Potting Soil

The objective of any soil treatment is to eradicate all pests, including weeds, insects and pathogens, with minimal effects on soil structure and beneficial microorganisms. The release and accumulation of materials toxic to plant growth should also be prevented when treating soil. Soil steaming at 212°F plus is the only *disinfesting method* that can be relied on to completely destroy all bacteria, viruses, fungi, nematodes, weeds and insects. But heat treatment at these temperatures may adversely affect soil structure, release materials into the soil that are toxic to plant, and be extremely costly. Another disadvantage of steam treatment is that all the beneficial microorganisms are killed creating a biological vacuum. The first microorganism to enter steamed soil will take over and, if it is a pathogen, severe disease losses may occur.

Figure 4. Some crops, such as tomatoes and cucumbers, grow well in bags of soilless media placed on the greenhouse soil. The medium stays warmer, and steam sterilization of ground beds is eliminated.

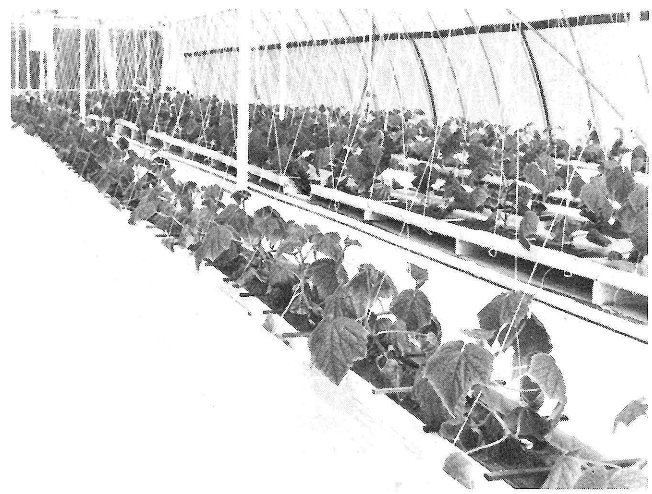

Figure 5. The nutrient film technique for growing crops hydroponically is an effective way to control root temperature by controlling ambient temperature and/or nutrient solution temperature (most efficient).

Beds can be steamed by the buried-tile or surface-steaming methods. The tile method consists of rows of perforated clay or plastic drain tile laid 10 inches below the soil surface in 18-inch centers connected to steam distribution headers. The initial installation cost is high, but once in place it will last for many years and require less operating labor than other systems. Tile systems provide uniform soil heating to depths of at least two feet and is also a costly method. Recent estimates of fuel usage (natural gas) during 1979 for tile steaming in vegetable greenhouses in Ohio were 1700 MCF (1000 cu. ft.) per acre. With the 1979 average costs of $3 per MCF, fuel costs for sterilization were $5,100 per acre.

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Some growers, whose greenhouses do not have permanent tile systems, surface steam. The major disadvantage of this method is that soil is rarely treated below 12 inches in sandy soils or eight inches in clay loam soils. Many crops quickly root below the treated zone and are exposed to infection by root rots, wilts and nematodes. However, with shallow-rooted crops such as flowers, surface steaming is generally satisfactory. Surface steaming is mainly useful in eliminating weeds, damping off, crown rot diseases and insect pests. Steaming to sanitize potting soils is also widely used. Using natural gas, at $3/MCF, the cost will be from $6 to $7 a cubic yard. As with bed steaming, results can be variable and should be monitored. A limitation is that it will take three to four hours to do a batch of soil and have it cool enough to use.

Despite limitations, steam sterilization continues to be important in the treatment of ground beds where aerated steam treatment may not be possible or where virus and bacterial control is necessary.

Aerated-Steam Sanitation of Potting Soils

It has been known for 30 years that soil-borne plant pathogenic fungi, bacteria, nematodes, weed seeds and most viruses are killed by heating soil at 140°F for 30 minutes. Until the development of aerated steam, however, it was not commercially feasible to treat soil at temperatures below live steam (i.e., 212°F). The introduction of air into a steam flow enables one to adjust the temperature of the resulting aerated steam to a predetermined level. Aerated-steam treatment has major advantages over live steam treatment and is particularly useful in treating soil benches and bulk soil. Unfortunately, a practical, aerated-steam treatment procedure has not yet been developed for ground-bed growing systems. These growers must still treat with steam or soil fumigants.

The principle of aerated-steam treatment of soil is to force a mixture of air and steam adjusted to 160°F through soil so that the soil mass heats to 160°F within 30 minutes. As noted above, 140° has been shown to be theoretically sufficient, but 160°F is usually prescribed for safety.

Equipment requirements for aerated-steam treatment of soil mixes are a source of steam, a blower for air, a hose for transporting the air-steam mixture to the soil and a soil container. The quantity of steam and the blower size required to heat the soil varies with the initial soil temperature, soil moisture content, quantity, density and thermal conductivity of soil mix treated and the time in which it must be heated. High pressure centrifugal blowers are generally the most satisfactory for supplying air. The blowers are sized according to the amount of air delivered (expressed as cubic feet per minute—cfm) for an equivalent static or back pressure produced as the air is forced through the soil (expressed as inches of water).

Guidelines have been published in "Treating Soil, Soil Mixtures, or Soil Substitutes with Aerated Steam" by R.A. Aldrich, P.J. Wuest and J.A. McCurdy, Special Circular 182, The Pennsylvania State University, University Park, Pennsylvania. One successful grower system in Ohio used a blower with a cfm of 1,400 at a back pressure of 28 inches of water to treat 4.0 cubic yards of mix of equal parts of soil, peat and perlite to a temperature 160°F in approximately 30 minutes. The blower was used in conjunction with a 100 hp boiler with a two-inch steam line. In another example, Ken Baker of the University of California, Berkeley, has reported that a blower capable of delivering 1,250 cfm at six inches of water will adequately treat 2.6 cubic yards of a mix of equal parts of peat, fir bark and fine sand. From these examples and by referring to the recommended Aldrich publication, a grower should be able to estimate a blower and steam boiler size necessary to meet his needs.

In Ohio, many growers steam their mixes in a dump truck bed. This bed with a few modifications could be converted for air-steam treatment. Important changes in the bed construction are required in converting from live steam to aerated steam because one is changing from a heat diffusion process to a forced air process. A rigid bed cover, preferably of metal, must be constructed. The cover must be tightly fastened with a seal between cover and bed to prevent leaks. Aerated steam is introduced into the bed through an inlet in the cover. Aerated steam should be pushed *down through* the soil to prevent channeling and "blow-outs" that may occur when treatment is from below. Soil in the bed should rest on a perforated expanded metal floor or plenum a few inches above the truck bed floor. Provisions must be made for an exhaust portal for the aerated steam. This is most conveniently the dump door at the end of the bed.

Within the last decade aerated-steam treatment of soils has proved to be feasible and economically desirable. The practice has, however, not been widely accepted commercially. The attitude prevails that if 140°F to 160°F will kill pathogens, 212°F will do a better job. It has, however, been shown by researchers and growers that air-steam pasteurization at a lower temperature is the most desirable.

Advantages—Steam vs. Aerated Steam

1. There is less chance of destroying soil microorganisms antagonistic to plant pathogens when treating soil at 140-160°F rather than 212°F.
2. Toxicity of soil to plants that is often induced by steaming at 212°F does not occur when treated at 140-160°F.
3. There is approximately a 60 percent reduction in the quantity of steam used. This means lower cost and greater treatment capacity with a given boiler.
4. The soil heats more rapidly and evenly to the required temperature.

5. The soil cools more rapidly to temperatures suitable for handling or planting when treated to 140-160°F than to 212°F. By turning off the steam and continuing the air flow, the temperature may be lowered even more quickly by evaporative cooling.
6. The danger to workers is reduced.

Soil Fumigation of Ground Beds and Potting Soils

Because of the increasing costs and scarcity of fuel, growers are considering soil treatment by fumigants as an alternative to steam. Soil fumigants are volatile chemicals that, when applied to soil, emit toxic fumes that penetrate the air spaces in soil in sufficient concentration to kill microorganisms. They are broad spectrum biocides, poisonous to most microbes, plants, insects, weed seeds and animals. Fumigants are generally applied to control nematode-incited diseases, root-rots and wilts caused by fungi and weeds.

The major advantage of soil fumigation over steam treatment is cost. Greenhouse growers in warmer climates where steam is not used for heating have long used fumigant chemicals to treat soils. Although the results have not been as effective as with steam treatment, on the whole they have been satisfactory. With the high volatility chemicals such as methyl bromide where the material has to be sealed with a plastic cover, the material costs (chemical and plastic) are $800 per acre. If the material is custom applied, the cost is $1,200 per acre.

For potting soil, fumigation is another sanitation method. Methyl bromide is sufficiently heavy to penetrate a soil pile 18 to 24 inches deep. Of course, it must be tarped with four- to six-mil plastic. Also, the pile should be on plastic or concrete to serve as a seal at the bottom. Some growers fumigate sandy mixes in cement mixers. It costs about $1.75 per pound of fumigant per cubic yard of soil.

There are, however, several major disadvantages to fumigation which growers should consider. These are:

1. Soil fumigants are extremely toxic to plants and animals. In many cases, they are best applied by professional applicators.
2. Because of fumigant toxicity, all plants must be removed from the greenhouse prior to treatment.
3. Soil fumigants are ineffective in controlling diseases caused by bacteria and viruses.
4. There is often a 10- to 14-day waiting period after fumigation before planting.
5. If bromide-containing fumigants such as methyl bromide are used, bromide-sensitive plants cannot be planted.

Plants sensitive to bromide residues in soil mixes include:

Ageratum	Iberis
Alyssum	Lettuce
Antirrhinum	Lobelia
Aster	Matricaria
Calendula	Myosotis
Celosia	Nemesia
Chrysanthemum	Nierembergia
Cleome	Portulaca
Coleus	Salpiglossis
Coreopsis	Salvia
Dahlia	Tomato
Dianthus	Verbena
Digitalis	Viola
Godetia	Vinca
Helichrysum	

For a complete description of soil treatment by fumigation read "Soil Fumigation," Ohio Cooperative Extension Service publication L-249.

Alternatives to Soil Sterilization

Alternatives are available to reduce substantially the cost of soil sterilization. One system used in bed growing is "bag culture" in which crops are grown in a plastic bag of presterilized soil mix. After each crop, the mix can be resterilized by steam or aerated-steam. The volume of media treated on a per plant basis is much less than on plants grown in ground beds. For example, most tomato growers steam sterilize to depths of two feet or approximately 87,000 cubic feet per acre (2 x 43,500 square feet). If the plant population is 10,000 per acre, 8.7 cubic feet of soil is sterilized per plant. In the bag system, each plant is grown in 0.75 cubic feet of soil mix; thus, the steam requirements are 11.6-fold less than steaming ground beds. On a dollar basis, the cost of fuel to steam treat the bag mix would be $439/10,000 plants vs. $5,100/10,000 plants grown on ground beds (natural gas prices at $3/MCF). If the bag mix were treated with aerated steam to 160°F rather than live steam, the grower would realize a further 60 percent savings for a total of $263. The bag system of growing is increasing steadily in Western Europe, and preliminary results in the United States show that crop yields and quality are equivalent to soil growing.

Work has been done in Europe with growing vegetable crops and some cut flowers in a hydroponic system called nutrient film technique (NFT). The crops are grown in a thin film of water that completely eliminates the need to sterilize. This method is still in the development stage and cannot yet be recommended to Ohio growers.

Many pot plant growers are now using a soilless media. Peat mixes are usually, but not always, sanitary prior to use. Hardwood barks that are composted will become clean through heat and/or chemicals during composting. The excellent aeration and drainage characteristics of bark or other soilless mixes will usually control soil fungi even if the mix is not completely sanitary. In addition, microbes that enter a bark pile during and after composting may compete with or antibiologically check development of root rotting fungi.

Conclusion

Soil sanitation is the most basic means of pest management we can practice in the greenhouse. The cost of the energy to sanitize soil is minor when compared to the cost of root diseases or of hand pulling weeds. Even so, there are ways to decrease sanitation energy costs. Each has advantages and disadvantages to be considered.

Change to Alternative Cool Crops

Possible Annual Savings—15 to 40% (25% Average)

Some growers have the potential to grow and market cooler crops or grow "cooler cultivars" (Table 5). This is far more advisable than to grow warm crops at less than optimum temperatures. A 10°F-reduction in greenhouse temperatures should reduce fuel consumption by approximately 25 to 30 percent. However, if the crops require a longer cropping time and/or have lower yields, this alternative should be carefully weighed. Likewise, the market for a cooler crop such as lettuce instead of tomato may be saturated quickly resulting in reduced prices and profits. Another concern is that many cooler flowers (cyclamen, cineraria, calceolaria, primula, alstroemeria and freesia) are not as readily accepted in the marketplace by the retailer and consumer, so a commitment in this direction must be coupled with an intensive marketing program. It would be both foolish and "fuelish" to grow a crop, even at cooler temperatures, that could not be sold. Other costs and production factors must be considered before selecting a cooler crop. These include labor and space requirements as well as overall profitability.

Convert Production Area to Holding or Sales Area

Possible Annual Savings — 0 to 50% (30% Average)

Many small retail growers attempt to grow a wide variety of crops in the same greenhouse. The production may not be economical because of the small numbers of each crop grown and having to compromise the different temperature, light, and other environmental conditions that result. If these crops are available from wholesale sources, the

TABLE 5. Minimal Recommended Night Temperatures for Selected Floral Crops

40°F

Anemone
Erica
Ranunculus
Tulipa
Viola

45°F

Calceolaria
Calendula
Gypsophila
Primula

50°F

Alstroemeria
Antirrhinum
Callistephus
Citrus
Cyclamen
Cymbidium
Dendrobium
Dianthus
Freesia
Heuchera
Lathyrus
Lupinus
Myosotis
Odontoglossum
Paeonia
Schizanthus
Senecio (floral initiation)
Solanum (fruit coloring)
Streptocarpus

55°F

Celosia
Centaurea
Cypripedium
Delphinium
Exacum
Fuchsia
Gerbera
Hyacinthus
Iris (forcing)
Mathiola (floral initiation)
Miltonia
Muscari (forcing)
Paphiopedilum
Pelargonium
Petunia
Tropaeolum
Zantedeschia

60°F

Achimenes
Alternanthera
Ardisia
Asparagus
Astilbe (forcing)
Begonia
Brassavola
Bromeliad
Calceolaria
Cattleya
Chrysanthemum
Cissus
Coleus
Cosmos
Crassula
Dahlia
Euphorbia
Ficus
Gardenia
Grevillea
Hedera
Hippeastrum
Hoya
Hydrangea (forcing)
Kalanchoe
Laelia
Lilium (forcing)
Mathiola (growing & forcing)
Narcissus (forcing)
Oncidium
Phlox
Rhododendron (forcing)
Rosa
Salvia
Senecio (forcing)
Tulipa (forcing)
Verbena
Vinca
Zebrina
Zinnia
Zygocactus

65°F

Aglaonema
Anthurium
Araucaria
Aspidistra
Browallia
Cactus
Caladium
Calanthe
Capsicum
Codiaeum
Cordyline
Diffenbachia
Dracaena
Eucharis
Ferns
Fittonia
Hyacinthus (forcing)
Impatiens
Lantana
Maranta
Pandanus
Peperomia
Phalaenopsis
Philodendron
Saintpaulia
Sansevieria
Sinningia
Strelitzia
Vanda

greenhouse can be insulated and used as a sales area for the retail trade rather than as a production unit. Since it would not be necessary to encourage plant growth, cooler temperatures could be used for most crops. The retailer should profit by offering a wider selection of plants, and better quality and displays, as well as enjoying lower fuel bills.

The wholesale grower could achieve similar savings by bringing in mature plants and either acclimating them or holding them for short periods of time at lower temperatures.

Close Greenhouse for Part of Winter

Possible Annual Savings—0 to 50% (30% Average)

It may be more profitable to close down some or all houses part of the winter when fuel supplies are short or too costly to maintain production. Many greenhouses are already empty or inefficiently run during the summer months. Growers generally sell the most during the spring and late fall. In fact, some growers are financially strapped during January, February, and March when their cash flow is consumed by fuel bills (Table 6). Before closing the greenhouse for part of the winter, however, consider some of the following disadvantages that may occur as a result of this action:

1. Loss of production and income;
2. Difficulty in re-entering the market each year, as other growers pick up accounts of the grower who is out of production;
3. Unless carefully preplanned, loss of plants already in place as well as loss of time and material resources expended on those plants;
4. Need to drain water pipes and steam lines to prevent freezing;
5. Providing for snow removal from unheated greenhouse roofs

By using progressive spacing and prefinished crops, parts of the greenhouse can be used for production as needed, and the rest can be run very cold. As spring approaches, the operation can go to full production. With careful planning and programming, reduced winter-heated greenhouse space would not have an adverse effect upon spring sales.

Caution: Some crop schedules may have to be adjusted.
Check with your insurance agent before proceeding. Your insurance may be nullified for an unheated greenhouse.

TABLE 6. Monthly Fuel Usage by Glass Greenhouse Growers in Ohio As a Percent of Annual Usage

Month		Percent Usage
October		8
November		14
December		18
January		18
February		13
March		11
April		7
May		2
June		2
July		1
August		1
September		5
	Total	100

2 management practices to reduce energy usage per crop

Management practices to increase greenhouse productivity may also reduce the energy requirement per crop unit (Table 7). In many instances, savings in labor and capital will be realized due to the increased productivity. These recommendations require extensive manager's attention and planning to succeed. However, the increased profitability potential should be well worth the investment of time and money. These recommendations illustrate means to reduce the total amount of heat required per crop unit (pound, bunch or pot) without necessarily reducing the fuel requirements of the greenhouse unit. This requires increasing productivity and/or turnover in the greenhouse and ultimately results in a profitable operation. The concepts presented in this bulletin require an intensive approach to greenhouse production and careful attention to detail. Failure to plan and organize scheduling, labor needs, cultural requirements and marketing can be disastrous for the greenhouse manager. However, close attention to details, accurate organization and accurate observation can reap tremendous rewards. These recommendations will not be equally feasible for all greenhouse-grown crops.

Improve Space Utilization

Possible Annual Savings—

Staggered spacing 10 to 20% (15% Average)
Progressive spacing 0 to 35% (20% Average)
Hanging crops 0 to 50% (20% Average)
Crops under bench 0 to 25% (10% Average)
Multiple shelves 0 to 60% (30% Average)
Movable bench tops 0 to 50% (25% Average)
Ferris wheel 0 to 50% (30% Average)

One obvious way to reduce fuel usage per plant unit is to use every possible cubic foot of heated

TABLE 7. Management Practices to Reduce Crop Energy Usage

Management Practice	Potential Energy Savings/Crop Unit Average	Range
A. Improving space utilization		
staggered spacing	15%	10-20%
progressive spacing	20%	0-35%
hanging crops	20%	0-50%
crops under benches	10%	0-25%
multiple shelves	30%	0-60%
moveable bench tops	25%	0-50%
ferris wheels	30%	0-50%
B. Prefinish crops	20%	0-50%
C. Reduce crop unit size	5%	0-10%
D. Grow Improved cultivars:		
cooler growing cultivars	10%	5-25%
more productive cultivars	10%	0-40%
shorter cropping times	5%	0-25%
E. Use supplemental lighting	10%	0-40%
F. Add supplemental CO_2	10%	0-40%
G. Preheat irrigation water	5%	0-20%
H. Harvest crops prior to market maturation	10%	0-20%
I. Reduce crop and marketing losses	5%	0-30%

greenhouse space. Many of these suggestions will require additional labor, planning, and perhaps result in reduced light intensities. The type of benching system used in the greenhouse will determine the available production area and overall energy efficiency as shown in Table 8 and Figure 6.

Staggered Spacing

Many growers insist on straight rows and columns of plants as a matter of neatness and principle. A spacing recommendation for 10-inch centers suggests rows of plants 10 inches apart and columns also 10 inches apart that would provide a square of 100 square inches of space per plant. However, plants grow in a circular pattern rather than a square. A spacing arrangement for 10-inch centers using circles would require only 79 square inches of space per plant. This comparison is illustrated in Figure 7. Using a staggered spacing as shown may crowd the aisles somewhat, but whereas 85 rows of standard spacing may fill a bench, 100 similar rows can be spaced in a staggered manner and still provide the same circular diameter for each plant. A comparison of spacing systems and approximate spacing for some common spacing recommendations is provided in Table 9.

Progressive Spacing

Just as temperature and light requirements are geared to specific crops, space requirements also should match the physical needs of the crop (Fig. 9). In order to reduce labor needs, many crops are potted and placed at final spacing when the crops do not use all of this space until nearer harvest time. For example, considerable savings can be accrued by harvesting flowering pot mums from December to May, if they are grown at close spacing for four weeks (8 inches x 8 inches), wider spacing for four weeks until disbud time (12 inches x 12 inches), and final spacing for the last four weeks (14 inches x 14 inches). (See section on Lower Day/Night Temperature.) These periods or moves can be coordinated with temperature and light requirements and offer great potential for fuel savings and supplemental lighting. Since these moves can be coordinated with cultural requirements, some or all aisles may also be used for production space, achieving even greater fuel savings and reducing overhead expenses. Progressive spacing of crops shows tremendous potential but must be coordinated with well-organized planning and efficient operation, or timing and labor costs can destroy fuel cost savings.

A common means of assessing space requirements and related production costs is to multiply the square footage required by the number of weeks required. This will give the number of square-foot-weeks required for each plant. Table 10 provides values commonly used in the greenhouse for standard and staggered spacings and summarizes them into square foot-weeks. Table 11 provides some typical examples of a 12-week crop

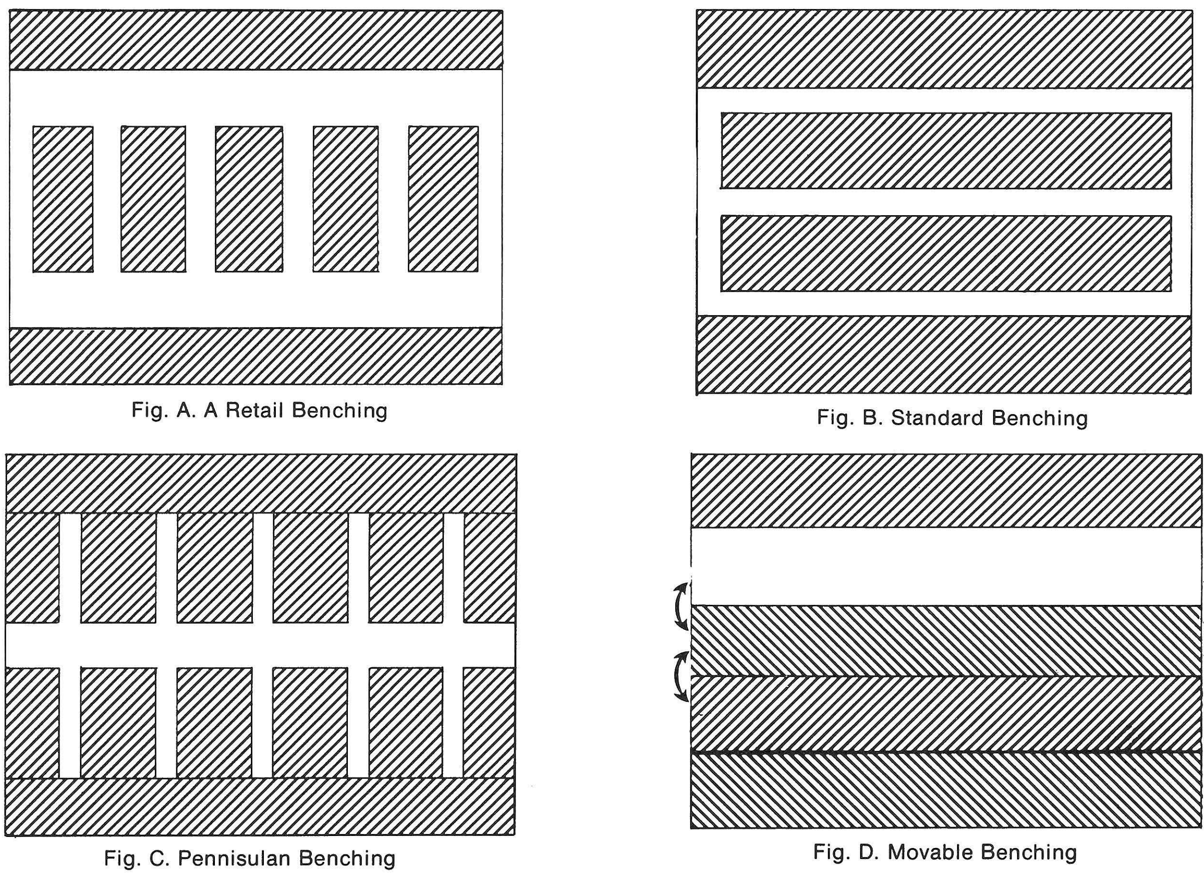

Fig. A. A Retail Benching

Fig. B. Standard Benching

Fig. C. Pennisulan Benching

Fig. D. Movable Benching

Figure 6. Common benching arrangements in greenhouses.

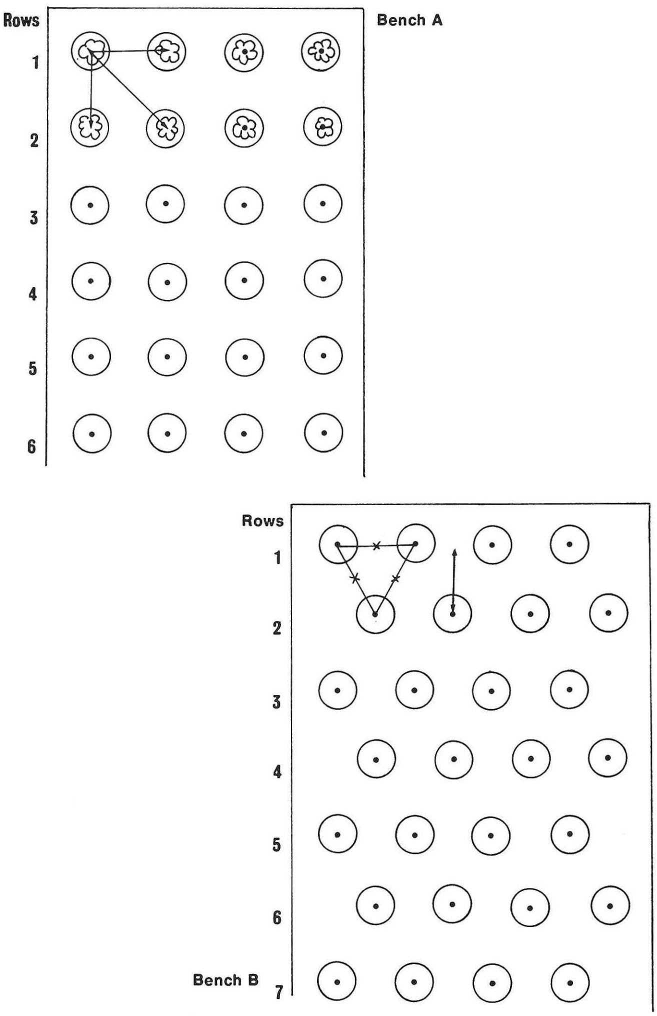

Figure 7. Spacing arrangements for standard and staggered systems with a common spacing distance. Note that approximately 15 percent more rows and plants can be placed on Bench B (staggered) than on Bench A (standard).

such as chrysanthemum or poinsettia on a no-move standard spacing system compared with staggered spacing using multiple moves in the progressive spacing. A relatively simple two-move system such

Figure 8. Cut chrysanthemums, as well as other crops, can be progressively spaced by growing them vegetatively in containers at close spacing and then transferring and spacing them to other beds or benches for flowering.

as example 5 will reduce the square foot-weeks required by 31 percent (standard spacing) or 41 percent using staggered spacing compared with a no-move, standard-spaced crop. Obviously, space savings are not profitable unless additional crops are grown in the space (no empty benches in a heated greenhouse).

Hanging Crops

Many growers have been using overhead space by growing hanging baskets over the aisles and crops (Figs. 9 and 10).

Whenever possible, hanging pots or baskets should be over the aisles so that drainage water does not harm the crop below them. Automatic water systems are highly desirable and often necessary. If a high light requiring crop is the main

TABLE 8. Effects of Benching System and Space Use on Fuel Consumption and Production Area.

Type of Benching System	Percent Usable Production Area	Comparable Fuel Use/Sq. Ft. of Production Area	Greenhouse Area Required To Provide 10,000 Sq. Ft. of Production Area (Sq. Ft.)
Retail (Wide Aisles & Narrow Benches)	50-60	2.00-1.67	20,000-16,700
Standard (Long, Narrow Benches)	65-70	1.54-1.43	15,400-14,300
Peninsular	75-80	1.33-1.25	13,300-12,500
Movable or Temporary	85-95	1.18-1.05	11,800-10,500
Total	100	1.00	10,000
Multiple Levels	140-180	.71- .56	7,100- 5,600

TABLE 9. Comparison of Spacing Systems

Standard Spacing (In.)	Staggered Spacing — Approximate Spacing: Within Rows (In.)	Staggered Spacing — Approximate Spacing: Between Rows (In.)	Approximate Area/Plant: Standard Sq. In.	Approximate Area/Plant: Staggered Sq. In.	Approx. Savings per Plant Staggered vs. Standard Sq. In.
6 x 6	6	5.0	36	30	6
7 x 7	7	6.0	49	42	7
8 x 8	8	7.0	64	56	8
9 x 9	9	8.0	81	72	9
10 x 10	10	8.5	100	85	15
11 x 11	11	9.5	121	105	16
12 x 12	12	10.0	144	120	24
13 x 13	13	11.0	169	143	26
14 x 14	14	12.0	196	168	28
15 x 15	15	13.0	225	195	30
16 x 16	16	14.0	256	224	32

TABLE 10. Spacing Requirements for Crops

Square Foot — Weeks/Plant

Number of Weeks

Standard Spacing	1	2	3	4	5	6	7	8	9	10	11	12
6 x 6	0.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.8	3.0
7 x 7	0.3	0.7	1.0	1.4	1.7	2.0	2.4	2.7	3.1	3.4	3.7	4.1
8 x 8	0.4	0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.5	4.9	5.3
9 x 9	0.6	1.1	1.7	2.3	2.8	3.4	3.9	4.5	5.1	5.6	6.2	6.8
10 x 10	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.5	6.2	6.9	7.6	8.3
11 x 11	0.8	1.7	2.5	3.4	4.2	5.0	5.9	6.7	7.6	8.4	9.2	10.1
12 x 12	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
13 x 13	1.2	2.4	3.5	4.7	5.9	7.0	8.2	9.4	10.6	11.7	12.9	14.1
14 x 14	1.4	2.7	4.1	5.4	6.8	8.2	9.5	10.9	12.2	13.6	15.0	16.3
15 x 15	1.6	3.1	4.7	6.3	7.8	9.4	10.9	12.5	14.0	15.6	17.2	18.7
16 x 16	1.8	3.6	5.3	7.1	8.9	10.7	12.5	14.2	16.0	17.8	19.6	21.4
Staggered Spacing												
6 x 6	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5
7 x 7	0.3	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.2	3.5
8 x 8	0.4	0.8	1.2	1.6	2.0	2.3	2.7	3.1	3.5	3.9	4.3	4.7
9 x 9	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
10 x 10	0.6	1.2	1.8	2.4	3.0	3.5	4.1	4.7	5.3	5.9	6.5	7.1
11 x 11	0.7	1.5	2.2	3.0	3.7	4.5	5.2	6.0	6.7	7.5	8.2	9.0
12 x 12	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.6	7.6	8.3	9.2	10.0
13 x 13	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
14 x 14	1.2	2.3	3.5	4.7	5.9	7.0	8.2	9.3	10.5	11.7	12.9	14.0
15 x 15	1.4	2.7	4.1	5.4	6.8	8.2	9.5	10.8	12.2	13.5	14.9	16.3
16 x 16	1.6	3.1	4.7	6.2	7.8	9.3	10.9	12.4	14.0	15.6	17.1	18.7

crop on the benches, then the number of hanging plants should be carefully controlled to reduce stretch and to maintain high plant quality. The following rule of thumb should be applied to six to ten-inch hanging pots maturing during the given months:

Maturity Date	Ratio	No. Hanging Pots 2400 sq. ft. House
December	1 pot:8 sq.ft.	300 hanging pots
March	1 pot:6 sq.ft.	400 hanging pots
May	1 pot:4 sq.ft.	600 hanging pots

Higher densities may be used if the bench crop is shade tolerant. Caring and harvesting of crops with limited access can be difficult. Likewise, pesticides may be difficult to apply by conventional methods. Be sure that the greenhouse structure can support the additional load.

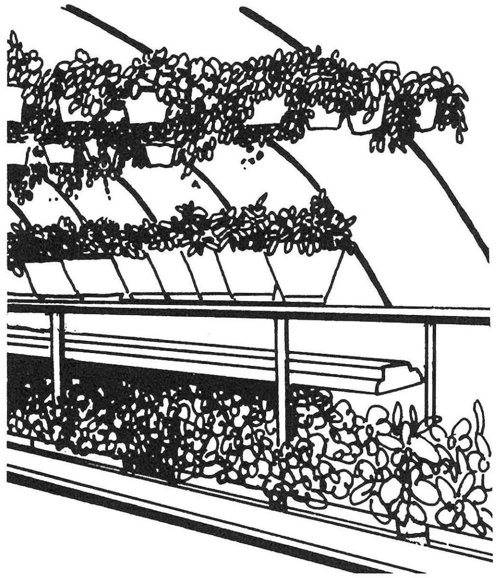

Figure 9. Effective use of greenhouse space for container-grown crops with three levels of production space without affecting plant quality.

Crops Under Benches

Some shade-tolerant crops can be grown under the benches (especially wire or metal lath) or in pots hung on the sides of the bench. Because of the disease potential and other factors that would affect quality, care must be taken in the selection of these crops. Many crops are often grown under the benches.

Multiple Shelves

Some crops, such as African violets or propagation of Rieger begonias, lend themselves nicely to multiple shelf arrangements. This permits several production layers. The topmost receives sunlight while in most cases, the lower levels may require supplemental lighting from fluorescent lamps. Crops that grow rapidly, are small and compact and which have a high dollar value and a low light requirement do best under these situations. Vining crops are often grown on tiered shelves rather than a flat bench (Fig. 11).

Movable Trays or Bench Tops

The main objective of movable benches or trays is to locate the work force centrally and decrease aisle space in the greenhouse. European growers have been using large trays that roll on heat lines,

TABLE 11. Progressive Spacing Systems

Alternatives	Standard Spacing			Staggered Spacing		
Spacing and Time	Square Feet — Weeks		% Savings	Square Feet — Weeks		% Savings
Example (inches)						
1. 14 x 14 for 12 wks.		16.3	0		13.9	15
2. 6 x 6 for 2 wks.	0.5			0.4		
14 x 14 for 10 wks.	13.6	14.1	14	11.7	12.1	26
3. 6 x 6 for 2 wks.	0.5			0.4		
10 x 10 for 4 wks.	2.8			2.4		
14 x 14 for 6 wks.	8.2	11.5	29	7.0	9.8	40
4. 6 x 6 for 2 wks.	0.5			0.4		
12 x 12 for 6 wks.	6.0			5.0		
14 x 14 for 4 wks.	5.4	11.9	27	4.7	10.1	38
5. 8 x 8 for 4 wks.	1.8			1.6		
12 x 12 for 4 wks.	4.0			3.0		
14 x 14 for 4 wks.	5.4	11.2	31	4.7	9.6	41
6. 6 x 6 for 2 wks.	0.5			0.4		
8 x 8 for 4 wks.	1.8			1.6		
12 x 12 for 3 wks.	3.0			2.5		
14 x 14 for 3 wks.	4.1	9.4	42	3.5	8.0	51

Figure 10. Often greenhouse aisle space offers an ideal opportunity to grow some crops that require minimal care. Note plants under the benches, in the aisles and over the aisles and benches.

eliminating most aisles and harvesting in the headhouse rather than in the production area (Fig. 12). The "aisle/eliminator[R]" bench system is marketed in the U.S. by Simtrac, Incorporated. This bench is a table-top with rollers set on a permanent frame. Homemade versions of these consist of a metal post, a metal cross piece, and the bench sitting on a long pipe. The bench moves laterally by rolling the long pipe. Only one pipe needs to be the full length of the bench. The other can be eight- or 10-inch pieces of pipe (sometimes called idlers), grooved to fit the top of the channel and located at each cross piece. With proper planning, most posts can usually be accommodated. Instead of several aisles within a greenhouse span, there is only one aisle, and the rest of the space is occupied by benches. An aisle can be created between any two benches by separating the appropriate benches. Automatic water systems should be installed for all movable bench systems.

Ferris Wheels

Another method for increasing the available growing space is the Roto-Shelf[R] marketed by Martindale Machine Co. It has eight benches attached to the ends of the spokes of large wheels and resembles a ferris wheel with elongated shelves (Fig. 13). Light and plant height are limiting factors in its use. Small size crops with low light requirements are best suited for this system.

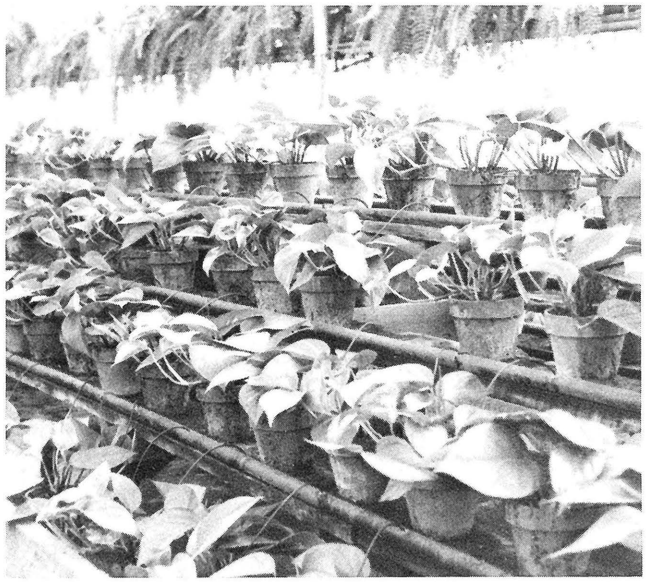

Figure 11. A tiered arrangement for trailing or hanging crops is often a more effective way to grow them both in space use and labor efficiency.

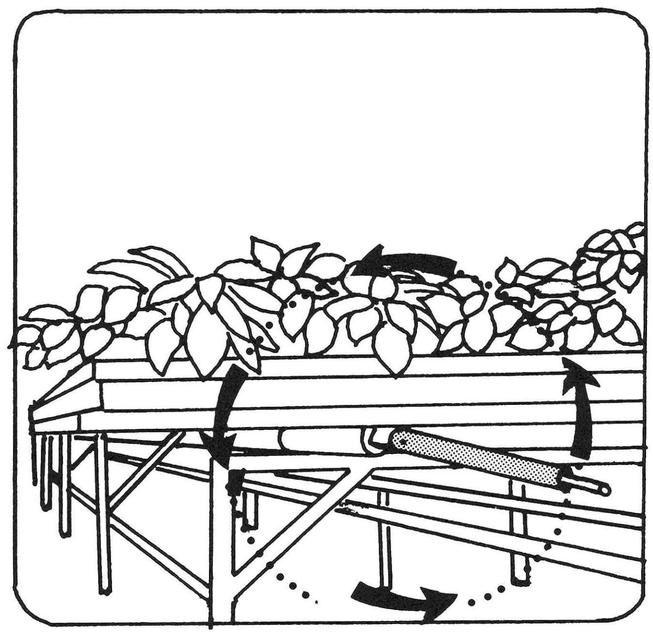

Figure 12. Mobile benches that provide one access aisle per greenhouse can be homemade or obtained from distributors.

Grow Prefinished Crops

Possible Annual Savings — 0 to 50% (20% Average)

Prefinished crops (already started but not ready to market) can be considered in four ways:

1. Growers can grow or propagate a larger quantity of plants than needed. These plants can be sold to other growers before space becomes limiting. One example has been the specialist propagators of geranium, poinsettia and chrysanthemum cuttings and of seedling specialists. However, more of the smaller and even six-inch prefinished plants are being sold. Most azaleas grown and sold in Ohio are prefinished plants from the south or west coast. This provides growers with another product, reduces overhead and increases total yield without having to expand their facilities.

2. Between holidays many growers have vacancies in their houses where they could grow four to eight-week crops. Other growers may find that growing prefinished holiday pot plants and year-round foliage will increase their turnover. They will also have plants available to help promotions and sales.

3. Spring accounts for more than 50 percent of many flower grower sales, yet to prepare for these sales, growers must start from December through February when approximately 50 percent of their fuel is consumed. During this period, many benches may be empty or inefficiently used. The grower could buy established plants (potted and bedding plants) four to eight weeks before sale date and finish them. This released space during the winter could be left empty and cold or devoted to cooler crops for February to April sales, increasing total sales by increasing turnover.

4. Greenhouse vegetable growers can often obtain transplants from other specialty growers and delay plantings for late winter and spring crops. This eliminates or curtails the need for heating greenhouses during the winter without forfeiting overall production.

Reduce Crop Unit Size

Possible Annual Savings — 0 to 10% (5% Average)

Many crops have been grown in big containers that require large amounts of time, space and fuel. Often the increased production costs have been difficult to pass on to the retailer or consumer. To combat this problem, many growers have been producing smaller units to increase their gross sales. For example, traditional six-inch pot mums have been grown with five pinched cuttings and a final spacing of 14 inches x 14 inches (196 square inches/plant). Today many growers are growing 5½-inch pot mums with four pinched cuttings and a final spacing of 12 inches x 12 inches (144 square inches/plant). Ideally the price will remain the same, but even a small price decrease is more than made up by the increase in sales and total units.

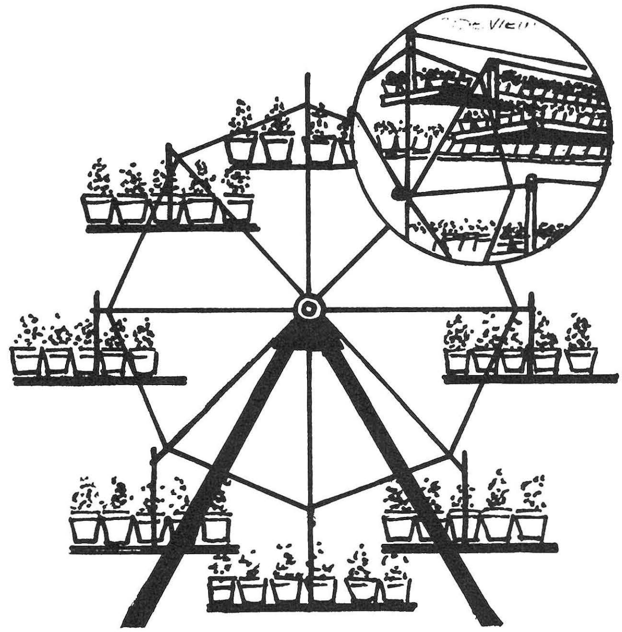

Figure 13. The "ferris-wheel" is another means of increasing bench space without increasing greenhouse area.

Grow Improved Cultivars

Possible Annual Savings — Cooler growing cultivars 5 to 25% (10% Average)
More productive cultivars 0 to 40% (10% Average)
Shorter cropping time 0 to 25% (5% Average)

Each grower has a responsibility to grow the best proven cultivars available to the industry. Quality should never be reduced by a change in cultivars, but opportunities to grow disease resistant, cooler growing, more productive crops or plants requiring shorter cropping times should not be passed over.

Greater emphasis has been placed on cooler-growing cultivars in most breeding and selection programs. Whether the crop be tomatoes, poinsettias, chrysanthemums, or bedding plants, new and better cultivars will be promoted to allow a two to five-degree F reduction in night growing temperatures. A major goal of present and future breeding programs will be to decrease the total energy requirement per crop unit without significant reductions in yield or quality.

Some growers get into a rut of growing the same cultivars year after year and do not respond favorably to newer, more productive cultivars. Major improvements have been made in increasing the yield of greenhouse vegetables and cut flowers. A 50 percent increase in yield under the same environmental conditions could represent a 33 percent savings in fuel per crop unit. Other cultivars may produce a higher percentage of top quality units, increasing gross revenues. Others may allow for closer crop spacings resulting in more crop units per area. A cultivar that does not return highest yields of highest quality is not an energy efficient plant.

Finally, fuel usage is partly dependent upon cropping time. Tomato cultivars that come into production earliest should demand the highest prices and increase gross revenues. A geranium cultivar that requires only 14 weeks from seed to May flowering will use less fuel than a comparable cultivar requiring 17 or more weeks to flower. During winter, chrysanthemum growers should grow cultivars that require the fewest weeks of long days and of short days without sacrificing quality.

Use Supplemental Lighting

Possible Annual Savings — 0 to 40% (10% Average)

Temperature, carbon dioxide and sunlight are the major limiting factors for optimum winter plant growth. However, because of the high initial capital investment and the use of expensive electrical energy, the possibility of increasing plant yields and quality by supplemental lighting is often ignored.

Radiant energy (sunlight) is a primary factor determining plant growth rate in the greenhouse. All other components affecting growth rate (e.g., carbon dioxide, fertilizer, water and temperature)

TABLE 12. Monthly Light Values (Gram-Calories/cm²) and Relative Percentages of June Daily Average Light in Wooster, Ohio.

Month	Daily Avg. gm-cal/cm²	%	Month	Daily Avg. gm-cal/cm²	%
January	170	33%	July	510	100%
February	240	47%	August	450	88%
March	290	57%	September	350	69%
April	370	73%	October	280	55%
May	460	90%	November	160	31%
June	510	100%	December	130	25%

are adjusted to changes in the radiant energy available for photosynthesis. Radiant energy must be used instantly. A low level of natural radiant energy during winter may be the most limiting condition in the growth of many northern United States greenhouse crops. Total daily radiation in Wooster, Ohio, ranges from 10 to more than 700 gram-calories/cm², and although the figures in Table 12 are the means for the last 18 years, month-to-month variations may be as high as 30 to 40 percent of the means. Typically, the months from October to March provide sub-optimal to marginal light intensities for most high-light-requiring horticultural crops. Frequently, cloudy weather in April or September will result in crop losses or variable growth and plant quality. Thus, there is a

TABLE 13. Summary of Supplemental Lighting Benefits to Greenhouse Crops.[1]

Crop	Illumination Lumens/ Sq. Ft.	Duration Hours/ Day	Lighting period after Transp.	Days from Propagation to Flowering: With Lights	No Lights
African violet	400-600	18-24	to flower	107-125	211
Begonia, fibrous	500-700	18-24	2-4 weeks	100-120	135-150
Rex, Rieger	500-700	18-24	2-4 weeks	—	—
Chrysanthemum pot or cut	800-1500	18-24	1-3 weeks	82-84	85
Cineraria	800-1200	18-24	to cold treat.	120-160	170-200
Coleus	800-1200	18-24	3-4 weeks	75-80	100
Geranium cutting	800-1200	18-24	2-3 weeks	34-45	46-59
seed	1000	24	6 weeks	80	110
Gloxinia	400-600	18-24	to flower	125-130	200
Impatiens	800-1200	18-24	2-4 weeks	55-60	75-80
Marigold	800-1200	18-24	2-3 weeks	40-45	60-65
Orchid	350-1500	16-18	seedlings	—	—
Petunia	1400-1600	16	3-4 weeks	42-45	59-83
Poinsettia	1400-1600	18-24	2-3 weeks	110	110
Rose	1400-2000	24	continuous	33-34	36
Tomato	600-800	24	2 weeks	18	32

[1] Adapted from Carpenter, W.J. 1975. Supplemental daylight with HID lamps. Ohio Flor. Assn. Bul. No. 551, pp. 8-9.

variable and unpredictable light source for six to eight months of the year when light may be limited for extended periods. For the rest of the year, light may actually be excessive, requiring shading and/or additional cooling. The control and predictability of supplemental lighting gives an advantage over natural daylight yet makes placing an economical value on it difficult.

Before installing and using supplemental lighting for greenhouse crop production, maximize natural light usage in the greenhouse. The glazing should be clean, wood sash bars should be painted white and unnecessary objects blocking sunlight should be removed. Objects painted white and reflective foils placed on sidewalls, benches and in aisles between row crops increase the total amount of sunlight or supplemental light reaching the crop.

Supplemental lighting in greenhouses during winter improves the growth rate, quality and yield of many horticultural crops (Table 13). In summary, these benefits are:

1. Accelerated plant growth and maturity,
2. Increased yields,
3. Increased plant or crop quality,
4. Reduced number of flower abortions and blind shoots,
5. More uniform bud initiation and development,
6. Additive advantages when coupled with supplemental carbon dioxide fertilization.

No supplementary lighting system can be expected to provide the environmental controls such as those found in growth chambers. The optimum supplementary light value fluctuates continuously according to the natural light level, the greenhouse temperature and the carbon dioxide concentration in the atmosphere. Even in chrysanthemums, the response to the same energy input differs from cultivar to cultivar.

While it is possible to make recommendations based on the physiological responses of the plants being lit, other factors affect the quantity of light finally provided. They are the relative efficiencies of the lamps, the effectiveness of the reflector and its potential to obscure daylight and the ease of obtaining the desired degree of uniformity.

In considering a supplemental lighting system, the specific lighting requirements must first be determined. Lamp selection to provide the desired illuminance is the most critical decision that the grower must make. (Most suppliers of horticultural lighting systems have qualified engineers trained to meet specific needs of individual grower situations.) With ever-increasing energy costs, emphasis for supplemental lighting systems should be placed on utilizing the most satisfactory and energy efficient lamps. However, light quality (spectrum) of the lamps becomes more important when the lamps become the predominant or only source of light for plant growth, as in growth chambers. One measure of lamp efficiency is a term referred to as "lumens/watt." The higher the value, the more efficient is the lamp source. Table 14 lists some common light sources, lamp efficiencies and illuminance (light intensity) at similar energy consumption rates (watts/square foot production area).

Obviously, higher light intensities will be possible using the more efficient lamp sources. Another means of reviewing operating costs is to compare electrical consumption (watts/square foot) at similar light intensities (lumens/square foot) as shown in Table 15.

TABLE 14. Lamp Comparisons for Efficiency and Illuminance at Similar Energy Consumption Rates.

Lamp	Efficiency Lumens/Watt	Illuminance (Lumens/sq.ft.) 5W/ Sq.Ft.	10W/ Sq.Ft.	20W/ Sq.Ft.	40W/ Sq.Ft.
Incandescent	17*	85	170	340	680
Fluorescent, Cool White	70	350	700	1400	2800
Metal Halide	75	375	750	1500	3000
High Pressure Sodium	140	700	1400	2800	5600
Low Pressure Sodium	183	915	1830	3660	7320

* Anon. 1978. SAF-Energy Audit for Growers. Society of American Florists, Alexandria, Va.

TABLE 15. Lamp Comparisons for Efficiency and Operating Costs at Similar Light Intensities

Lamp	Efficiency Lumens/Watt	Watts/sq. ft. required (¢/day) 500 lumens	1000 lumens	2000 lumens
Incandescent	17*	20.5 (3.0**)	59.0 (5.9)	118.0 (11.8)
Fluorescent, Cool White	70	7.1 (0.7)	14.2 (1.4)	28.2 (2.8)
Metal Halide	75	6.7 (0.7)	13.4 (1.3)	26.8 (2.7)
High Pressure Sodium	140	3.5 (0.4)	7.1 (0.7)	14.2 (1.4)
Low Pressure Sodium	183	2.7 (0.3)	5.4 (0.5)	10.8 (1.1)

* Anon. 1978. SAF-Energy Audit for Growers. Society of American Florists. Alexandria, Va.
** Cost estimated at 5 cents/Kwh for 20 hrs.

The more efficient sources will require fewer lamps to be installed but also lower operating costs per day for similar light intensities (Tables 14 and 15). The cool white is the most commonly used fluorescent lamp. The "wide-spectrum" or "grow lamps" are less efficient fluorescent lamps and very expensive. Although they are often very effective in indoor situations because of their spectral qualities, the cool white fluorescent is the more efficient and preferred lamp when fluorescent lamps must be used to supplement natural sunlight. The high pressure sodium lamp is the most commonly used high-intensity lamp. Some work with the more efficient low pressure sodium lamp shows promise but has not been widely adopted by growers to date. Because of spectral differences and varying crop responses, a mix of lamp sources may be beneficial.

A supplemental lighting system will range between three to 20 watts/square foot of production area and provide between 2,500 to 12,000 lux (250 to 1,200 foot-candles) of light for 12 to 16 hours each day. This range will meet the requirements of most commonly grown greenhouse crops and the practical, economical limitations of most lighting systems.

Photoperiod Control

Many of the major floral crops (chrysanthemums, poinsettias, kalanchoe, etc.) require an interrupted dark period (simulated short night) to maintain vegetative growth. Typically, incandescent or fluorescent lamps are used for approximately four hours during each long night (10 p.m. to 2 a.m.). The major lighting requirement is usually a minimum of 100 lux (10 foot-candles) uniformly distributed over the crop.

Many electrical utilities determine electrical rates by using demand meters which measure the largest electrical demand (Kw) for any 15-minute period during the billing period. Cyclic and split night lighting either alone or in combination can substantially reduce these demands when using incandescent lamps.

Cyclic lighting (cycles of lights being on and off) can reduce electrical demand by 60 to 80 percent for photoperiod control. Chrysanthemums will respond under Ohio conditions to as little as six of every 30 minutes during the prescribed lighting period. This means that only 20 percent of the electrical demand is required at any one time.

Split night lighting provides an alternative to the 10 p.m. to 2 a.m. standard. In many areas, vegetative growth can be maintained by lighting from 9 p.m. to 1 a.m. or from 1 a.m. to 5 a.m. This form of lighting reduces the peak electrical demand for photoperiod control by 50 percent. Even greater efficiency in electrical usage can be achieved when the split-night lighting is combined with cyclic lighting.

Caution: Check timers regularly when in use to be certain that a power outage has not shifted their schedule. Light bulbs should also be checked on a weekly basis to assure proper lighting.

Add Supplemental Carbon Dioxide (CO_2)

Possible Annual Savings—0 to 40% (10% Average)

The beneficial effects of adding CO_2 to the greenhouse environment have been well established by research and grower experience. The crops which respond most consistently to supplemental CO_2 are lettuce, chrysanthemums, carnations, tomatoes and roses, although most all other greenhouse crops also benefit. Carbon dioxide is required for the process of photosynthesis during which green plants use radiant energy to convert CO_2, water and nutrients into sugars used in the various growth processes within the plant.

Normal air contains about 0.03 percent or 300 parts per million (ppm) of CO_2. Most plants grow well at this level, but if levels are higher but below harmful levels, the plants will respond by growing more quickly. When supplementing with CO_2, levels between 1,000 and 1,500 ppm should be maintained for most greenhouse crops.

During the day, in a closed greenhouse without supplemental CO_2, the plants use the CO_2 in the air and reduce the level below the normal 300 ppm. This is the point at which CO_2 addition is most important. Figure 15 shows the effects occurring in greenhouses with and without CO_2 enrichment and ventilation. Research has shown that greenhouse crops will almost always be improved if CO_2 levels are raised to 1,000 to 1,500 ppm. Providing adequate nutrients are available, the level to which the CO_2 concentration should be raised is dependent on the crop, light intensity, temperature, growth stage of the crop and tightness of the greenhouse.

The interaction of light and CO_2 levels is the predominant factor affecting plant growth (Fig. 14). Light saturation (when no additional light can be used by leaves) takes place at light levels at 15 to 20 percent of full sunlight, but for established crops such as carnations, roses, tomatoes and cucumbers, the light saturation point may never be reached, as higher light levels will give a deeper penetration of light into the plant cover and increase the productivity zones. As can be seen from Figure 14 it is possible at least partially to compensate for light by adding CO_2 to the atmosphere.

The response of greenhouse-grown vegetables and flowers to CO_2-enriched atmosphere has been well-established. Young seedlings are often stronger, have greater height, better root systems, larger leaf areas and higher dry matter contents. The effects on lettuce are an accelerated maturity, substantially higher yields and an additional crop per year. Tomato fruit size and number are increased, and the harvest peak shifted forward. Cucumbers show increased yields and a higher

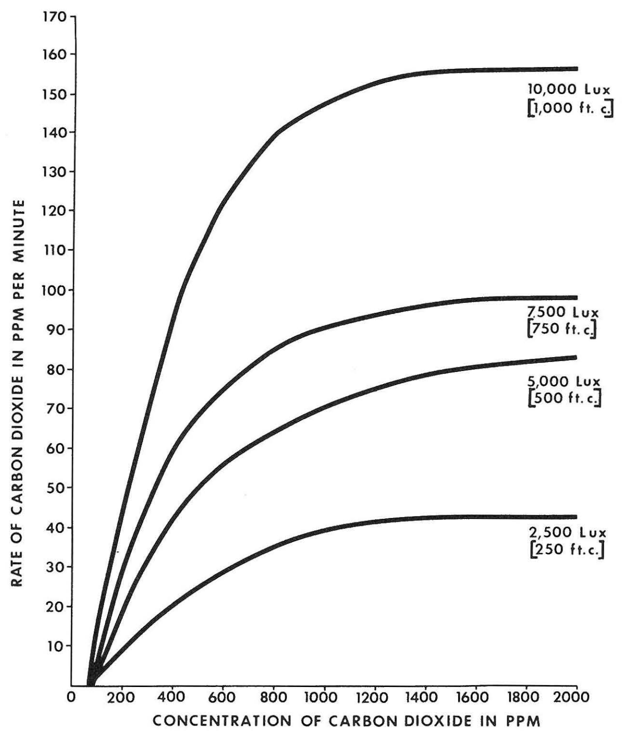

Figure 14. Carbon dioxide utilization rates for chrysanthemum using different light intensities over a range of carbon dioxide concentrations. From: Wiebe, J. and R. A. Fleming. 1965. Rate of use of CO_2 by greenhouse chrysanthemums at changing concentrations. Can. Flor. Grnh. & Nurs., June 5.

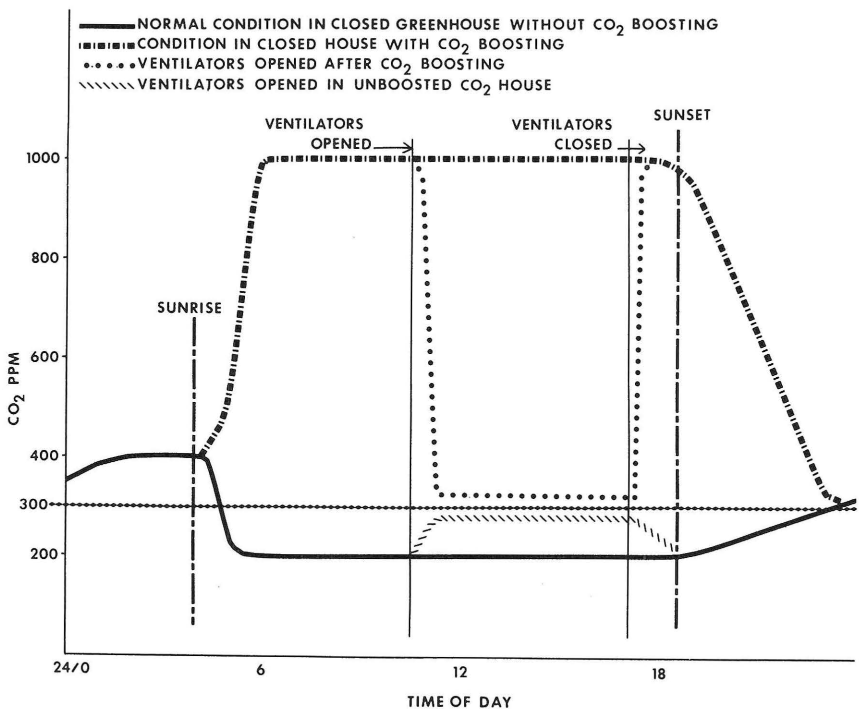

Figure 15. Concentration of CO_2 under various conditions. From: Heys, G. 1967. Carbon dioxide enrichment in greenhouses. Proc. Fourth Ann. Symp. on Thermal Agr., pp. 62-69.

percentage of pistillate flowers. Roses, carnations, chrysanthemums, snapdragons, petunias and geraniums produce larger and earlier flowers, more desirable flower stem lengths, improved texture and quality of blooms, higher yields and have a shorter production cycle. Higher rates of production over a given period are particularly significant with roses and carnations during winter. The production schedule for chrysanthemums and snapdragons can be shortened by two to three weeks. For some crops, summer cultivars can be grown in winter with supplemental CO_2 fertilization.

Çarbon dioxide fertilization increases yield and quality by increasing plant and root growth, and good cultural conditions are essential. To produce these higher yields, the plant must have access to adequate moisture and nutrients. Increased day temperatures, possible when enriching with CO_2, will reduce day-time ventilation. Plant growth will be greater and more luxuriant. It is essential that in mild weather the plant should be "hardened off." Ventilation and reduced humidity at night will help achieve this goal.

Automatic devices such as a photoelectric cell or a 24-hour cycle time clock can be used to control CO_2 enrichment. Ideally, enrichment should be started an hour before sunrise and cut off two hours prior to sunset and when ventilating. The burner can be shut off with the ventilation control circuit when the vents are open and restarted when the ventilators close, provided the light is available.

Preheat Irrigation Water

Possible Annual Savings — 0 to 20% (5% Average)

Preheating the irrigation water will indirectly save energy for the greenhouse owner. It requires the same amount of energy to heat the water to room temperature whether it's done in the irrigation lines or in the soil surrounding the plant roots. Some simple methods of heating irrigation water are illustrated in Figure 16. With the exception of the damaging effects cold water has on the leaves of various gesneriads such as African violet and gloxinia, very little information is available citing the merits of preheated irrigation water.

However, there are tangible reasons to anticipate improved plant growth, development and quality when the irrigation water is applied at or near day temperatures. For example, root temperature is very important in plant growth and influences the absorption of water and nutrients by the roots. This would be more critical where the soil is in beds or large containers and less important in smaller containers and more porous media. Second, some research has shown that cool soil temperatures will close the leaf stomates and inhibit photosynthesis. Since irrigation is closely associated with solar radiation, any wilting or stomatal closing of the leaves during infrequent periods of sunny weather in the winter would be expected to have adverse effects on plant growth.

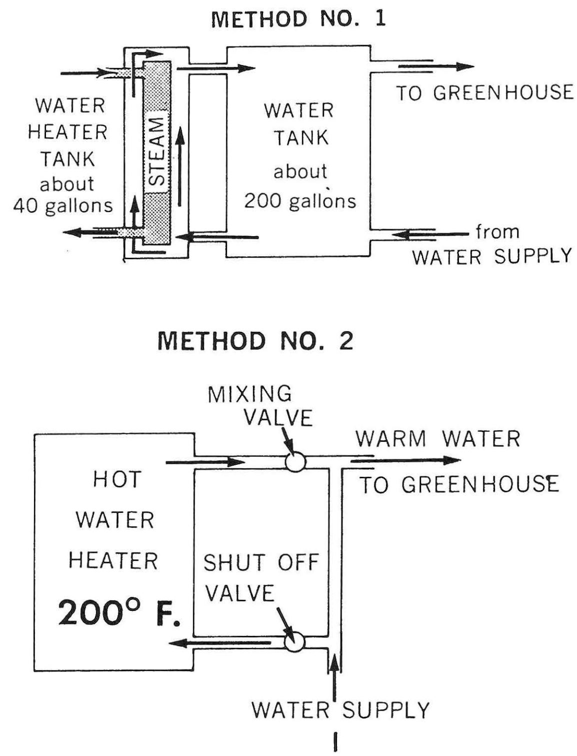

Figure 16. Simple methods of heating irrigation water. From: Cumbo, Woody. Simple Methods of Heating Irrigation Water. BPI News, December, 1979.

Generally, growers feel that preheating the irrigation water is worth the investment. They can see significant effects in cropping time, yield and quality compared with their earlier experiences before preheating.

Harvest Crops Prior to Market Maturation

Possible Annual Savings — 0 to 20% (10% Average)

Some crops reach a stage of "green maturity." After harvest they will continue to ripen or flower under certain environmental conditions outside of the greenhouse or off the plant. Gathering crops before maturation can speed harvest and permit a once-over harvest or reduce the cropping time.

Ethephon has been used to ripen mature green tomatoes either on the plant or in harvest crates to permit an earlier pull-out date for the fall crop and to reduce temperatures for the period normally required for maturation.

The bud-harvest of chrysanthemums followed by opening in preservative solutions reduces bench time and fuel requirements as well as increasing crop turnovers. The flowers can be opened in insulated rooms under low light intensities (and at higher flower densities). Other flower crops show similar potential.

Some pot chrysanthemums can be harvested in a tight-bud stage (1/3 to 1/2 open), sleeved and opened in the storeroom or preferably in the marketing channels saving a week or more on the greenhouse bench.

Caution: Be certain to obtain proper crop recommendations before trying these suggestions even on a small scale.

Reduce Crop and Marketing Losses

Possible Annual Savings — 0 to 30% (5% Average)

Some production losses are inevitable. However, once the crop has been grown properly and arrives in the marketing channels, every effort should be made to see that each product reaches the consumer in optimum condition. Crop losses in the headhouse or grading room or with the wholesaler or retailer represent substantial amounts of all production resources including energy. (These losses are not well documented in most instances.) However, up to 30 percent of all fresh cut flowers may be lost between the grower and the ultimate consumers. Such a loss means that this segment of the floral industry uses nearly 50 percent more fuel than retail sales for fresh cut flowers would justify. These energy costs include all production inputs as well as cooling and transportation.

Growers need to do a better marketing job before the crop is ever planted. Improved merchandising can reduce losses at harvest by ensuring that a market exists. Losses from non-existent markets are often substantial, especially for newcomers with limited experience in growing and marketing. However, experienced growers also hurt themselves when they attempt to switch to new crops or to expand their production facilities faster than they can expand their marketing capabilities.

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