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THE INFLUENCE OF PHOTOPERIOD ON LATERAL SHOOT DEVELOPMENT OF CARNATION

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Low intensity night lighting with incandescent lights will induce flower initiation in carnation shoots which have 4 to 7 expanded leaf pairs (3, 9). These shoots flower earlier than non-lighted shoots but these shoots will have reduced lateral branching. This reduction in branching at the lower position of the plant is undesirable. For instance, if a lateral shoot is already 2 inches long at the time the flowering stem is harvested, that return shoot will flower 30 to 60 days sooner than a return shoot that must develop from a "blind cut" where there is no lateral bud activity (8). Porkorny and Kamp in 1960 showed that carnation plants grown under short photoperiods developed many lateral shoots but flowering was delayed (10). The opposite response was observed under long photoperiods.

Light quality also influences plant development. In general a light source high in far-red light will induce stem elongation while at the same time far-red light will inhibit lateral shoot growth; while red light will stimulate lateral branching while inhibiting stem elongation (5). Incandescent lamps, the common source of lights for flower control in carnations, are high in far-red light.

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Light Quality Study

An experiment was set up to determine if the light quality used to provide long days to a carnation shoot would influence lateral branching. Plants were lighted for 4 hrs from 10:00 to 2:00 with a light source high in red light (cool white fluorescent), or with a light high in far-red light (incandescent, as well as, a BCJ ruby-red incandescent lamp) or were grown under short days (8 hr light) or under natural day lengths. While shoots flowering under the red light source had significantly more lateral shoots than the incandescent lighted shoots, the date to flower was delayed (Table 1). Shoots flowering under normal photoperiods and short photoperiods had significantly more lateral shoots than any of the plants flowering under the light treatments.

Lights were maintained on the plants which were receiving long days and the second flush was allowed to flower. Irrespective of treatments, all shoots flowered in the same number of days from planting and all had a consistent low number of lateral shoots. The interesting thing to note is that all shoots on the second flush flowered during the long days of spring.

Photoperiod Study

The light quality experiment suggested that photoperiod played a more important role in lateral shoot development than did light quality. Experiments were conducted for 2 more years to determine if photoperiod could be used to control lateral branching (4, 6). Plants were grown under

Table 1. Influence of photoperiod treatments on time to flower and on no. of vegetative shoots greater than 2 cm long present at flowering. Exp. started September 1, 1975.

Treatment[z]	No. flowers cut/plant		No. vegetative 2 cm shoots		Days to flower	
	Flush 1[y]	Flush 2	Flush 1	Flush 2	Flush 1	Flush 2
ND	4.0	5.7	4.2 c[x]	0.5 a	194 c[x]	252 a
SD	4.0	—	6.3 d	—	216 d	—
FL	4.5	3.4	2.3 b	0.6 a	179 b	249 a
IN	4.5	3.4	1.4 a	0.8 a	162 a	249 a
FR	4.3	3.8	2.9 b	0.9 a	172 b	250 a

[z]N - Normal day; S - short day; FL, IN, FR - Night interruption from 2200 to 0200 with cool white fluorescent light (FL), incandescent (IN), or BCJ Ruby Red incandescent lamp (FR) respectively.

[y]Flush 1 was the first group of shoots to flower after the original pinch. Flush 2 was the second group of flowers which developed from the lateral shoots which were present when the first flush of flowering shoots were removed or developed later.

[x]mean separation, within columns by Tukey's HSD test, 5% level.

normal days, short days or long days and then transferred to one of the other photoperiods during different stages of a shoot's development. The complete data is presented elsewhere (4, 6) so only the conclusions will be presented here.

Based on these studies, we will present the following summary and model for lateral shoot development and flowering in the carnation. A developing carnation shoot remains vegetative until at least 12 to 14 nodes are present. After this stage of development, floral initiation is dependent upon photoperiod. Under short photoperiods, floral induction is delayed; under long photoperiods, it is enhanced. During the initial vegetative growth stage, very little lateral shoot activity or elongation is observed until after 12 to 14 nodes are present, suggesting strong apical dominance. Phillips (9) reported a similar inhibition of lateral shoot development until at least 10 nodes had formed. After the 12 to 14 node stage, lateral bud growth can be seen at many of the nodes that are subsequently formed, provided that the shoot remains vegetative. Once the lateral shoots start to elongate, they frequently continue elongation after floral initiation has occurred and are present as growing lateral shoots at the time flowers are harvested. If lateral shoot growth has not commenced before floral induction (as with shoots given long photoperiods at the 12 to 14 node stage with 5 to 7 expanded leaves) subsequent lateral shoot growth does not occur. It appears that after 12 to 14 nodes have formed, apical dominance is reduced and lateral shoots can begin growth. Perhaps these lateral shoots then develop into a sink for metabolites which can be maintained even after floral initiation. It follows that after floral initiation, flower buds may re-establish apical dominance and may become a dominant sink compared to non-actively growing subtending lateral buds. These lateral buds would be inhibited from further growth. This would explain why short photoperiods stimulate lateral shoot development before floral induction but not afterward.

It is interesting to follow production of carnations over a 2 year period. Production tends to follow the total solar radiation curve, decreasing in winter and increasing in spring and summer (1). Since it takes 5 to 6.5 months for a lateral shoot to flower under normal day (7) conditions, it is obvious that those flowers harvested in winter, when production is low, are the lateral shoots which were initiated during the long photoperiods of summer and the high production period in spring and summer are the shoots which were initiated under the short photoperiods of winter. This supports the model that long photoperiods, which hasten flower initiation, inhibits lateral shoot growth while short photoperiods, which delays flower initiation, stimulated lateral shoot growth. Thus, can we emulate these seasonal changes?

In most cases commercial greenhouses receive carnation plants from the propagator which are frequently already reproductive or will become so shortly after planting (personal observation). This early floral initiation will delay the development of and will decrease the number of potential vegetative lateral shoots from which future vegetative shoots and future flower production will arise once the apical growing point, which is reproductive, is removed. Vegetative cutting from the propagator should insure future plants with adequate vegetative shoots present for a large crop of flowers after planting. Cuttings are vegetative no doubt when they are removed from the stock plants during the winter and spring months and stored in coolers until needed for rooting in May and June. However, by May and June, the natural days are long (13½ to 15 hours) and many of the cuttings no doubt initiate flowers while rooting under long normal photoperiods. The use of short photoperiods while rooting should insure vegetative cuttings being sold to the commercial grower.

Single cropping of carnations may be economically feasible under certain conditions such as growing a crop of carnations for a particular holiday. The use of short photoperiods could insure vegetative plants with many vigorous lateral vegetative shoots. These plants could then be lighted giving long days to induce rapid uniform flowering for a particular date.

Acres of chrysanthemums are given short days/long days to control reproductive/vegetative cycles. Perhaps it is wise to consider day length reduction not only in the propagation areas, but also for the stock block areas used for cutting production any time natural photoperiods are over 12 hrs. While both the stock block and propagation areas are relatively restricted areas in size to cover with "black shading cloth", the main production sites should also be considered. Cloth could also be used as a heat conservation factor in the winter, and to control photoperiod in the late spring and summer.

Nevertheless, it appears that photoperiodic control of flower initiation is the factor which controls the upper limit for number of laterals on a carnation shoot. Many environmental factors subsequently determine if a lateral shoot will fulfill it's potential to develop and flower (2).

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Arch roofed, gutter connected greenhouses, with air-inflated double poly roofs, each unit 17×96 ft, enclosing 22,848 sq.ft. were heated by condenser cooling water from a coal-fired power plant, 45 miles northwest of Minneapolis. Winter design, minimum cooling water condenser outlet temperature was 85°F at full load electrical output. Design criteria for the greenhouse heating systems were based on a -30 F outside temperature and 50 F inside, with a calculated heat loss of 2 million BTU per hr. Both air heating and soil heating was employed, although the air heating system was designed to handle the full load. Air was distributed down each bay from the heat exchanger with a 30-inch poly tube.

The heating systems performed wholly satisfactorily during 1975-76 and 1976-77. In the last season, performance was less than optimal due to fouling of the fan coil heat exchangers. The lowest temperature recorded was -42.9 F, with an inside temperature of 58 F, and warm water available at 91 F. Crop production included roses, tomatoes and peppers, with improved production of tomatoes in the second season as experience was gained with the system and CO_2 injection was installed. Crops included freezias, snapdragons, cineraria and geraniums.

In 1977, a one acre commercial floral greenhouse, of similar construction, was built, with bay widths of 17.5 ft., and a length of 144 feet.

Warm water service became available in 1977, operating with an over-all availability of 96.4%, unavailability primarily due to pipeline failures. Water was not always warm enough to maintain temperatures desired by commercial operators, due primarily to reduction in electrical load at the power station. Condenser water temperature could vary over a 20 F range due to load. Despite this, waste heat was available at the condenser outlet for 73% of the time above 85 F. A backup system is provided, using propane, and the 1 acre floral range consumed 8,000 gallons of propane, with about 2,000 gallons for CO_2. It is expected that as operating availability improves, standby heat requirements will decrease.

Because of the relatively low temperature differences, a significant amount of electrical energy is required for pumping. In the one acre commercial operation, the heating system requires 85 hp, with 10 hp for liquid pumping, or about 70 kw electrical load at full operation. The total consumption during the first heating season was 237,000 kw, with about 85% directly attributable to the heating system. Presently, the cost of electric energy to operate a warm water system for an acre is $7,000 per year, while the cost to deliver warm water is about $8,000 per year.

Economic feasibility to utilize condenser heat is dependent upon many variables. The most important are: 1) distance from waste heat source to greenhouse, 2) climatic conditions, 3) electric rates, 4) land cost, and 5) distance to market. At least at this particular site, conditions are such that the concept appears feasible. The most recent cost estimates to install pipeline services for 14 acres within one-half mile of the waste heat source is $35-40,000 per acre of greenhouse served. In addition to the capital cost of the pipelines, there is the cost associated with pumping and with maintenance of the pipeline. The power company estimates that the total variable operating cost will run roughly 1¢ per 1,000 gallons delivered to the user. At this rate, one acre in Minnesota will have an operating cost of $1,500 per year. The approximate total cost at the site is now $8,000 per acre-year, with the power company providing waste heat on a cost-of-service basis with a return on investment equivalent to the rate of return for other utility investments.

There is also a significant investment in heating equipment, and for Minnesota conditions, including controls, electrical work and back-up, is about $85,000 per acre.

The big advantage of waste heat systems is more apparent in the future as fuel costs escalate. The overall waste heat costs would not increase as fast as other costs due to the fact that a large part of waste heat cost results from the fixed pipeline investment.

The actual operating costs for the one acre commercial range totaled 36¢ per sq.ft. for the period of November to May. This compared to 63¢ per sq.ft. for a glass house owned by the same company. At least 8¢ per sq.ft. was saved as the result of using waste heat. The actual experience in the first year showed the waste heat system falling considerably short of the projected annual savings of $8,000. But, the outlook for achieving projected savings is optimistic.

The increased transportation costs must be considered by the greenhouse owner if he locates far from the metropolitan centers, as most power stations may be close to fuel sources or removed because of pollution requirements. A second consideration is cost of the land. At Sherco, MN, the power company owns the land, and is