THE EFFECT OF CUMULATIVE PHOTOSYNTHETICALLY ACTIVE RADIATION ON THE GROWTH AND FLOWERING OF SEEDLING GERANIUM *PELARGONIUM* X *HORTORUM* BAILEY

By

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ABSTRACT

THE EFFECT OF CUMULATIVE PHOTOSYNTHETICALLY ACTIVE RADIATION ON THE GROWTH AND FLOWERING OF SEEDLING GERANIUM PELARGONIUM X HORTORUM BAILEY

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Two experiments were conducted to determine the effect of cumulative photosynthetically active radiation (PAR) on the growth and flowering of Pelargonium x hortorum Bailey cvs. Sprinter Scarlet, Sprinter White, and Ringo.

Plants were grown under 5 light levels, with all treatments receiving natural light. Treatment 1 also included 24 hours HPS and 2 layers of Saran; treatment 2, 24 hours HPS and 1 layer Saran; treatment 3, natural light only; treatment 4, 12 hour HPS; and treatment 5, 24 hour HPS. Cumulative PAR, number of days to flower, total plant height, vegetative plant height, number of breaks, and fresh weight were taken for each plant when the first flower on the initial inflorescence opened.

Within experiments and cultivars, 41-65% of the variability around the regression line for days to flower can be accounted for by cumulative PAR. The lower the treatment light level, the greater the number of days to flower, and the less PAR received. For each cultivar, plants in treatment 5 flowered in significantly fewer days than plants

in treatment 1 and treatments 2, 3, and 4 which flowered in a similar number of days.

Vegetative and total plant height decreased as supplemental light levels increased. The number of breaks increased as light levels increased; fresh weight did not show any consistent pattern.

'Sprinter Scarlet' light saturation occurred at approximately 900 μE $m^{-2}sec^{-1}$, with the light compensation point being approximately 15 μE $m^{-2}sec^{-1}$.

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INTRODUCTION

Historically, geraniums have been regarded as a pot plant crop; Larsen (1968) has indicated that the major income has come from the sale of pot plants. This attitude, however, is changing due to the extensive development of the seed propagated F_1 hybrid geranium used for the bedding plant industry in the past 25 years (Craig, 1976). F_1 hybrid geraniums represent a new concept within the floriculture industry, allowing for the production of a "bedding plant" type of geranium rather than the standard 4-inch geranium pot plant now on the market (Lindstrom, 1967).

In 1977, 45.9 million geranium pot plants were sold at a wholesale value of 30.8 million dollars (Crop Reporting Board, 1978). If seedling geraniums are added, the total geranium production for 1977 would be closer to 250 million plants (Carlson, 1978), and approaching 100 million dollars a year from growers in all states, led by Massachusetts, Michigan, Ohio, and New York respectively. Until the end of World War II, the geranium was a stable crop; since then sales have tripled (Reilly, 1977). Yearly Bedding Plant Inc. surveys have shown the geranium to be a consistent leader in production increase. Carlson (1977) predicted that seed geraniums will comprise 90% of the geranium market in 10 years.

An initial seed geranium problem was the increased number of days to flower when compared with cutting geraniums. Earlier flowering cultivars have been developed. Scheduling the number of days to flower

with certainty is another disadvantage of seed geraniums, as delayed or advanced flowering can cause loss of revenue and loss of market for the grower. Light, temperature, and use of growth regulators are important factors affecting seedling geranium growth and flowering. The controlling influence of daylength on flowering in many plants was established between 1910 and 1920, and with the discovery of photoperiodism by Garner and Allard (1920) light has become an increasingly important dimension in horticulture. Craig and Walker (1963) suggested that the number of days to flower for seed geraniums is directly related to the cumulative solar energy received by the plant.

This study describes the effect of cumulative light energy in the 400 to 700 nm region on the growth and flowering of three cultivars of Pelargonium x hortorum Bailey, 'Sprinter Scarlet', 'Sprinter White', and 'Ringo'.

REVIEW OF LITERATURE

Systematics. The florists' or garden geranium Pelargonium includes the garden geranium, regal pelargonium, the ivy-leaved geranium and all of the scented geranium types (Craig, 1971). Pelargonium L'Her. ex Ait. of the family Geraniaceae is native to South Africa and contains about 280 species of annual or perennial herbs or shrubs. Pelargonium x hortorum L.H. Bailey, the most important species for commercial geranium production, is commonly known as the fish geranium, zonal geranium, house geranium, horseshoe geranium, or bedding geranium (Hortus III, 1976). The name storksbill is sometimes applied in reference to the schizocarp fruit (Smith, 1977).

Intercrossing of species within the sub-genus Ciconium resulted in the hybrid species Pelargonium x hortorum (Harney, 1976). The phylogeny of the cultigen is difficult to determine and there is considerable controversy among horticulturists; Craig (1971), however, postulated that Pelargonium zonale L., Pelargonium inquians L., Pelargonium hybridum L., Pelargonium frutetorum Dyher, and Pelargonium scandens Ehrhart are the major contributing species. Hortus III (1976) agrees with Craig in that Pelargonium zonale L., and Pelargonium inquians L. were the largest contributors to Pelargonium x hortorum. Craig (1971) also notes that the species is erroneously referred to as Pelargonium zonale L. the natural species.

The presence of a spur, consisting of a tube extending downward from the base of the uppermost sepal and fused to the pedicel or flower-stalk with a slightly swollen nectary at its base distinguishes

Pelargonium from its relatives in the Geraniaceae. Moore (1971) devised a key in which the species are arranged, in part, according to the type of spur.

Pelargonium x hortorum contains both diploids (2N=18) and tetraploids (2N=36). Tetraploid seed set is usually low and consequently most are asexually propagated (as are a few diploids). Seed produced cultivars are diploids because of their inherent fertility (Craig, 1971).

Floret type (Craig, 1971) (typically 5 petals in seedling cultivars) is controlled by one major gene acting without dominance. The expression of the double character is affected by modifiers and environmental conditions. Three independent genes govern flower color in Pelargonium x hortorum; darker colors are dominant over lighter colors, and epistasis plays an important role in geranium flower color. Plants with lighter flower colors (Craig, 1968) generally flowered faster and at a shorter height than plants with darker flower colors. It has been postulated that the presence of a recessive gene inhibiting anthocyanin pigments results in white flowers. Two genes control the 3 leaf zonation types Craig studied; no zone was dominant over zoning, and anthocyanin presence dominant over its absence. Henault and Craig (1970) concluded that plant habit was conditioned by one major gene acting with no dominance.

Seed Geraniums. Early in 1958, Craig (1968) found that geranium seed coat scarification raised the germination percentage from 40% in 3-4 weeks to 90-100% germination in 2 weeks. Craig and Walker released 'Nittany Lion Red', the first commercial variety to come true from

seed, in 1964; this cultivar was developed specifically as a bedding plant. Subsequent seed geranium introductions are commercially available from many seed companies (Harris, Pan American, Goldsmith, Denholm, and Sluis and Groot), and are being used and promoted as bedding plants. The following F_1 varieties are now commercially available: 'New Era' (1966), 'Carefree' (1968), 'Sprinter' (1973), 'Cherie' (1976), 'Firecracker' (1977), 'Scarlet Flash' (1977), 'Showgirl' (1977), 'New Early' (1977), 'Sooner' (1977), and 'Ringo' (1978) (Adams, 1978). A semidouble seed geranium was available in 1962 but not introduced because seed production was inefficient. In 1970 a limited series of semidouble flowered cultivars 'Double Dip' in a seed mixture called 'Parfait' were introduced.

Progeny uniformity is a major factor required in the production of commercial geraniums. Geraniums propagated from cuttings are uniform, while seedling uniformity results from the genetic homozygosity of inbred lines and the uniformity of F_1 hybrids (Craig, 1971).

Advantages of growing geraniums from seed are: seed is free from pathogens; germination percentage is high; many flower colors are available (Larsen, 1968); no stock plants need be maintained; seeds cost less than cuttings; seed geraniums outperform cutting varieties later in the season (Adams, 1978); less bench space needed in propagation areas; growth and flowering are more uniform; outdoor performance is good (Konjoian and Tayama, 1978). Disadvantages include: lack of floriferousness; long flowering time required (Larsen, 1968); specific germination temperatures must be maintained; flowers are single and petals have a tendancy to drop off prematurely during shipping or poor environmental conditions (Adams, 1978).

Craig (1968) felt that cultivars should be adapted through breed-into to optimum cultural conditions. Larsen (1968) found that germination percentages were almost identical for 3 scarification sites on the geranium seed coat, and that transplanted seedlings were generally superior to direct-sown seedlings. Pinching produced a short, well branched plant at the expense of a substantial delay in flowering (Craig and Walker, 1963; White , 1970). Lindstrom (1967), however, reported that pinching did not delay flowering.

A low fertility level produced an almost stunted plant (Wick and White, 1968). Plant height, fresh weight, and total number of flowers and buds increased with increasing quantities of Osmocote for all varieties tested, with leaves being too large and succulent to be of commercial value. Days to flower decreased as fertility level increased.

Some growth retardants (mostly Cycocel and A-Rest) hasten flowering, reduce fresh weight, total height, vegetative height, and increase the number of breaks (Armitage et al., 1978; Carlson, 1976; Carpenter and Carlson, 1970). However, Semeniuk and Taylor (1970) did not find that Cycocel affected lower initiation or time of flowering although it supressed vegetative growth, shortened internodes, and increased the number of basal shoots. Jansen (1973) found that Cycocel treated plants flowered 8-14 days earlier, and flower primordia differentiation occurred at least one week earlier on treated plants. Miranda (1979) found that with A-Rest and Cycocel the decrease in number of days to flower over control is similar for varying numbers of applications and time of applications. Miranda also found that for 'Sprinter Scarlet' A-Rest and Cycocel treated plants produced flower primordia earlier than controls.

Fresh weight increased with increased watering for all fertility levels except zero (White and Wick, 1968). Increased weight resulted mostly from increased foliage size and succulence. White (1970) reported that water stress was more effective than Cycocel in height control on seedling geraniums, but that flowering was adversely affected. Plant height, leaf area, and dry weight increased as soil moisture increased (Metwally, et al.). High moisture plants had increased petiole and stem diameters, thicker leaves, and a greater number of xylem elements.

Geranium seeds germinate uniformly in about one week if the media is at a nonfluctuating temperature between 70 and 75°F (Stinson, 1971). Optimum growth temperatures for geraniums are 65°F on dull days, and 70°F on bright days (Laurie et al., 1968) with night temperatures of 60-62°F (Stinson, 1971). Under growth chamber conditions a 75°F light period of 12 hours (Carpenter and Carlson, 1970) resulted in a 5 and 15 day delay in flowering when the dark period was 60°F and 50°F as compared to 70°F. Night temperatures of 55, 60, and 65°F (Konjoian and Tayama, 1978) did not alter plant quality, plant height, number of flowers, or number of breaks, but did decrease days to flower by 9-10 days for each temperature increase of 5°F.

Light. Light (electromagnetic energy) provides energy for photosynthesis, and the stimuli for photoperiodism, and photomorphogenesis (Bickford and Dunn,1972).

It has long been observed that shade affects internode and petiole elongation, leaf area, and flowering. Gourley (1920) found that shading decreased flowering of geranium, tomato, and nasturtium. In the same study, anthesis in geranium was delayed 16 days by shade. These

findings were later confirmed by Gourley and Nightingale (1921), and Craig and Walker (1961). Craig and Walker (1961) also noted that while geranium seedlings flowered in about 90 days in summer, under winter conditions it took twice that long; seeds sown early in the spring also took longer to flower than those sown later.

Supplemental light from February 13 to April 9 (Laurie and Poesch, 1932) increased the size of cutting geraniums, but did not lead to earlier flowering. Post (1942) found that daylength has no effect on geranium flowering; cutting geraniums are photoperiodically neutral in regard to flower induction. This has also been confirmed for seedling geraniums (Carpenter and Carlson, 1969; Craig, 1963; Larsen, 1968).

Craig and Walker (1963) hypothesized that flowering in seed geraniums is directly related to cumulative solar and sky radiation and not to chronological time. Sowing at various intervals from October to February and pinching half of each sowing they found that as a group, pinched plants took 37 days longer to flower, and the earlier the sowing date the greater the number of days to flower. Although plantings were significantly different in mean number of days to flower, all plantings needed equal amounts of energy to flower, non-pinched plants 55,000 g-cal/cm^2 and pinched plants 76,000 g-cal/cm^2 of solar energy. Craig and Walker concluded that cumulative solar energy was a major environmental factor controlling flowering in Pelargonium x hortorum, and suggested that a hypothetical substance independent of number of days and photoperiod but dependent on cumulative solar energy and temperature influences flower production. They also suggested that solar energy might be used to regulate the time of geranium seedling flowering.

In a pinching study, Lindstrom (1967) found that pinched and unpinched plants flowered in 150-160 days when sown in November. He felt that both groups of plants must have formed floral primordia simultaneously when light intensity increased, and concluded that seedling geraniums might require high light intensity for flowering.

Based on experimental evidence, Larsen (1968) postulated that seedling geranium response to solar energy followed two equations:

Seedling geraniums + low solar energy = delayed flower initiation, longer period for vegetative growth, and taller plants.

Seedling geraniums + high solar energy = accelerated flower initiation, reduced period for vegetative growth, and shorter plants.

Larsen hypothesized that precise scheduling of seedling geranium flowering would require knowledge of how much solar energy was received in an area for any given time of year, plus knowledge of cultivar response to solar energy. This information was incorporated in seedling geranium production schedules (White and Randolph, 1971), as in the northern hemisphere during spring months lower latitudes have greater light intensities than higher latitudes, permitting more rapid growth and flowering of geraniums.

Supplemental Light. Following the invention of a practical incandescent lamp by Edison in 1879 (Evans, 1969), experiments in 'electrohorticulture' by Bailey (1893) and others showed that flowering of several horticultural plants could be accelerated by extending natural daylengths with incandescent light.

Wilkins (1968) significantly hastened maturity, when young geranium seedlings were exposed to high intensity artificial light (1000-2000

ft-c) under growth chamber conditions.

Carpenter and Carlson (1969) found that adding 850 ft-c of artificial light did not result in significantly earlier flowering or greater plant height for 'Carefree'. They concluded that low intensity artificial light used as a sunlight supplement or to lengthen the photoperiod did not cause significantly earlier flowering.

Carpenter and Rodriguez (1971) concluded that supplemental lighting at 14 lamp watts/ft^2 for 1, 2, 3, or 4 weeks was of little value since it did not induce earlier flowering; the benefits of supplemental lighting up to 4 weeks were lost relatively quickly after lighting was discontinued since their days to flower were similar. Geraniums lighted 6 weeks or more flowered uniformly and appeared to be similar morphologically, indicating no value of supplemental light energy received after a threshold level.

Stinson (1971) concluded that geraniums grow slowly in periods of low light intensity and most rapidly when light intensity is over 5000 ft-c, if the plants don't overheat.

Maturity was hastened in geranium seedlings (White and Randolph, 1971) by about 30 days when Cool-White or Wide Spectrum Gro-lux fluorescent lamps were used at 1000 ft-c for the first 30 days after seedling emergence with 2000 ppm CO_2. They concluded that research findings lent support to the theory that hybrid geraniums are more responsive to an accumulation of energy units than to low energy lighting or day-length control.

Seed geraniums (Norton, 1973) can be flowered 3 weeks earlier than greenhouse-grown controls if grown with high intensity lighting (high pressure sodium and metal halide lamps) in the early seedling stage.

Although lighting was supplied in a growing room with daylight absent, Norton predicted a similar response if the lighting had been supplementary to daylight. He concluded that low winter light intensity and duration appear to be the primary factors in delayed flowering of seed propagated geraniums in northern latitudes.

Carpenter and Beck (1973) used Lucalox lamps at 58W/m^2 to supplement natural light on bedding plants for 1 to 4 weeks after transplanting and found that lighting increased plant height, root length, and fresh weight; differences became larger between lighted and unlighted treatments as the lighting period increased. Plants lighted 4 weeks flowered 9 to 23 days earlier, were slightly shorter and had larger top fresh weight than those unlighted. Benefits from supplementary light appeared to be cumulative.

Carpenter (1974) found that both seed and cutting propagated geraniums respond well to high intensity supplementary lighting. Plants lighted during propagation and after transplanting consistently flowered in fewer days from propagation and had as many branches, buds, and flowers as plants lighted only after transplanting. Lighting only during propagation was not as effective as lighting only after transplanting; either, however, was more effective than using only seasonal light.

Norton (1975) used a HPS supplementary light source from 10 AM to 10 PM at 500 ft-c for 44 days on seed geraniums after transplanting in 1974. He also used ancymidol and Cycocel in both spray and drench applications. Results showed a significant enhancement of flowering with growth retardants, with Cycocel spray at 1500 ppm being superior in considering cost and effectiveness. He found that lighting alone

resulted in 6 days earlier flowering, and that lighting was additive to the effect of growth regulators in enhancing bloom. In 1975, Norton conducted another group of experiments using supplementary HPS lighting and Cycocel at 1500 ppm. Lighting was reduced to 21 days after transplanting with the photoperiod being increased to 24 hours. Results were similar to the 1974 experiment. Cycocel alone enhanced flowering slightly, and reduced height at a low cost. Supplemental lighting alone enhanced flowering by a week and increased branching. HPS and Cycocel together was better than either alone. Norton concluded that flowering in F_1 geraniums is enhanced by light, and that lighted plants are stockier, have less disease problems, more breaks, and show less transplant shock.

Konjoian and Tayama (1978) used incandescent lights (approximately 10 ft-c) and Cycocel spray at 1500 ppm on 6 sowings of geranium seeds spaced every 2 weeks from December 6 through February 14. Plants were grown at 55, 60, and 65^{o}F night temperatures. They found that days to flower steadily decreased as sowing dates progressed which was attributed to increasing light intensity in the latter part of winter and into spring. Later propagation dates produced later flowering plants, but actual growing time was reduced. Incandescent dusk to dawn supplemental lighting resulted in 4-6 days earlier flowering, with slightly more flowers and taller plants. Lights and Cycocel together produced flowers earliest (9 days before control), and with more flowers per plant. Cycocel alone produced flowers 3-4 days earlier than controls. Control plants produced the most breaks, lights and Cycocel the fewest, and lights or Cycocel alone intermediate numbers.

In an experiment to determine the joint effect of HPS lighting

and Cycocel (Armitage et al.,1978) on the growth and flowering of F_1 hybrid seed geraniums, the combination of both treatments produced the earliest flowering (31 days less than controls), but the plants were dwarfed and of no commercial value. The HPS lighting treatment alone was the most effective, reducing the number of days to flower by 26, with the plants being of good quality. Cycocel hastened flowering more under ambient light than under supplementary light. Plants seemed most responsive to supplementary light during periods of low light intensity in late February and March.

Lighting. Many types of lamps have been used for supplemental and photoperiodic lighting; most were developed for home or industry, and then "borrowed" by horticulturists. Various light sources have been compared (Campbell et al., 1971; Carpenter, 1974; Norton, 1973), but controversy over the best lamp type and how light should be measured has not been resolved.

Incandescent lights are inefficient as most of the electrical energy is converted to heat; visible energy is largely red which can cause excessive plant elongation if used as night lighting. Fluorescent lamps have a better balance in light color emisssion than incandescent lamps and give a diffuse light with high electrical energy efficiency. Cool-White, warm white, or daylight fluorescent lamps emit predominately in the blue-green-yellow range. Mercury lamps are similar to fluorescent, they are used as supplemental lighting and have accelerated plant growth of higher quality. Without a phosphor coating inside the glass lamp, however, mercury lamps can cause plant damage from excessive ultraviolet emission. Phosphor coated metal halide lamps have a better color

balanced light emission for plant growth than mercury lamps. Sodium vapor lamps have a spectral emission primarily of yellow-orange-red (550-650 nm) (Carpenter, 1974).

Meijer (1971) grew gherkin seedlings under 4 different types of fluorescent lamps and found no reproducible differences between the effects of the lamps in fresh or dry weight. In a comparison of fluorescent growth lamps with emission spectra adapted to plant growth and Cool-White fluorescent lamps on bedding plants in a growing room, Norton (1971) found that the Cool-White illumination resulted in greater fresh weight and dry weight, and produced a more marketable plant type. He concluded that fluorescent lamps, used either as supplementary to natural light, or alone, appeared efficient for commercial production of some bedding plants, and that the standard industrial type of Cool-White was the better light source. In another experiment, Norton compared fluorescent supplemental lighting during the day with lighting at night and found that 7 hours of supplemental lighting during the middle of the night period was almost as beneficial as 14 hours during the day.

High output fluorescent lamps were used alone and in combination with tungsten and delux mercury lamps by Leiser et al. (1960) in a series of light intensity studies for each light source to measure the effect on growth rate of Knox wheat and red kidney bean. A growth/light intensity curve for each source was then plotted to compare light sources by the position and slope of the response curve. The growth response was reported in total radiant power (watts) in the visible spectrum, but also in ft-c as the authors felt it provides for great convenience in reporting illumination even though it does not correct for differences in spectral distribution. Increasing intensity of each

light source resulted in a highly significant increase in growth rate. Maximum wheat growth occurred under fluorescent plus mercury vapor lamps and maximum for bean under fluorescent and tungsten. Wheat and bean growth rates were the most reduced under fluorescent lights alone, the authors felt this illustrated better growth could be obtained when longer wave-length light is added. They also felt that their method of evaluating light sources by means of growth curves is more practical than comparing various spectral regions at uniform illumination intensities as was introduced in the mid fifties.

Cook et al. (1971) determined the action spectrum of cucumber and used it to compute the photosynthetic flux of lamps investigated and interpret their effects. Lamps used as supplementary light were high-pressure mercury arc (MB/U), mercury iodide (MBI/U), low pressure sodium arc (SOX), and high pressure arc (HPS). Results indicated no significant difference between the lamps when they were compared in terms of photosynthetic flux. The order of promotion of plant development was SOX, HPS, MBI, MBF, MB, and control. The rate of development of the plants was in the same order as the photosynthetic flux from the lamps under which they were grown.

Bickford and Dunn (1972) found the sodium vapor lamp to be the most efficient of the high intensity discharge lights in converting input energy to luminosity.

Norton (1973) found that at equal intensities (750-1000 ft-c) metal halide illumination was slightly superior to high pressure sodium in lessening the number of days to flower for seed geranium, although HPS is considerably more efficient in converting electricity to visible light. He felt, however, that if the lights had been installed at

equivalent wattage the HPS illumination would be just as effective.

Meijer (1971) grew tomatoes and cucumbers in glasshouses with high pressure gas discharge lamps as supplementary lighting. The SON gave the best results (efficiency about 27%) followed by the HPI lamp (efficiency about 22%). Meijer, taking into account the gherkin study, concluded that light quality of the visible part of the spectrum was much less important for plant growth than has often been stated. The efficiency of the lamp (energy output of visible radiation/energy x 100%) is a much more important factor.

Norton (1975) compared three lamps used as supplemental light, a 400W phosphor coated metal halide, a 400W HPS, and 215W Cool-White fluorescent with internal reflector. He found that seed geranium response was identical in terms of flowering and vegetative growth when the three lamps were at equivalent light intensities (500 ft-c). He concluded that from a practical view, therefore, a ft-c meter could be used to lay out greenhouse supplementary lighting installations instead of using the more expensive meters that measure photosynthetically active radiation. Norton also believed spectral energy distribution of the light source is much less important in supplementary lighting in the greenhouse than it would be in a growth chamber.

Cambell et al. (1971) reviewed characteristics and performance of electric lamps used in horticultural applications in the United States. They agreed that the universal meter for light measurement is the illumination (ft-c) meter, although they caution that the information is based on light efficient for human vision, which is not necessarily light efficient for plant response.

McCree (1972) concluded that quantum flux was clearly superior to energy flux as a measure of photosynthetically active radiation, and that quantum flux in the 400-700 nm waveband was an acceptable definition of photosynthetic flux. He also found that the high pressure sodium lamp produces the most visible light per watt, as well as producing most of its light in the most photosynthetically active part of the spectrum.

MATERIALS AND METHODS

Two cumulative PAR (400-700 nm) energy experiments were conducted using three Pelargonium x hortorum Bailey (seed geranium) cultivars, 'Sprinter Scarlet', 'Sprinter White', and 'Ringo'. The 5 light treatments (Table 1) were conducted on the north side of an east-west oriented house, in the Plant Science Range at Michigan State University, with one light treatment per bench.

Table 1. Five light treatments used in cumulative PAR energy experiments on 3 cultivars of Pelargonium x hortorum.

Treatment	
1	24 hours a day HPS, natural light, 2 layers Saran
2	24 hours a day HPS, natural light, 1 layer Saran
3	natural light
4	12 hours a day HPS[z], natural light
5	24 hours a day HPS, natural light

[z]HPS on from 6 AM to 6 PM.

Seeds were sown in Speedling Mix (a peatlite mix manufactured by Speedling, Inc., Sun City, FL) in plastic master flats on 23 February and 12 April, 1978, and germinated in the mist bench at 21-24°C;

seedlings were removed from the mist bench two days before transplanting.

The growing medium for the first experiment, Speedling Mix plus 3 kg/m^3 Osmocote (18-6-12), did not allow for frequent watering under cloudy Michigan conditions, so a more porous 1:1:1 medium by volume of soil:peat:perlite with 0.8 kg/m^3 superphosphate (0-20-0) was used for the second experiment. Three weeks after sowing, 125 seedlings in the two leaf stage of each cultivar were selected and transplanted into 7.6 cm square plastic cells.

Three days after transplanting a dimethylaminobenzenediazo sodium sulfonate (Dexon) - pentachloronitro benzene (Terraclor) drench was applied at a rate of 0.6 gm of 35% wettable powder Dexon and 0.3 gm of 75% wettable powder Terraclor per liter of water. Chlormequat (Cycocel) was applied to run-off at 1500 ppm 35 and 42 days after sowing.

Soil was sampled at the beginning of the experiment, and then at weekly intervals until the conclusion of the experiment to maintain pH and soluble salts. Constant liquid fertilization of 200 ppm 25-0-25 was applied to plants at each irrigation. The pH of the irrigation water was lowered to 6.0 by addition of phosphoric acid to the fertilizer stock solution.

Greenhouse temperatures were set at 17°C nights and 21°C days. Actual greenhouse temperatures were measured by thermograph (Taylor Instruments, Asheville, NC). Degree days (Table 7) were calculated using methods of Baskerville and Emin (1968); the daily maximum and minimum temperatures were added, divided by 2, and the base temperature of 16.7°C subtracted.

Twenty-five seedlings of each cultivar were randomly distributed within each of the 5 light treatments utilizing a completely randomized

design. Original spacing was 97 plants/m^2; an outside row of guard plants was used in each experiment. When experiment II plants were transplanted they were moved onto the center portion of each bench, with experiment I plants respaced around them. Plants were respaced (expt I day 69, expt II day 71) when their leaves began to overlap.

All benches received natural light. Four G.E. Duraglow luminaires with high pressure sodium (HPS) 400 watt Lucalox lamps (General Electric Company, Hendersonville, NC) were suspended 239 cm above each of four benches. Blackcloth was suspended between benches and along the center aisle to block extraneous light, and pulled at 5 PM and retracted at 8 AM. Saran cloth (50% light reduction weave) was stretched at a height of 122 cm above two of the benches, with one bench having 2 layers. The outer perimeters of these two benches also had a single layer of Saran hung from 122 cm above to below the bench to equalize light entering from the side of the bench. Light treatments began on 18 March and 3 May respectively for experiment I and II.

Quantum flux density from the HPS lamps was determined with a Lambda LI-185 Quantum/Radiometer/Photometer with Quantum Sensor Li-190S (Lambda Instruments Corporation, Lincoln, NE) and seedlings were placed where light energy was most uniform. A Lambda LI-500 Integrator was used with Quantum Sensor LI-190S on each bench to record total cumulative light energy in the 400 to 700 nm waveband, the photosynthetically active radiation (PAR). Mathematical conversion from integrator counts to microeinsteins/m^2 can be found in the Appendix. Quantum sensors were leveled on inverted 7.6 cm plastic cells, and placed on the bench to measure the average light energy received.

The following observations were recorded for each plant on the day

the first flower on the first inflorescence opened; cumulative PAR, number of days to flower from sowing, vegetative plant height (cm) measured from soil line to the uppermost leaf held parallel to the soil, total plant height (cm) from the soil line to tip of the flower petal, number of breaks (growing point 0.5 cm from the stem or more and 3 fully developed leaves), and fresh weight (gm) of plants above the soil line.

A photosynthetic light saturation study was done on one 'Sprinter Scarlet' guard plant from experiment II on 9/29/78. Photosynthetic (Pn) and photosynthetic light responses were determined using an open gas analysis system, similar to that described by Wolf et al. (1969). Briefly, air was pumped into whole leaf chambers (Paige Instruments, Davis CA) which enclosed the leaf. Environment control within the chamber was held constant at 25 $\pm$ ½°C; 90% R.H. and 346-358 ppm CO_2. Light intensity was varied by raising or lowering a 400W metal halide lamp above the chamber. Air leaving the chamber was analyzed for CO_2 with a Beckman 865 CO_2 analyzer used in the differential mode. Leaf area was determined immediately after removing the leaf from the chamber. Pn was expressed as mg of $CO_2 dm^{-2} h^{-1}$.

Data were analyzed using the SPSS package on the Michigan State University CDC Computer for one way analysis of variance, regression, and Duncan's Multiple Range Test at the 0.05 level (Duncan, 1955). Regression was used since light is a quantitative factor (Chew, 1976). Statistics were done on each cultivar separately.

RESULTS

Plant data taken were regressed on cumulative photosynthetic radiation. Correlation coefficients were significant at the .01 or .05 level with exceptions of fresh weight for all 3 cultivars in experiment I, and 'Ringo' vegetative height in experiment II. Regression for cumulative PAR against number of days to flower for 'Sprinter Scarlet', 'Sprinter White', and 'Ringo' (Figures 1-3) were negatively correlated, with correlation coefficients significant at the .01 level. Correlation coefficients (Table 2) relating cumulative PAR to number of days to flower ranged from -0.64 to -0.80; vegetative plant height from a non-significant -0.07 in experiment II to a high of -0.74 for 'Ringo' in experiment I; total height from -0.45 to -0.79; number of breaks from 0.50 to 0.87; and fresh weight from 0.01 to 0.67.

Geraniums sown 23 February (experiment I) took longer to flower and received more cumulative PAR for corresponding treatments than those sown 12 April (experiment II) (Table 3). In general, the lower the treatment light level, the higher the number of days to flower and the less amount of PAR the plants received when they first flowered. Cumulative PAR received within each of the 3 cultivars at time of flowering in experiment I were all significantly different from each other except for treatments 3 and 5 for 'Sprinter White'. In experiment II, treatments 4 and 5 received similar amounts of cumulative PAR within each of the 3 cultivars while all other treatments within cultivars received different levels of cumulative PAR.

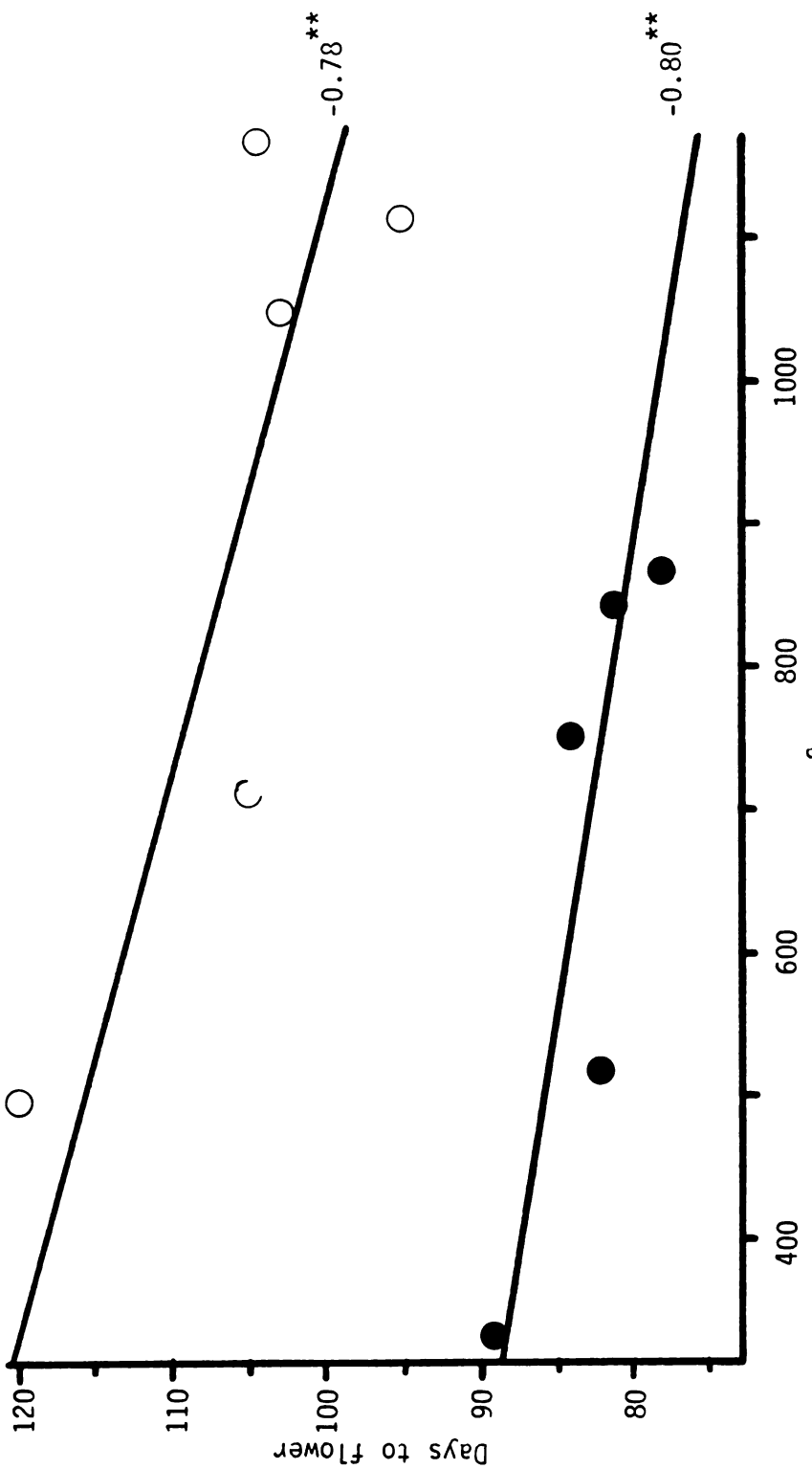

Figure 1. Scatter plots and regression lines for 'Sprinter Scarlet' in experiment I (○) and experiment II (●). Cumulative PAR against number of days to flower.

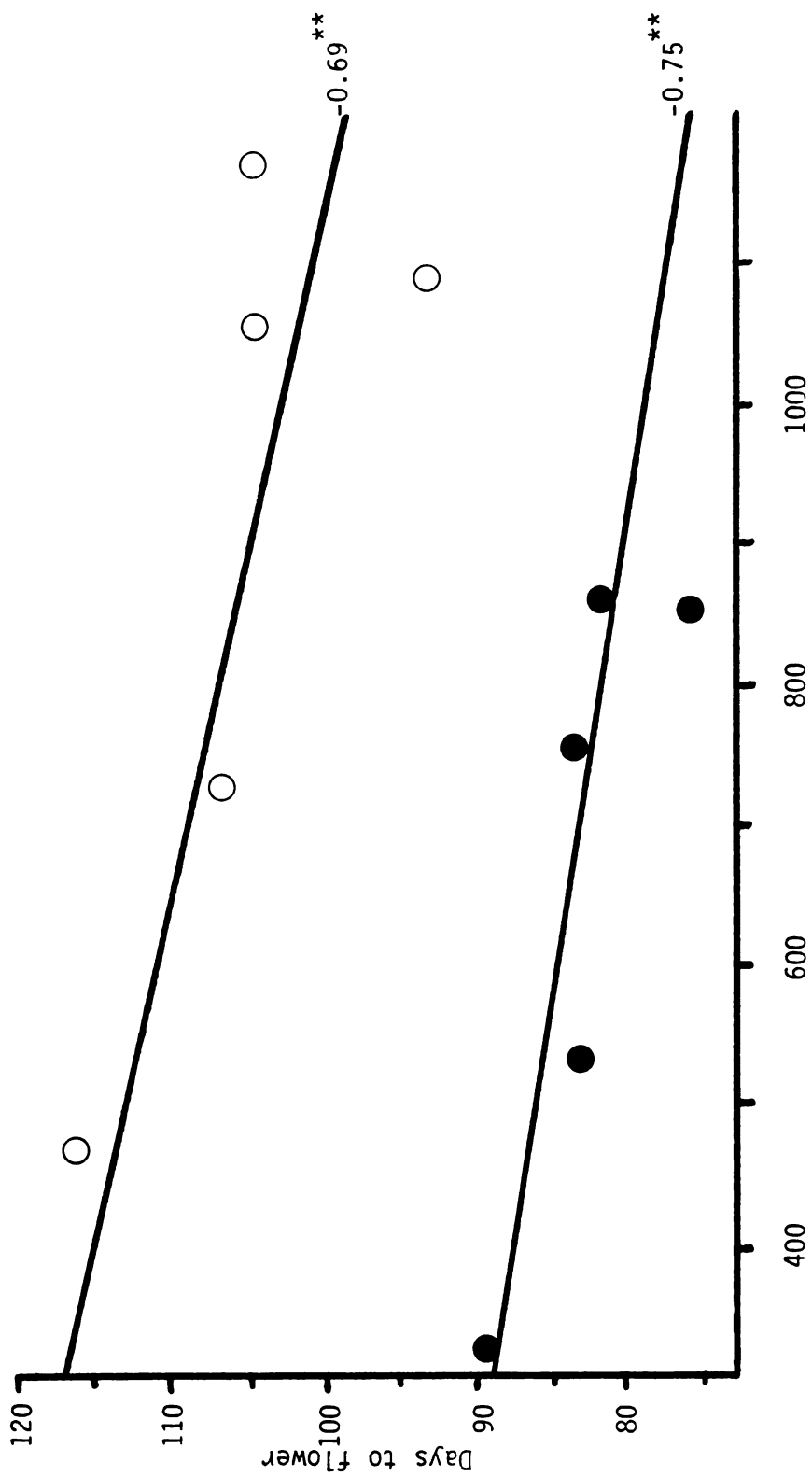

Figure 2. Scatter plots and regression lines for 'Sprinter White' in experiment I (○) and experiment II (●). Cumulative PAR against number of days to flower.

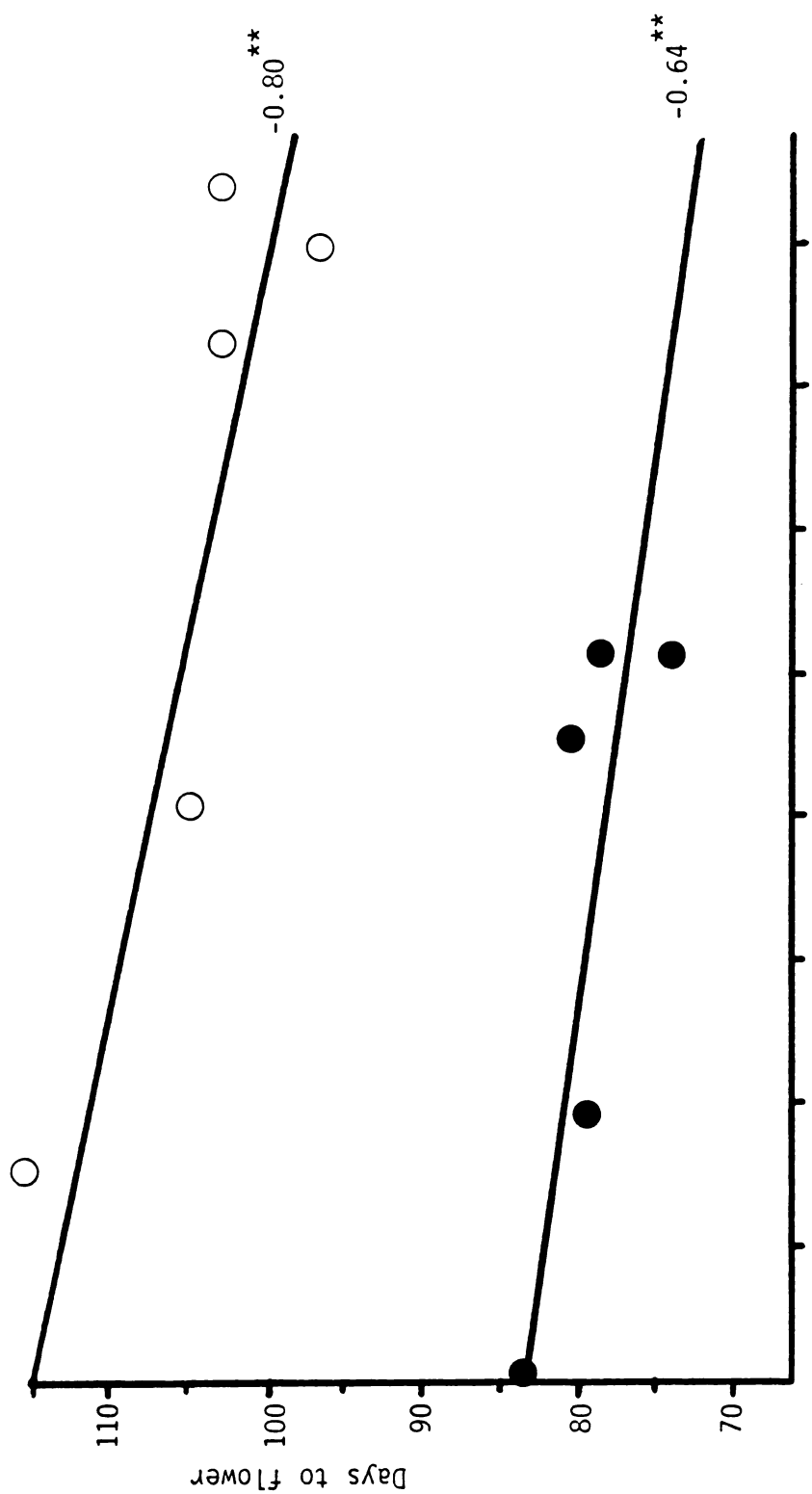

Figure 3. Scatter plots and regression lines for 'Ringo' in experiment I (○) and experiment II (●). Cumulative PAR against number of days to flower.

Table 2. Correlation coefficients (CC) and R^2 values for number of days to flower, vegetative plant height, total plant height, number of breaks, and fresh weight as a function of cumulative energy for 3 seed geranium cultivars. N=24.

Cultivar	Days to flower CC (R^2)	Vegetative plant ht CC (R^2)	Total plant ht CC (R^2)	No. of breaks CC (R^2)	Fresh weight CC (R^2)
Sprinter Scarlet					
Experiment I	-0.78**(61)	-0.66**(44)	-0.79**(62)	0.72**(52)	0.01 (00)
Experiment II	-0.80**(65)	-0.62**(38)	-0.60**(36)	0.77**(59)	0.50**(25)
Sprinter White					
Experiment I	-0.69**(48)	-0.65**(42)	-0.68**(46)	0.50**(25)	-0.26 (07)
Experiment II	-0.75**(58)	-0.42* (18)	-0.53**(28)	0.77**(59)	0.44* (19)
Ringo					
Experiment I	-0.80**(64)	-0.74**(55)	-0.72**(52)	0.69**(48)	0.06 (00)
Experiment II	-0.64**(41)	-0.07 (00)	-0.45* (20)	0.87**(76)	0.67**(45)

**Significant at 1% level.

*Significant at 5% level.

Table 3. The effect of cumulative light energy (E/m^2) on the average number of days to flower for 3 seed geranium cultivars.

Cultivar		Treatments 1 Natural light 24HPS,2 Saran	2 Natural light 24HPS,1 Saran	3 Natural light	4 Natural light 12HPS	5 Natural light 24HPS
Sprinter Scarlet						
Experiment I	E/m^2	497.77 a[z]	725.40 b	1050.13 c	1165.40 d	1123.99 e
	Days	119.7 a	105.4 b	103.9 b	104.9 b	96.3 c
Experiment II	E/m^2	335.19 a	518.38 b	752.93 c	847.87 d	865.68 d
	Days	88.8 a	82.8 bc	83.6 b	81.2 c	78.0 d
Sprinter White						
Experiment I	E/m^2	480.46 a	732.56 b	1057.82 c	1165.50 d	1085.78 c
	Days	116.0 a	106.3 b	104.5 b	104.8 b	93.9 c
Experiment II	E/m^2	339.22	520.32 b	752.93 c	854.60 d	844.17 d
	Days	89.6 a	83.0 b	83.4 b	81.9 b	76.4 c
Ringo						
Experiment I	E/m^2	472.05 a	714.11 b	1029.22 c	1131.52 d	1099.48 e
	Days	114.4 a	104.0 b	102.3 b	102.6 b	94.8 c
Experiment II	E/m^2	307.78 a	495.35 b	726.20 c	805.93 d	806.04 d
	Days	83.4 a	79.4 b	80.5 b	78.1 b	73.7 c

[z]Mean separation in rows by Duncan's multiple range test, 5% level.

In experiment I, for all cultivars, the number of days to flower for treatment 1, which flowered in the greatest number of days, was significantly different at the 5% level from the number of days to flower for treatment 5, which flowered in the fewest number of days; the number of days to flower for both treatments 1 and 5 were significantly different from the number of days to flower for treatments 2, 3, and 4 which flowered in a similar number of days. The same pattern was followed in experiment II by 'Sprinter White' and 'Ringo'. 'Sprinter Scarlet' followed the same general trend, with the variation of treatments 2 and 4 flowering in a similar number of days, and treatments 2 and 3 flowering in a similar number of days.

To obtain an equalization factor, cumulative PAR for each treatment, experiment, and cultivar was divided by the respective number of days to flower to obtain an average of E/m^2 received per day (Table 4). Letters for Duncan's multiple range test at the 5% level for cumulative PAR and number of days to flower (from Table 3) are included in Table 4.

In general, as the supplemental light level increased, the vegetative and total plant height (Table 5) decreased significantly as heights for treatments 1, 3, and 5 are compared for all cultivars and both experiments. In experiment II 'Ringo' vegetative height was similar for all five treatments.

For all cultivars in both experiments, plants grown under the highest light level, treatment 5, had significantly more breaks than those grown under natural light, treatment 3, or the lowest light level, treatment 1 (Table 6); plants receiving the lowest amount of cumulative light energy, treatment 1, had the fewest breaks.

Table 4. Average light energy (E/m^2) received per day for 3 seed geranium cultivars with letters from Duncan's multiple range test for cumulative PAR (E/m^2) and days to flower.

Cultivar		Treatments 1	2	3	4	5
Sprinter Scarlet						
Experiment I	E/m^2	a[z]	b	c	d	e
	Days	a[z]	b	b	b	c
	Avg	4.16	6.88	10.11	11.11	11.67
Experiment II	E/m^2	a	b	c	d	d
	Days	a	bc	b	c	d
	Avg	3.77	6.26	9.01	10.44	11.10
Sprinter White						
Experiment I	E/m^2	a	b	c	d	c
	Days	a	b	b	b	c
	Avg	4.14	6.89	10.12	11.12	11.56
Experiment II	E/m^2	a	b	c	d	d
	Days	a	b	b	b	c
	Avg	3.79	6.27	9.03	11.43	11.05
Ringo						
Experiment I	E/m^2	a	b	c	d	e
	Days	a	b	b	b	c
	Avg	4.13	6.87	10.06	11.03	11.60
Experiment II	E/m^2	a	b	c	d	d
	Days	a	b	b	b	c
	Avg	3.69	6.24	9.02	10.32	10.94

[z]Mean separation in rows by Duncan's multiple range test, 5% level.

Table 5. The effect of cumulative light energy (E/m^2) on the average vegetative[z] and total[y] plant height (cm) for 3 seed geranium cultivars.

Cultivar	Treatments 1 Natural light 24HPS,2 Saran	2 Natural light 24HPS,1 Saran	3 Natural light	4 Natural light 12HPS	5 Natural light 24HPS
Sprinter Scarlet					
Experiment I Veg	14.2 a[x]	11.3 b	11.1 b	12.1 c	10.2 d
Total	25.7 a	22.1 b	21.4 b	21.9 b	20.1 c
Experiment II Veg	10.7 a	10.5 ab	9.8 bc	10.1 abc	9.4 c
Total	20.1 a	19.1 b	18.9 b	19.5 ab	16.5 c
Sprinter White					
Experiment I Veg	14.2 a	12.6 b	11.5 b	12.5 b	10.0 c
Total	25.1 a	22.9 b	21.9 b	22.0 b	19.0 c
Experiment II Veg	10.7 a	10.3 ab	9.7 bc	10.5 ab	9.5 c
Total	21.1 a	20.1 ab	18.7 bc	20.1 ab	17.8 c
Ringo					
Experiment I Veg	13.4 a	11.6 b	11.0 c	11.8 b	10.2 d
Total	23.9 a	21.7 b	20.3 b	21.0 b	18.0 c
Experiment II Veg	10.6 a	10.6 a	10.3 a	10.9 a	10.0 a
Total	20.2 a	18.2 b	18.3 b	19.6 a	16.0 c

[z]Measured from soil line to tallest leaf held parallel to soil.
[y]Measured from soil line to tip of flower petals on first flower.
[x]Mean separation in rows by Duncan's multiple range test, 5% level.

Table 6. The effect of cumulative light energy (E/m^2) on the average number of breaks[z] per plant for 3 seed geranium cultivars.

Cultivar	Treatments 1 Natural light 24HPS,2 Saran	2 Natural light 24HPS,1 Saran	3 Natural light	4 Natural light 12HPS	5 Natural light 24HPS
Sprinter Scarlet					
Experiment I	1.1 a[y]	2.4 b	2.3 b	3.6 c	5.4 d
Experiment II	1.4 a	2.7 b	2.3 b	3.5 c	4.6 d
Sprinter White					
Experiment I	1.0 a	2.1 b	2.2 b	1.8 ab	4.0 c
Experiment II	1.2 a	2.2 b	2.5 b	2.8 b	3.6 c
Ringo					
Experiment I	1.0 a	2.5 b	2.3 b	2.5 b	4.1 c
Experiment II	1.4 a	2.4 b	2.8 bc	2.9 c	3.6 d

[z]Growing point 0.5 cm from the stem or more and 3 fully developed leaves.

[y]Mean separation in rows by Duncan's multiple range test, 5% level.

Plants in experiment I had greater fresh weight (Table 7) for corresponding treatments than plants in experiment II for all 3 cultivars. The effect of cumulative PAR on fresh weight in these experiments did not seem to follow any consistent pattern or trend.

Plants in experiment I had a greater number of degree-days (Table 8) for corresponding treatments and cultivars than plants in experiment II. Degree-days increased as the number of days to flower increased; plants in treatment 1 had a greater number of degree-days than plants in treatment 5. Degree-days for 'Sprinter Scarlet' ranged from a high of 423^{o}C in treatment 1 of experiment I to a low of 294^{o}C in treatment 5 of experiment II. The other 2 cultivars followed the same pattern; 'Sprinter White' had a high of 400^{o}C and a low of 278^{o}C, 'Ringo' a high of 387^{o}C and a low of 264^{o}C. Day temperatures averaged 26.7-27.2^{o}C for experiments I and II. Night temperatures averaged 14.4-15^{o}C for experiment I and 16.7^{o}C for experiment II.

'Sprinter Scarlet' light saturation (Figure 4) occurred at approximately 900 $\mu Em^{-2}sec^{-1}$, which is approximately half full sunlight outside on a sunny summer day; the light compensation point was approximately 15 $\mu Em^{-2}sec^{-1}$.

Table 7. The effect of cumulative light energy (E/m^2) on the average fresh weight (g) of 3 seed geranium cultivars.

Cultivar	Treatment 1 Natural light 24HPS,2 Saran	2 Natural light 24HPS,1 Saran	3 Natural light	4 Natural light 12HPS	5 Natural light 24HPS
Sprinter Scarlet					
Experiment I	31.2 ab[z]	27.8 c	28.5 ac	33.6 b	26.6 c
Experiment II	19.7 a	22.0 bc	19.8 ab	24.2 c	23.2 c
Sprinter White					
Experiment I	29.4 a	33.6 a	29.7 a	29.5 a	25.1 b
Experiment II	19.9 a	21.4 ab	19.8 a	24.3 b	22.5 ab
Ringo					
Experiment I	24.7 ab	27.6 ac	24.8 ab	27.8 c	24.0 b
Experiment II	18.9 a	21.7 b	23.1 b	26.1 c	21.8 b

[z]Mean separation in rows by Duncan's multiple range test, 5% level.

Table 8. Degree-days in $^{o}C(^{o}F)$ for the average number of days to flower for 3 seed geranium cultivars.

Cultivar	Treatments 1 Natural light 24HPS,2 Saran	2 Natural light 24HPS,1 Saran	3 Natural light	4 Natural light 12HPS	5 Natural light 24HPS
Sprinter Scarlet					
Experiment I Days	119.7	105.4	103.9	104.9	96.3
Degree-Days	423(760)	355(639)	350(630)	355(639)	311(560)
Experiment II Days	88.8	82.8	83.6	81.2	78.0
Degree-Days	361(650)	317(570)	322(579)	313(562)	294(529)
Sprinter White					
Experiment I Days	116.0	106.3	104.5	104.8	93.9
Degree-Days	400(720)	358(645)	350(630)	355(639)	292(526)
Experiment II Days	89.6	83.0	83.4	81.9	76.4
Degree-Days	365(657)	317(570)	317(570)	314(564)	278(500)
Ringo					
Experiment I Days	114.4	104.0	102.3	102.6	94.8
Degree-Days	387(697)	350(630)	342(616)	346(622)	302(543)
Experiment II Days	83.4	79.4	80.5	78.1	73.7
Degree-Days	317(570)	303(546)	313(562)	294(529)	264(476)

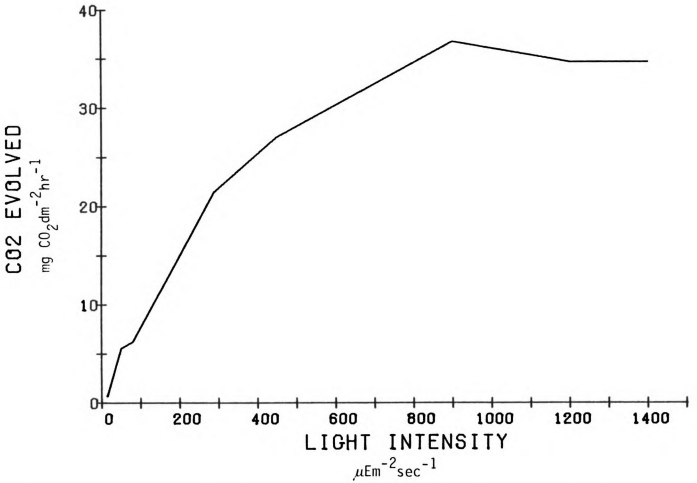

Figure 4. Photosynthetic light saturation study on 'Sprinter Scarlet' 9/29/78.

DISCUSSION

The scatter plot, regression lines, and significant negative correlation coefficients for cumulative PAR against number of days to flower for 'Sprinter Scarlet', 'Sprinter White', and 'Ringo' (Figures 1-3) indicate that 41-65% of the variability in the number of days to flower can be accounted for by cumulative PAR. This suggests that cumulative light energy is the most important factor in influencing the number of days to flower, although it is not the only factor.

Craig and Walker (1963) suggested that cumulative solar energy is a major environmental factor controlling the flowering of seed geraniums, and that the hypothetical substance that influences flower production was independent of photoperiod and number of days, but dependent on cumulative solar energy. As plants in experiment I flowered with higher levels of cumulative PAR than those in experiment II, and there were only 4 instances (treatments 3 and 5 for 'Sprinter White' in experiment I and treatments 4 and 5 for all 3 cultivars in experiment II) where plants flowered with similar amounts of energy and a significantly different number of days, the data suggests that there is not a set amount of cumulative PAR the plant must receive before it will flower, as suggested in previous work by Craig and Walker. It must be kept in mind that Craig and Walker measured all sun and sky radiation, however, while cumulative PAR was the light energy of interest in these experiments. The connection between these experiments and previous work may be the effect cumulative light energy has in producing carbohydrates and other

products in the plant that influence flowering.

Light, through quality, period, and intensity, is important for plant growth and development in photosynthesis, photoperiodism, and photomorphogenesis. It is through photosynthesis, however, that plants are able to obtain what they require for growth, as photosynthesis converts radiant energy into chemical energy in the form of carbohydrates and other organic compounds which are used as structural components and as a source of energy (Mastalerz, 1977). McCree (1972) maintains that quantum flux is the most superior measure of photosynthetically active radiation.

Proper spectral composition and high intensity of light are necessary for adequate photosynthesis to take place. This builds up a carbohydrate store which is probably necessary for the proper function of the photoperiodic mechanism as well as metabolic processes (Bickford and Dunn, 1972). According to Bickford and Dunn, Hamner (1940) clearly demonstrated what has been called the "high-intensity-light reaction" which was verified by Liverman and Bonner (1953) when they found that sucrose treatments could substitute for sunlight exposure. It is possible that the carbohydrate levels built up much more quickly in treatment 5, the highest daily light level, and hastened flowering significantly when compared with treatment 3, natural light, and treatment 1, the lowest light level treatment. Mastalerz (1977) stated that the supply of photosynthates in excess of energy requirements determines the yield and quality of a flower crop.

In these experiments, treatments 2, 3, and 4 showed similar plant growth patterns, although the total amount of light energy they received was significantly different from each other. Treatments 1 and

5 showed marked differences as well. Larsen (1968) found that the number of days from macroscopically-visible flower buds in seedling geraniums to the time the first flower expanded was approximately 25 days regardless of the plant's sowing date. Plants receiving higher levels of cumulative PAR may have initiated flowers sooner, thereby decreasing vegetative growth, while plants in the lowest cumulative PAR treatments didn't initiate flowers as quickly and thus had more time to grow vegetatively. Plants in the higher light level treatments had more breaks than those in lower light level treatments; apical vegetative growth is sometimes depressed and axial growth enhanced when apical meristems become reproductive. The high light intensity seems to have a similar effect to Cycocel, which decreases apical vegetative growth and produces a shorter, better branched plant.

It is likely that plants receiving high light level treatments produce more carbohydrates and therefore became reproductive more quickly compared with plants under low light. This is not a new idea. According to Sachs and Hackett (1969) Kraus and Kraybill (1918) stated that carbohydrate levels may control floral initiation and development. They worked on tomato, another plant that needs high light levels to produce flowers. Allsopp (1965) in a review on morphological changes concludes that "...sugar concentration appears to play a major role in morphogenesis...and...some of the effects of sugar concentration are probably relatively direct, while others represent a genetically determined response of the plant to a particular level of sugar concentration". Cumming (1967) suggested there might be optimal levels of carbohydrates for reproductive development. The lowest light level treatment, treatment 1, may have been producing carbohydrates at a much slower rate

and it therefore took much longer for a supply to build up that would lead to inflorescence development.

The geranium seems to be quite efficient photosynthetically, as shown by the steep slope of the line in Figure 4 as light energy is increased at the beginning of the study. Small increases in light energy levels resulted in much higher photosynthetic rates. Plants grown under high light conditions have a thicker leaf, with more chlorophyll (Greulach, 1973). 'Sprinter Scarlet', used in the photosynthetic study, was from experiment II which was grown under higher light energy levels. Plants in experiment I, therefore, may have had less chlorophyll and would have saturated for photosynthesis at a lower light intensity, allowing for less carbohydrate synthesis, which could possibly explain why they took longer to flower when compared with experiment II plants.

In Table 8 it is interesting to note that although experiment I plants took more days to flower, and received higher levels of cumulative PAR, average daily energy levels are quite similar within each treatment to those of experiment II for all cultivars. Treatment 1 averages are much less than those for treatment 5. Treatments 2, 3, and 4 all flowered in a similar number of days within each cultivar and experiment, although their average daily light energy levels vary. Averages for treatments 4 and 5 are also similar, although treatment 4 plants took longer to flower. A possible explanation for this is that plants in treatments 3, 4, and 5 may have saturated for photosynthesis on extremely bright days, so some of the cumulative PAR recorded was not being used by the plant. The amount of light energy added to treatment 4 from the HPS lamp was approximately

37 $\mu Em^{-2}sec^{-1}$ from 6 AM to 6 PM, which might not have had much effect in hastening flowering when compared with natural radiant energy. Treatment 2, however, received 23 $\mu Em^{-2}sec^{-1}$ during the night period. According to the photosynthetic study, this is enough light energy for photosynthesis to occur. It is possible that the effect of the 1 layer of Saran was compensated for by the HPS lamp at night. Treatment 1 plants received an average of 10 $\mu Em^{-2}sec^{-1}$ from the HPS lamp, so it is not likely that they photosynthesized during evening periods. Treatment 5 plants received an average of 40 $\mu Em^{-2}sec^{-1}$ from the HPS lamp at night, so they should have been able to continue photosynthesis during the night. This might account for the earlier flowering of treatment 5 plants compared with treatment 4 plants. It is likely that duration of light energy at a level high enough for photosynthesis to occur can also influence the number of days to flower in seedling geraniums.

SUMMARY AND CONCLUSIONS

The two experiments run on three cultivars of seedling geraniums indicated that light energy in the photosynthetically active region influences the number of days to flower. Cumulative photosynthetically active radiation accounted for 41-65% of the variaton in the number of days to flower in these experiments, so although it may be a major controlling factor it is not the sole controlling factor, and other factors will have to be investigated before a precise seedling geranium scheduling mechanism can be developed.

As cumulative PAR increased, the number of days to flowering decreased, as did total and vegetative plant height, while the number of breaks increased. This could be a result, perhaps, of floral initiaton occuring sooner when daily energy levels are high.

It is possible that flowering in seedling geranium might be connected with the amount of photosynthetically active radiation the plant receives, and the build up of photosynthetic products in the plant.

APPENDIX

APPENDIX

Given: 14 counts/μa-hr

Sensor calibration constant (SCC)

Time period in hours (TPH)

Time period in seconds (TPS)

Integrator counts (IC)

A. $$\frac{IC}{(14 \text{ counts}/\mu\text{a-hr})(\text{SCC-}\mu\text{a}/1000\ \mu\text{E m}^{-2}\text{sec}^{-1})} = \mu\text{E m}^{-2}\text{sec}^{-1}\text{-hr}$$

B. $$\frac{\mu\text{E m}^{-2}\text{sec}^{-1}\text{-hr}}{\text{TPH}} = \mu\text{E m}^{-2}\text{sec}^{-1}$$

C. $$(\mu\text{E m}^{-2}\text{sec}^{-1})(\text{TPS}) = \mu\text{E m}^{-2}$$

Figure 5. Converting integrator counts to total microeinsteins/meter^2. (Adapted from Appendix A4 of Li-Cor Instruction Manual for Li-500 Integrator.)

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DISCUSSION

Correlation coefficients for regression lines of 'Sprinter Scarlet', 'Sprinter White', and 'Ringo' were significant for both experiments (Table 2) when days to flower were regressed on cumulative PAR. For 'Sprinter Scarlet' 61% (experiment I) and 65% (experiment II) of the variability in the number of days to flower could be accounted for by cumulative PAR, for 'Sprinter White' 48% (experiment I) and 58% (experiment II), and for 'Ringo' 64% (experiment I) and 41% (experiment II). This suggests that cumulative light energy may be an important factor in influencing the number of days to flower.

Craig and Walker (1963) suggested cumulative solar energy as a major environmental factor controlling the flowering of seed geraniums. As plants in experiment I flowered with higher levels of cumulative PAR than those in experiment II, and there were only 4 instances (treatments 3 and 5 for 'Sprinter White' in experiment I and treatments 4 and 5 for all 3 cultivars in experiment II) where plants flowered with similar amounts of energy and a significantly different number of days, the data suggests that there is not a set amount of cumulative PAR the plant must receive before it will flower, as suggested in previous work by Craig and Walker. The connection between these experiments and previous work may be the effect cumulative light energy has in producing carbohydrates and other products in the plant that influence flowering.

Light, through quality, period, and intensity, is important for plant growth through photosynthesis, photoperiodism, and photomorphogenesis. It is through photosynthesis, however, that plants are able to obtain materials necessary for growth, as photosynthesis converts radiant energy into chemical energy in the form of carbohydrates and other organic compounds which are used as structural components and as a source of energy (Mastalerz, 1977).

Proper spectral composition and high intensity of light are necessary for adequate photosynthesis to take place. This builds up a carbohydrate store which is probably necessary for the proper function of the photoperiodic mechanism as well as metabolic processes (Bickford and Dunn, 1972). According to Bickford and Dunn, Hamner (1940) clearly demonstrated what has been called the "high-intensity-light reaction" which was verified by Liverman and Bonner (1953) when they found that sucrose treatments could substitute for sunlight exposure. It is possible that the carbohydrate levels built up much more quickly in treatment 5, the highest daily light level, and hastened flowering significantly when compared with treatment 3, natural light, and treatment 1, the lowest light level treatment. Mastalerz (1977) stated that the supply of photosynthates in excess of energy requirements determines the yield and quality of a flower crop.

In these experiments, treatments 2, 3, and 4 showed similar plant growth patterns, although the total amount of light energy they received was significantly different from each other. Treatments 1 and 5 showed marked differences as well. Larsen (1968) found that the number of days from macroscopically-visible flower buds in seedling geraniums to the time the first flower expanded was approximately 25 days

regardless of the plant's sowing date. Plants receiving higher levels of cumulative PAR may have initiated flowers sooner, thereby decreasing vegetative growth, while plants in the lowest cumulative PAR treatments may not have initiated flowers as quickly and thus had more time to grow vegetatively. Plants in the higher light level treatments had more breaks than those in lower light level treatments; apical vegetative growth is sometimes depressed and axial growth enhanced when apical meristems become reproductive. The high light intensity response is similar to the Cycocel response which decreases apical vegetative growth and produces a shorter, better branched plant.

It is likely that plants receiving high light level treatments produce more carbohydrates and therefore became reproductive more quickly compared with plants under low light. This is not a new idea. According to Sachs and Hackett (1969) Kraus and Kraybill (1918) stated that carbohydrate levels may control floral initiation and development. They worked on tomato, another plant that needs high light levels to produce flowers. Allsopp (1965) in a review on morphological changes concludes that "...sugar concentration appears to play a major role in morphogenesis...and...some of the effects of sugar concentration are probably relatively direct, while others represent a genetically determined response of the plant to a particular level of sugar concentration". Cumming (1967) suggested there might be optimal levels of carbohydrates for reproductive development. The lowest light level treatment, treatment 1, may have been producing carbohydrates at a much slower rate and it therefore took much longer for a supply to build up that would lead to inflorescence development.

The geranium seems to be quite efficient photosynthetically, as shown by the steep slope of the line in Figure 4 as light energy is increased at the beginning of the study. Small increases in light energy levels resulted in much higher photosynthetic rates. Plants grown under high light conditions have a thicker leaf, with more chlorophyll (Greulach, 1973). 'Sprinter Scarlet', used in the photosynthetic study, was from experiment II which was grown under higher light energy levels. Plants in experiment I, therefore, may have had less chlorophyll and would have saturated for photosynthesis at a lower light intensity, allowing for less carbohydrate synthesis, which could possibly explain why they took longer to flower when compared with experiment II plants.

In Table 8 it is interesting to note that although experiment I plants took more days to flower, and received higher levels of cumulative PAR, average daily energy levels are quite similar within each treatment to those of experiment II for all cultivars. Treatment 1 averages are much less than those for treatment 5. Treatments 2, 3, and 4 all flowered in a similar number of days within each cultivar and experiment, although their average daily light energy levels vary. Averages for treatments 4 and 5 are also similar, although treatment 4 plants took longer to flower. A possible explanation for this is that plants in treatments 3, 4, and 5 may have saturated for photosynthesis on extremely bright days, so some of the cumulative PAR recorded was not being used by the plant. The amount of light energy added to treatment 4 from the HPS lamp was approximately 37 $\mu Em^{-2}sec^{-1}$ from 6 AM to 6 PM, which might not have had much effect in hastening

flowering when compared with natural radiant energy. Treatment 2, however, received 23 $u\text{Em}^{-2}\text{sec}^{-1}$ during the night period. According to the photosynthetic study, this is enough light energy for photosynthesis to occur. It is possible that the effect of the 1 layer of Saran was compensated for by the HPS lamp at night. Treatment 1 plants received an average of 10 $u\text{Em}^{-2}\text{sec}^{-1}$ from the HPS lamp, which is probably too low for photosynthesis. Treatment 5 plants received an average of 40 $u\text{Em}^{-2}\text{sec}^{-1}$ from the HPS lamp at night, so they should have been able to continue photosynthesis during the night. This might account for the earlier flowering of treatment 5 plants compared with treatment 4 plants. It is likely that duration of light energy at a level high enough for photosynthesis to occur can also influence the number of days to flower in seedling geraniums.

SUMMARY AND CONCLUSIONS

The two experiments run on three cultivars of seedling geraniums suggested that light energy in the photosynthetically active region may influence the number of days to flower. Within experiment and cultivar 41-65% of the variability around the regression line for days to flower can be accounted for by cumulative PAR. Although cumulative PAR may be a factor in controlling number of days to flower, other factors will have to be investigated before a precise seedling geranium scheduling mechanism can be developed.

As cumulative PAR increased, the number of days to flowering decreased, as did total and vegetative plant height, while the number of breaks increased. This could be a result, perhaps, of floral initiation occurring sooner when daily energy levels are high.

It is possible that flowering in seedling geranium might be connected with the amount of photosynthetically active radiation the plant receives, and the build up of photosynthetic products in the plant.