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Crop Productivity and Morphology of Petunia and Geranium in Response to Low Night Temperature

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Abstract. **Seedlings of *Petunia hybrida* 'Snow Cloud' and *Pelargonium ×hortorum* 'Red Elite' and 'Cardinal Orbit' were grown to anthesis at day air temperatures of 27° ± 3°C (9 hr) and either 7° ± 3° or 18° ± 3° night air temperatures (15 hr). Petunia crop productivity (CP, grams of dry matter produced per square meter of crop) and crop productivity efficiency (CPE, percentage of photosynthetic photon flux incident on the crop stored in the form of crop dry matter) were the same at both temperature regimes from canopy closure to anthesis, but anthesis was delayed 10 days at 7°. Petunias grown at 7° had four more basal branches and were only one-third the height of petunias grown at 18° (12 vs. 37 cm). CP and CPE were 20% lower for geraniums grown at 7° compared to CP and CPE for geraniums grown at 18°. The geraniums grown at 7° flowered 3 weeks later, were more compact, and were 16 to 19 cm shorter than geraniums grown at 18°.**

Crop productivity of bedding plants and vegetables has been studied to understand the factors determining plant growth in greenhouses with limited photosynthetic photon flux (PPF). Interest for production at low night temperatures has been stimulated by high greenhouse heat demands. Petunia crops grown in growth chambers had the same crop productivity (total dry weight per unit area) when grown at either 7.2° or 15.6°C (5). The petunia crops in that study had closed canopies, many sinks (lateral branches), and the same day temperature (21.1°). Similar results have been reported for chrysanthemum (2, 3) and for the juvenile growth of cabbage, lettuce, pansy, and petunia (8).

Our study was designed to test the hypothesis that bedding plants such as geranium and petunia can have high crop productivity under low PPF and night temperatures when the plant canopy is closed, and when the plants have an adequate number of sinks. The geranium cultivars selected for this study have many basal branches. Lateral branch development in petunia can be obtained by growing seedlings under short-day photoperiods (5, 6).

Materials and Methods

Seeds of 'Snow Cloud' petunia and 'Red Elite' and 'Cardinal Orbit' geranium (Goldsmith Seeds, Gilroy, Calif.) were sown 8 Jan. 1987 in New Brunswick, N.J. Seedlings were grown with a 9-hr photoperiod at a minimum 21° day/18°C night air temperature on heated porous concrete benches that maintained the medium at 24° to 26°. Petunia seedlings were transplanted on 28 Jan. into 10-cm square plastic pots and geranium seedlings were transplanted on 29 Jan. into 13-cm square plastic pots filled with an amended medium of 9 sphagnum peat : 6 vermiculite : 4 perlite (by volume).

Plants from each cultivar were visually matched into four groups of 26 plants each on 5 Feb. for geranium and 10 Feb. for petunia. Because of the variability in seedling size, each group did not consist of plants of the same size. However, the visual matching attempted to produce four identical plant populations. One plant from each of the four groups was selected for each treatment block. The goal was to have 26 visually identical treatment blocks. The experimental design was a 2 × 3 factorial design with two night temperatures (7° or 18° C, hereafter referred to as 7N and 18N, respectively), three harvest dates [less than critical leaf area index (LAI), greater than critical LAI, and when the first crop reached 50% anthesis] replicated in four locations in each greenhouse. The four replicates, each with three groups of four matched plants, were placed pot to pot in the low night temperature greenhouse. The same procedure was used for plants placed in the warmer night temperature greenhouse. Pot-to-pot spacing was maintained throughout the experiment. To minimize edge effects, pots with seedlings of comparable size were used to form two border rows on all sides of each treatment. Growth data were analyzed by an analysis of variance.

PPF was measured by LI-COR 190-SB quantum sensors attached to a Campbell CR-7 datalogger, a LI-COR 1776 solar monitor, and a Doric Digitrend 235A Data Acquisition System. The sensors were located at the same level as the plant canopy. Readings were taken at 7-sec intervals and averaged hourly. Air and soil temperatures were measured to 0.1°C with copper–constantan thermocouples attached to a Campbell CR-7 datalogger. Leaf areas were measured with a LI-COR 3100 area meter. Roots were not measured.

Both greenhouses were maintained from 0800–1700 HR at 24° to 30°C. The warmer night air temperature greenhouse (18N) was maintained at 18° ± 3° from 1700–0800 HR and the low night temperature greenhouse (7N) at 7° ± 3°. Fans were used at 1700 HR to quickly lower the temperature in the LNT greenhouse. The average mean daily temperature (daily min. + max./2) change for the duration of the study was 7° in the WNT greenhouse and 19° in the LNT greenhouse. The number of hours that the crops were subjected to air temperature in the range of 4° to 10° and the effect these low air temperatures had on soil temperature at mid and bottom pot levels were also measured.

Crop productivity (CP) was calculated as follows: $CP = [(DW_t - DW_{t-1}) \times PD]/D$; where DW_t = mean plant dry weight (g) at harvest number t, DW_{t-1} = mean plant dry weight at previous harvest, D = number of days between harvest t and t − 1, and PD = plant density in units of plants per square meter.

Crop productivity efficiency (CPE) was calculated as follows:

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CPE = (CP × TEC)/(PPF × PPFEC), where TEC = tissue energy content in units of $kcal \cdot g^{-1}$ dry weight. A TEC of 4.0 $kcal \cdot g^{-1}$ was used since this is the usual average for herbaceous plants (4); PPF = mean daily PPF in units of $mol \cdot day^{-1} \cdot m^{-2}$; PPFEC = energy content of PPF in units of $kcal \cdot mol^{-1}$. A PPFEC of 52 $kcal \cdot mol^{-1}$ was used (9) since this is the usual value of sunlight.

Results and Discussion

Petunia plant growth. Plants grown in the 7N greenhouse were one-third the height, had main stems 71% shorter, and four more basal shoots than the 18N plants by 24 Mar. (Table 1). The 7N plants were very compact and flowered 10 days later than the 18N plants. CPE results (Table 2) support the hypothesis that the dry weight gain potential per unit area at 7N was as great as at 18N, provided that the canopy was closed so that essentially all the light was collected, and provided there was an adequate number of sinks. During the period of 3 to 25 Mar., when the petunia canopies were closed and there were many axillary shoots (760 to 1330/m^2), the CPE was the same for both 7N and 18N plants (Table 2).

Prior to canopy closure, the dry weight gain of the 7N crop lagged behind the 18N crop because of a lower capacity to collect light, as indicated by the lower LAI (Table 2). This slower rate of leaf area formation at 7N was due primarily to the lowered efficiency in use of dry weight to form leaf area, as indicated by a lower leaf area ratio (LAR) for the 7N crop than for the 18N crop (Table 3). This difference in LAR was evident even during the period from greater than critical LAI stage of growth to anthesis of 18N crops (Table 3). The equal CPE on 25 Mar. (Table 2) indicated that photosynthesis was the same for both crops. It is most likely that this was due to a slower growth rate of aerial plant parts rather than to the photosynthetic process or sink capacity. This slower growth was not only evident in the smaller number of leaves at the 7N, but also in the smaller area of the leaves during most of the period (Table 4).

Planting petunia seeds 10 days earlier might have resulted in more compact plants at 7N being in flower simultaneously with the 18N plants. Growing plants closer together during the early growth of the crop would have given further savings due to lower heating costs(1). The use of robots in the greenhouse might substantially reduce the spacing cost in the future and make this production technique more profitable. Another approach to reducing the development time for the 7N plants might be to raise the day temperature by 5°C.

Geranium plant growth. 'Red Elite' and 'Cardinal Orbit' responded similarly to 7N. Plants grown in 7N were half the height of 18N plants when the 18N plants first flowered. The reduced height was due to a 42% shorter main stem and 60% shorter leaf petioles. The horticultural characteristics of the 7N plants were excellent, but date to anthesis was delayed 21 days

Table 1. The influence of two night temperatures on growth characteristics of seedlings of 'Snow Cloud' petunia.

Variable	Night temp (°C)	Sampling date[z] 10 Feb.	20 Feb.[y]	3 Mar.[y]	24 Mar.[y]
Plant height (cm)	7	1	2	5	12
	18	1	4	10	37
Length of main stem (cm)	7	0	0	0	9
	18	0	0	4	32
No. main stem leaves	7	6	8	13	21
	18	6	10	18	23
Main stem leaf area (cm^2)	7	12	34	119	346NS
	18	12	58	200	375
Area of largest leaf(cm^2)	7	3	8	16	36
	18	3	11	23	25
Main and lateral leaves	7	25	122	615	2180
dry weight (mg)	18	25	153	752	1680
Main and lateral stems	7	0	34	72	1080
dry weight (mg)	18	0	49	301	1540
No. lateral shoots	7	2	5NS	8	13
	18	2	5	9	9
Length of longest	7	0	0	4	17
lateral shoot (cm)	18	0	0	16	37
Lateral leaf area (cm^2)	7	0	6	57	295
	18	0	11	106	442
No. open flowers	7	0	0	0	0
	18	0	0	0	4
Flower dry weight (mg)	7	0	0	0	325
	18	0	0	0	745
Top dry weight (mg)	7	25	155	687	3590NS
	18	25	201	1053	3960
Total leaf area (cm^2)	7	12	41	176	642
	18	12	69	305	818

[z]Mean, n = 16 plants.
[y]All data pairs except those indicated NS and 10 Feb. data are significantly different at <5% level due to temperature treatment on a given sampling date as determined by F-test.

Table 2. Effects of air temperatures (15 hr each night) on crop productivity (CP), crop productivity efficiency (CPE), leaf area index (LAI), and anthesis with seedling petunia and geranium grown in a greenhouse (1987).

Crops	Night temp. (°C)	Start of expt. Date	Start of expt. LAI	Start of expt. CP[y]	Less than critical LAI Date	LAI	CP[y]	CP[x]	PPF[w]	CPE (%)	Greater than critical LAI Date	LAI	CP[y]	CP[x]	PPF[w]	CPE (%)	Anthesis[z] Date	LAI	CP[y]	CP[x]	PPF[w]	CPE (%)	Anthesis %	Date	Days[v]
Petunia (Snowcloud)	7	10 Feb.	0.12	2.5	20 Feb.	0.4*	16*	13*	115	0.8	3 Mar.	1.8*	69*	53*	114	3.6	25 Mar.	6.4*	359	290	290	7.7	75	4 Apr.	53
	18	10 Feb.	0.12	2.5	20 Feb.	0.7	20	18	115	1.2	3 Mar.	3.1	105	85	114	5.8	25 Mar.	8.2	396	291	290	7.7	94	25 Mar.	43
Geranium (Red Elite)	7	5 Feb.	0.08	2.1	6 Mar.	0.4*	27*	25*	314	0.6	25 Mar.	1.6*	123*	96*	251	2.9	13 Apr.	4.4*	311*	188	227	6.4	50	4 May	88
	18	5 Feb.	0.08	2.1	6 Mar.	1.3	70	68	314	1.7	25 Mar.	5.0	248	178	251	5.5	13 Apr.	8.6	466	218	227	7.4	88	13 Apr.	67
Geranium (Cardinal Orbit)	7	5 Feb.	0.08	2.1	6 Mar.	0.4*	29*	27*	314	0.7	25 Mar.	1.3*	124*	95*	251	2.9	16 Apr.	5.0*	334*	211*	258	6.3	50	5 May	88
	18	5 Feb.	0.08	2.1	6 Mar.	1.6	76	74	314	1.8	25 Mar.	5.9	276	200	251	6.1	16 Apr.	9.9	541	266	258	7.9	44	13 Apr.	67

[z]Date when 50% of the plants were in flower.
[y]Gram dry weight/m².
[x]Gram dry weight/m² from previous sample date, e.g., from start to less than critical LAI, etc.
[w]Photosynthetic photon flux (mol·m⁻²).
[v]From start of experiment when matched seedlings were placed in greenhouse.
*Significant differences between temperature treatments on a certain sampling date determined by an analysis of variance F-test at the 5% level of significance.

Table 3. The influence of two night temperatures on the leaf area ratio (LAR) (square centimeters of leaf area per milligram of dry top matter) on seedling 'Red Elite' and 'Cardinal Orbit' geranium and seedling 'Snow Cloud' petunia.

Cultivar	Night temp (°C)	Feb. 5	Feb. 10	Feb. 20	Mar. 3	Mar. 6	Mar. 25	13 Apr.
		Leaf area ratio						
Snow Cloud	7	---	0.46	0.26	0.26	---	0.18	---
	18	---	0.46	0.34	0.29	---	0.21	---
Red Elite	7	0.37	---	---	---	0.14	0.13	0.14
	18	0.37	---	---	---	0.19	0.20	0.18
Cardinal Orbit	7	0.35	---	---	---	0.14	0.14	0.15
	18	0.35	---	---	---	0.22	0.22	0.18

(Tables 2 and 4). At the beginning of the 7N experiments main stem leaves exhibited a purpling of the foliage, but only during the first few weeks.

From the examination of the growth data (Table 4) it is evident that geraniums adapted less efficiently to 7N than petunias. Yet, as with petunias, the 7N plants were compact, attractive plants. A difference in photosynthetic potential could be the reason why the 7N geraniums were less efficient than 18N geraniums. This difference in efficiency is indicated by the difference in CPE for the time period from greater than critical LAI (canopy closure) to anthesis (Table 2). Other possible explanations are insufficient sink activity per unit area or that the critical LAI, which is based on a visual estimate of canopy closure, was somewhat greater than assumed. The number of sinks (lateral shoot growing points) at 7N was smaller for gernaiums than for petunias, 210 to 500 vs. 760 to 1330 per m² (Tables 1 and 4).

From 6 to 25 Mar., the number of growing points of the 18N gernaiums changed from 100 to 440 (average of RE and CO), with the lower resulting average CPE indicating that lack of sufficient sinks may be the most reasonable explanation of the lower CPE of 7N geranium crops.

Starting the 7N geraniums 22 days earlier might have resulted in both 7N and 18N geraniums in flower on 13 Apr. The longer growing time period might not be economical when compared to the 10-day extension for petunias. It is very likely that an interim closer spacing of plants to decrease the area heated would be a more important management consideration to explore with geraniums than with petunias. There are two other reasons that an interim closer spacing for geraniums might be in order. First, when the number of growing points per unit area was low, lack of sink capacity probably limited CPE. The number of growing points per unit area can be increased by increasing the number of plants per unit area (1, 7). Second, geraniums, relative to petunias, had a much lower LAR (Table 3), which indicated that they took longer to reach a critical LAI. This efficiency can be markedly increased with no loss in dry weight gain per plant by closer spacing of small plants and respacing to increase the area per plant appropriately. The potential gain in efficient use of area is particularly important for 7N plants that have a low LAR. Such a spacing procedure would result in the same area-days (the cumulative measurement of the area occupied per plant each day for the entire growing period) needed to produce plants of equal weight at 7N and 18N. To get the same results as reported here, however, would require more area-days for 7N plants, since the finished plants weighed more.

Table 4. The influence of two night temperatures on growth characteristics of seedlings of 'Red Elite' (RE) and 'Cardinal Orbit' (CO) geranium.

Variable	Night temp (°C)	Sampling date[z]							
		5 Feb.		6 Mar.[y]		25 Mar.[y]		13 Apr.[y]	
		RE	CO	RE	CO	RE	CO	RE	CO
Plant height (cm)	7	3	3	5	5	9	10	17	18
	18	3	3	9	10	20	22	36	34
Length of longest petiole (cm)	7	---	---	4	3	5	5	7	8
	18	---	---	6	6	9	10	12	12
Length of main stem (cm)	7	---	---	2	2	3	4	8	9
	18	---	---	3	4	9	10	20	22
Main and lateral stems dry weight (mg)	7	---	---	39	41	226	247	1265	1530
	18	---	---	125	150	677	768	2065	2710
No. main stem leaves	7	3	3	6	7	11	10	12	13
	18	3	3	10	10	14	15	15	17
Main stem leaf area (cm^2)	7	13	13	62	67	238	242	516	577
	18	13	13	221	266	787	924	1020	1330
Area of largest leaf (cm^2)	7	6	5	17	16	40	48	76	77
	18	6	5	51	49	92	105	127	144
Main and lateral leaves dry weight (mg)	7	---	---	406	444	1840	1850	3930	4100
	18	---	---	1050	1130	3520	3890	5230	6150
No. lateral shoots	7	---	---	1	2	4	4NS	9NS	11
	18	---	---	2	3	8	9	9	11
Lateral shoot leaf area (cm^2)	7	---	---	1	2	25	42	220NS	264
	18	---	---	6	11	60	80	427	346
Flower clusters dry weight (mg)	7	---	---	---	---	0	0	49	22
	18	---	---	---	---	0	0	576	289
No. flower cluster	7	---	---	---	---	0	0	1NS	1
	18	---	---	---	---	1	0	2	1
No. open flower clusters	7	---	---	---	---	---	---	0	0
	18	---	---	---	---	---	---	1	0
Top dry weight (mg)	7	36	36	445	485	2070	2090	5250	5650
	18	36	36	1180	1280	4190	4650	7880	9150
Total leaf area (cm^2)	7	13	13	63	70	263	285	737	841
	18	13	13	226	276	848	1000	1450	1670

[z]Mean, n = 16 plants.
[y]All temperature pairs except those indicated NS and 5 Feb. data are significantly different at <5% on a given sampling date as determined by F-test.

Relationship to primary crop productivity parameters. Seven parameters have been proposed (6) that should be considered in analyses of crop investigations. In this study, depletion costs (predation, harvest) were zero; synthesis respiration was considered equal per gram of dry weight at both temperatures; maintenance respiration was considered equal between the 7N and 18N crops, although it was surely larger for the 18N crop. With low biomass per unit area and the difference in temperature limited to the relatively low temperature at night, the difference in maintenance respiration was probably small. If it were large, the high CPE of 7.7% would not have been possible. The effectiveness of the crop in absorbing incident irradience (PPF, LAR, and LAI) were quantitatively measured, and sink strength was measured as number of growing points and number and size of leaves. CO_2 supply was assumed to be adequate, as the greenhouse fans operated regularly during the day.

Soil temperature. 7N affected the entire crop production environment—air, plants, and soil. Canopy air temperature is usually the same at night as surface soil temperature, but different during daytime as a function of the soil albedo, quantity of irradience, and canopy closure. The mean number of hours of temperatures in the 4° to 10°C range from 10 Feb. to 8 Mar. were: a) canopy air 10.1 hr, b) mid pot soil 8.3 hr, and c) bottom of the pot soil 7.7 hr. Fluctuations of 4° to 44° due to solar heating of bare soil occurred at the beginning of the study. After canopy closure, a considerable number of hours of air temperatures <10° occurred, but the canopy trapped enough warm air so that the soil temperatures did not drop below 10°.

This study indicates the importance of a closed plant canopy and many growing points per square meter in relation to crop productivity of bedding plants grown in a greenhouse maintained at 7°C.

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Hydrology of Horticultural Substrates: I. Mathematical Models for Moisture Characteristics of Horticultural Container Media

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Abstract. **Moisture retention data were collected for five porous materials: soil, phenolic foam, and three combinations of commonly used media components. Two mathematical functions were evaluated for their ability to describe the water content–soil moisture relationship. A cubic polynomial function with linear parameters previously used on container media was compared to a closed-form nonlinear parameter model developed to describe water conductivity in mineral soils. In most tests for precision, adequacy, accuracy, and validation, the nonlinear function was superior to the simpler power series. The nonlinear function provides an excellent tool for describing the water content for media with widely varying physical properties.**

Understanding the physical environment surrounding roots in containers (relative volumes of air, water, and solid) is based on the relationship between water energy status and water content of the medium. This relationship is a reflection of the pore size distribution of the medium. A plot of this relationship, i.e., a plot of volumetric wetness (Θ) vs. soil water pressure (negative quantity) or soil moisture tension (MT, positive quantity) is called the soil moisture characteristic or moisture retention curve (4).

Ever since Bunt (3) first reported moisture retention curves for pot-plant media, there has been considerable effort to determine the utility of these curves in explaining plant growth, and the best way to quantify these data for both descriptive and predictive purposes. White (20) realized the importance of moisture retention curves on water content in containers and introduced the concept of "container capacity" (in contrast to field capacity).

Fonteno et al. (7) used the classification suggested by De Boodt and Verdonck (6) and introduced regression analysis to describe the moisture retention curve for horticultural media. A linear relationship between Θ and moisture tension was found between 0 and 2 kPa, whereas a quadratic relationship existed from 2 to 10 kPa. Several researchers developed a cubic regression model to describe the moisture retention curve, with the goal of predicting the container-specific values of air space and container capacity (8, 10, 16).

Soil scientists have also had great interest in using moisture retention models (5). As reviewed by Van Genuchten and Nielson (18), there are at least four basic nonlinear empirical functions relating Θ to MT that are continuously differentiable (smooth): King (11), Laliberte (12), Su and Brooks (15) and Van Genuchten (17). The Van Genuchten model (17) is gaining acceptance in the field of soil science.

Van Genuchten's function stems from an analysis by Brooks and Corey (2), given by

$$\Theta = (\Theta_s - \Theta_r)(\alpha h)^L + \Theta_r \quad [1]$$

where Θ_s is the saturated water content, Θ_r is the residual water content, α is the inverse of the "air entry value", h is the log of the moisture tension, and L is the "pore size distribution index". In order to provide a better fit, Van Genuchten (17) proposed:

$$\Theta = \Theta_r + (\Theta_s - \Theta_r)/[1 + (\alpha h)^n]^m \quad [2]$$

where he assumed unique relations between n and m, i.e., $m = 1 - (1/n)$. To improve flexibility of the model, the "new" model (18) has removed this restriction on n and m, so all five parameters are independent. Θ_s and Θ_r are known empirical parameters, while α, n, and m are unknown and are determined using standard nonlinear least squares parameter estimation methods.

Quantifying the soil profile (or container) air and water variables is important not just in specific applications, such as the container work of Karlovich and Fonteno (10) or the unsaturated conductivity modeling of Van Genuchten and Nielsen (18), it is also necessary in developing overall growth models for containerized crops, whether they are evapotranspiration models, transpiration-available water models, or transpiration-Θ models (9, 13, 19).

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