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Quantifying the Effect of Plug-flat Color on Medium-surface Temperatures

James E. Faust,[1]
Royal D. Heins,[2] and
Hiroshi Shimizu[3]

ADDITIONAL INDEX WORDS. solar radiation, longwave radiation, evaporation

SUMMARY. Medium-surface temperature of black, gray, and white plug sheets was measured with thermocouples and an infrared camera. During the night, there were no medium-surface temperature differences between the plug flats; however, medium-surface temperature was 2 to 3 °C below air temperature. Medium-surface temperature increased as solar radiation (280 to 3000 nm) increased. About 80 W of solar radiation/m² was incident on the plug-flat surface before medium-surface temperature equaled air temperature. Medium-surface temperature in the black, gray, and white flats was 6.3, 6.1, and 5.3 °C above air temperature, respectively, when 300 W of solar radiation/m² (30% of the maximum solar radiation during the summer) was incident on the medium surface. Thus, incident solar radiation has a greater effect on medium surface temperature than plug-flat color.

Commercial bedding plant growers typically germinate seeds in plug sheets designed with 128 to 800 cells/flat (800 to 5000 plants/m²) (Karlovich and Koranski, 1994). Although most seeds are germinated on top of the medium surface, germination percentage of some species is improved by covering the seeds with a fine coating (1 to 2 mm) of a material such as vermiculite. After seeds are sown, the plug flats are placed into either a germination chamber or the greenhouse.

Temperature is a critical factor influencing seed germination (Carpenter, 1994). Whenever seed temperatures are not optimum, germination will be delayed or its percentage will decrease. The temperature of the germinating seed is influenced primarily by the medium-surface temperature, which is affected by many variables, including plug-flat color. Plug-flat color influences the amount of solar radiation absorbed. Black plug flats most commonly are used by commercial growers, although white plug flats are used during the summer to prevent excessively high temperatures. Soil temperatures are often excessive during container-grown plant production in periods of high solar radiation (Martin and Ingram, 1992).

We are unaware of any data showing the influence of plug-flat color on medium temperature. The objective of this project was to quantify the effect of plug-flat color on medium-surface temperature under different irradiance conditions.

Materials and methods

White, gray, and black 406-cell plug flats obtained from a commercial grower (Blackmore Co., Inc., Belleville, Mich.) were filled with a peat-based medium. The flats were placed on a solid aluminum subirrigation bench in a greenhouse with air maintained at 25 °C, the optimum temperature for germination of many bedding plant species (Karlovich and Koranski, 1994). The medium was kept moist for the duration of the experiment, which was conducted over a 10-day period in a glass greenhouse in July 1993.

The medium-surface temperature in the center of nine randomly chosen plug cells (three per plug-flat color treatment) was measured with 80-µm-diameter fine-wire thermocouples. The thermocouples were inserted into the top 1 mm of media and in the center of the plug cell. The measurement variation between the thermocouples was about ±0.15 °C. A pyranometer (Eppley Laboratory, Inc., Newport, R.I.) was used to measure solar radia-

[1]Former graduate student. Current address: University of Tennessee, Department of Ornamental Horticulture and Landscape Design, Knoxville, TN 37901-1071.

[2]Professor, Michigan State University, East Lansing, MI 48824.

[3]Agricultural engineering instructor, Kyoto University, Kyoto, Japan.

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Table 1. Parameter estimates for the nonlinear equation describing the effect of solar radiation on the difference between medium surface and air temperature (medium – air temperature = $b_0 + b_1 \exp(+ b_2 \times$ solar radiation)).

Plug-flat color	Parameter	Estimate	Asymptotic 95% confidence interval Lower	Upper
White	b_0	12.6	11.9	13.4
	b_1	–15.8	–16.5	–15.1
	b_2	–0.00259	–0.00279	–0.00239
Gray	b_0	16.2	15.1	17.2
	b_1	–19.2	–20.2	–18.2
	b_2	–0.00219	–0.00237	–0.00202
Black	b_0	18.5	17.0	20.0
	b_1	–21.8	–23.3	–20.4
	b_2	–0.00195	–0.00214	–0.00175

tion (280 to 3000 nm). Air temperature was measured in an aspirated shaded weather station adjacent to the plug flats. One-minute average values for each sensor were recorded with a datalogger (CR10; Campbell Scientific, Inc., Logan, Utah). An infrared imaging radiometer (model 740; Inframetrics, Billerica, Mass.) was used to create a "visual image of the plug-flat and medium-surface temperatures".

The difference between medium and air temperature was calculated. The functional relationship between solar radiation and the difference between medium and air temperature was described by the following equation:

Medium – air temperature = $b_0 + b_1 \exp$ $(+ b_2 \times$ solar radiation)

Estimates for parameters (Table 1) were obtained using the nonlinear regression procedure (NLIN) of the Statistical Analysis System (SAS Institute, Cary, N.C.).

Results and discussion

Medium-surface temperature was seldom equal to air temperature (Fig. 1). At night, the medium-surface temperature was always 2 to 3 °C below the greenhouse air temperature, regardless of plug-flat color. Medium-surface temperature at night was not influenced by plug-flat color. The lack of a nocturnal temperature difference between flats of different colors is expected, since the emissivity of the plug flat is a function of the surface material, not color, and energy loss from water evaporation and longwave radiation (3000 to 50,000 nm) loss to the surrounding greenhouse structure would be the same among the different-colored flats.

During the day, medium-surface temperature increased 13 to 16 °C relative to air temperature as solar radiation increased from 0 to 700 $W \cdot m^{-2}$ (Fig. 2). About 80 W of solar radiation/m^2 (8% of maximum solar radiation at noon in the summer) was required to offset evaporative and thermal cooling so the medium-surface temperature equaled air temperature. When solar radiation was 300 $W \cdot m^{-2}$, the medium temperature in the white flat was 1 °C cooler than that in the black and gray flats. However, the white and black flats were 5.3 to 6.3 °C above air temperature; therefore, since the air temperature was 25 °C, medium-surface temperature was 30 to 31 °C. When solar radiation was 700 $W \cdot m^{-2}$, the medium in the white flat was 3 °C cooler than in the black flat. However, the medium in the white plug flat was still 10 °C above air temperature.

As observed from the thermal-image camera that surface temperatures across the plug flat varied by as much as 4 °C. During the day, the temperature of the plastic was always higher than the temperature of the medium, and the black plastic was always warmer than the white plastic. However, temperature differences between black and white plastic did not translate into large differences in medium temperatures. A typical thermal image of plug flats indicated that the

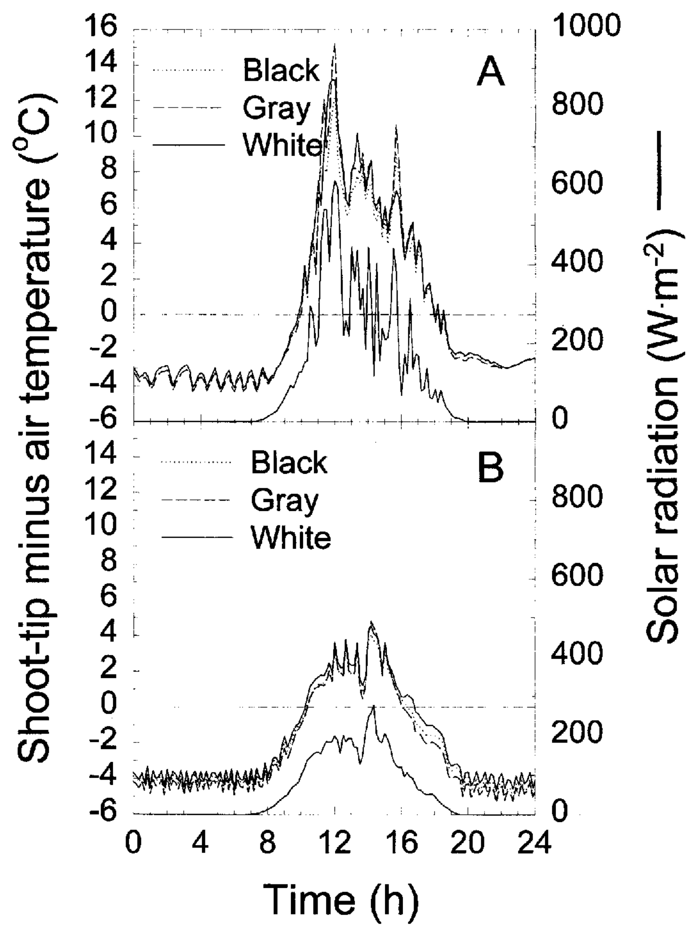

Fig. 1. The effect of plug-flat color on the difference between medium-surface and air temperatures recorded on (A) a partly sunny day and (B) a cloudy day. Incident solar radiation (280 to 3000 nm) was measured at the surface of the plug flat.

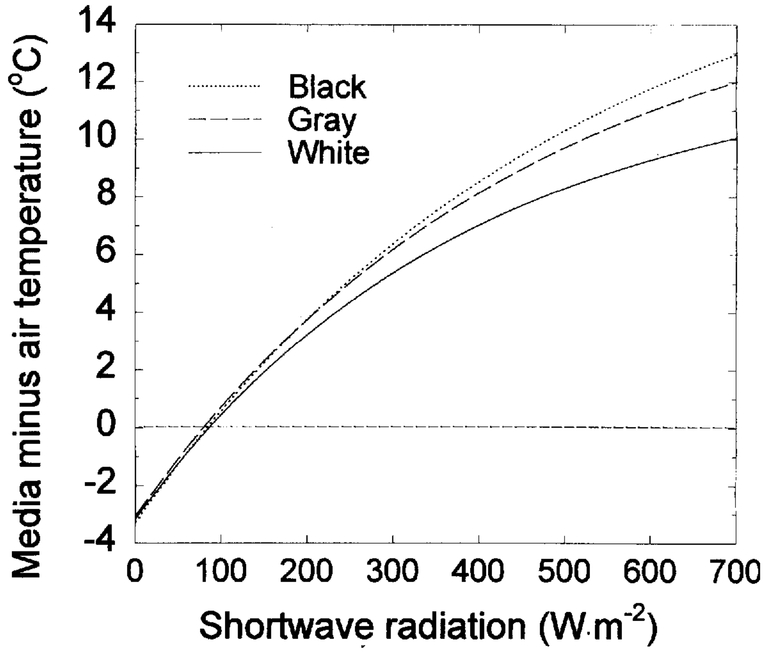

Fig. 2. The effect of plug-flat color on medium-surface temperature shown as a function of the incident solar radiation (280 to 3000 nm). Air temperature was maintained at 25 °C and the water vapor pressure deficit averaged 1.4 kPa.

point of the plastic tray where any four square plug cells connected was 3 °C warmer than the center of media surface during a sunny day. The plastic rib dividing any two adjacent plug cells was 2 °C warmer than the center of the media surface, and the media surface within 1 to 2 mm of the plastic was 1 °C warmer than the rest of the plug media surface. There was a <1 °C difference in media surface temperature across the center portion of the plug cell. Therefore, seeds placed near the edge of the cell could be influenced by the plastic's temperature and color more than seeds placed in the center of the plug cell.

The results of this experiment underscore the value of shading plug flats to control the amount of solar radiation received or using a closed chamber for germination. Commercial growers that germinate seeds inside the greenhouse will typically use 60% light-reduction shadecloth in addition to the shading caused by the greenhouse structure. However, this would still allow 400 to 500 $W \cdot m^{-2}$ of solar radiation to be incident on the medium surface. Our data suggest that temperature excesses of 7 to 10 °C could occur during germination under these solar loads; therefore, the irradiance should not exceed ≈200 $W \cdot m^{-2}$ (≈400 $\mu mol \cdot m^{-2} \cdot s^{-1}$) if medium temperatures are to remain within 2° to 3° degrees of the air temperature. Using white plug flats will help limit medium temperature elevation when solar radiation is high; however, high irradiance levels should be avoided. During the night, maintaining high humidity and using thermal screens will help limit medium-surface temperature depressions. The amount of bottom heat required to maintain medium temperature near air temperature during the night depends on how much thermal and evaporative losses can be minimized (Yang and Albright, 1985).

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Broadcast versus Band Fertilizer Applications on Vegetable Crops

R.L. Parish,[1] R.P. Bracy,[2] and H.F. Morris, Jr.[4]

ADDITIONAL INDEX WORDS. fertilizer, fertilizer application, band, broadcast, application, sweetcorn, turnip, cabbage

SUMMARY. A study was conducted to evaluate the effect of banding or broadcasting fertilizer on yield and quality of turnip (*Brassica rapa* L. Rapifera group), sweetcorn (*Zea mays* var. *rugosa* Bonaf.), and cabbage (*Brassica oleracea* L. Capitata group). Preplant fertilizer was applied broadcast before bedding, broadcast after bedding, or banded after bedding. Sidedress applications were broadcast or banded on the beds. Differences in plant size and vigor were noticed early in the season in the spring turnip crop, with the growth in the broadcast-and-bed treatment appearing superior. The yield at first harvest and total yield were lower for turnip grown with the bed-and-broadcast treatment. No differences in yield of cabbage or sweetcorn resulted from the treatments. Few differences in turnip stem-to-leaf ratio were noted due to fertilizer treatment. Few differences in yield due to sidedress method were noted with any of the crops. Analysis of soil samples in a

[1]Professor, Biological and Agricultural Engineering Department, Hammond Research Station, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, 21549 Old Covington Highway, Hammond, LA, 70403.

[2]Associate professor, Hammond Research Station, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, 21549 Old Covington Highway, Hammond, LA, 70403.

[3]Head, Agricultural Chemistry Department, Louisiana Agricultural Experiment Station, Louisiana State University Agricultural Center, P.O. Box 25055, Baton Rouge, LA, 70894.

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