Solar Radiation and Water Loss from Glasshouse Roses[1]

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Abstract. Measurements of global radiation above, and net solar radiation below, the roof of a glasshouse were both highly correlated on a daily and hourly basis with the water loss from a flowering rose crop as measured with a weighing lysimeter. The relationship can be used for an automatic system of irrigation control. Under local glasshouse, soil, and crop response conditions such a system would require an application of 6 liters of water per square meter of bed for every 730 cal cm^2 global radiation above the glasshouse. Alternatively, a foliage spray irrigation system to ensure that the upper part of the canopy is kept continuously moist, would require applications of at least 0.4 liters per square meter at radiation intervals between 15 and 4 cal cm^2 of global radiation outside the greenhouse, the exact figure depending mainly on the rate of air movement around the foliage. The latent heat equivalent of the crop water loss was 87% of the global radiation incident on the canopy, a figure similar to those listed for other, tall glasshouse crops.

The relation between solar radiation and water loss from roses, the most important glasshouse crop in Israel, is of interest for 2 reasons: 1) if the rose crop shows the same close linear relationship which has been reported for a number of other glasshouse crops (1, 2, 4, 6, 7), then this could form the basis for a fully automatic irrigation system. 2) Solar radiation is the major heat source in the glasshouse, while transpiration forms the major heat sink. Information on the relationship between the 2 energy fluxes is needed for the design of both the heating and cooling systems of glasshouses used for rose culture.

The investigation reported in this paper was designed to provide the necessary information for a mature rose crop growing under good commercial conditions during the mid-winter portion of the cropping season.

Materials and Methods

Measurements were made at the Glasshouse Research Center at Bet Dagan in the central coastal plain of Israel in an aluminum-structured greenhouse glazed with diffusing glass. The house is orientated N-S; it is 15 m in length, 12.5 m wide, 3 m high to the eaves and 6 m high to the ridge. Heating was by hot water circulated through 4- and 6-cm-diam pipes at soil level.

Ventilation was provided automatically when the air temp within the glasshouse exceeded 28°C. Outside air was cooled and humidified at the point of entry with a water spray and then distributed through the length of the house via 2 perforated tubes of transparent plastic 60 cm in diam.

Rose plants, cv. Baccara on *R. indica* rootstock, were planted 21 months previous to the measurements at a distance of 30 cm in the row, with 3 rows in each of the 6, l-m-wide beds. The beds, which covered 45% of the greenhouse floor area, were raised 30 cm above ash-covered paths and were filled to a depth of 50 cm with a mixture of light sandy loam and organic matter.

Water loss by transpiration from the rose canopy plus evaporation from the soil surface, E_T, was measured by a lysimeter[4] 3 m^2 in area which contained a 3.00-m-long section of rose bed situated in the center of one of the middle beds of the greenhouse. The lysimeter, which was 30 cm deep, was supported by a continuous balance system which produced an electric signal proportional to the wt change in the lysimeter. The sensitivity of the weighing system was determined on 10 occasions during the measurement period by recording the change in the electrical output as 3 different weights were placed on and removed from the center of the lysimeter. The mean sensitivity, used subsequently for data reduction, was 0.827 mv kg^{-1}. Individual calibrations had a standard deviation of 0.017 mv kg^{-1} or 2.1% of the mean and for this study the accuracy of the water loss determination was taken to be equivalent to ± 0.06 mm water depth. Subsequently, improvements in hydraulic damping have doubled this accuracy. During the operation of the forced ventilation system in daylight hours, the wind-induced movement of the rose canopy caused short-term variations in the signal from the balance system which were as much as 10 times the uncertainty in the sensitivity of the lysimeter. To avoid this source of error, measurements of daily water loss were made in the morning before ventilation began and the ventilation was switched off for 5 min each hour to allow reliable hourly figures to be obtained.

The lysimeter was irrigated once a week with a nutrient solution through 2 lines of low pressure spray nozzles set at ground level, with a volume equivalent to 1.2 times the measured water loss. Drainage was removed and measured 3 hours after the cessation of irrigation.

Global radiation from the sun and sky incident on a hortizontal surface, $K{\downarrow\downarrow}$, was measured with a Kipp pyranometer placed on the roof of the greenhouse. Net solar radiation K_*, i.e., the difference between the incident and reflected global radiation, was measured within the greenhouse above the top of the 2-m-high rose canopy with a 3-m-long linear strip net pyranometer[5] suspended horizontally from the roof approx 15 cm above the top of the canopy growing on the lysimeter, and along its center line.

Both pyranometers were recalibrated immediately after the measurement period and the results showed that daily totals of both $K{\downarrow\downarrow}$ and K_* were accurate to within 3%, with hourly values showing deviations up to twice this amount.

The output from both the pyranometers and lysimeter were fed to recently calibrated integrating mv-meters.

Results

Twenty daily totals of E_T, expressed as mm water depth loss per unit lysimeter surface area, have been related to the

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[4]Grateful acknowledgment is made to L. G. Morris and N. Lavav, Manager and Comanager, respectively, of the F.A.O. High Value Crops Project, who designed the lysimeter, had it built, and provided other facilities for this study at the Glasshouse Research Center.

[5]Manufactured by Swissteco Pty. Ltd., 26 Miami Street, Hawthorne, Victoria, Australia.

[6]S. Dasberg, Div. of Soil Physics, ARO, Volcani Center (personal communication).

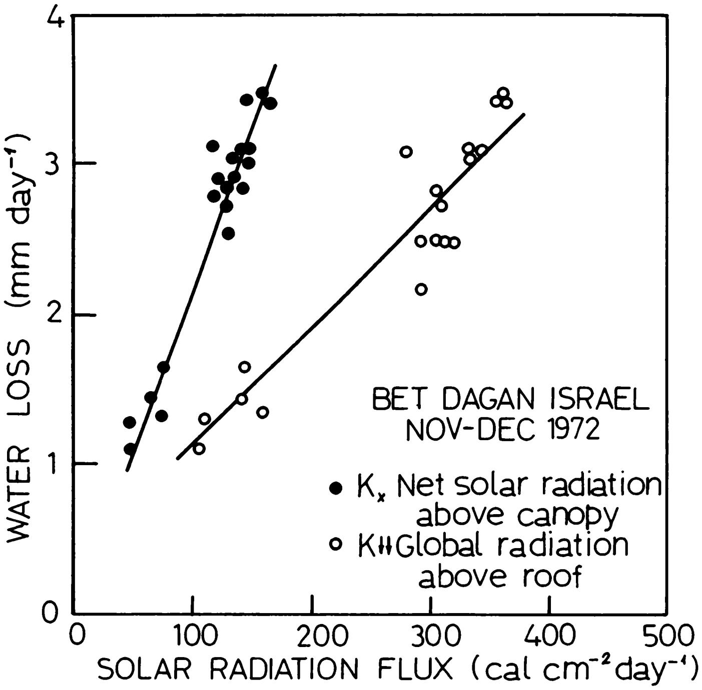

Fig. 1. Relation between daily totals of solar radiation above a glasshouse roof and above the rose canopy within the glasshouse and water loss from the rose crop. Data are from Bet Dagan, Israel.

corresponding radiation flux totals of $K{\downarrow\downarrow}$ and K_* in Fig. 1. The linear relations, fitted by the method of least squares, are

$$E_T = .0082\,\underline{K{\downarrow\downarrow}} + 0.30 \text{ mm day}^{-1}$$
$$r = 0.96, \sqrt{Sy.x^2} = 0.78 \text{ mm day}^{-1}$$
$$E_T = .0211\,\underline{K_*} + 0.06 \text{ mm day}^{-1},$$
$$r = 0.96, \sqrt{Sy.x^2} = 0.75 \text{ mm day}^{-1}$$

where r is the correlation coefficient and $\sqrt{Sy.x^2}$ the sample standard deviation from the regression. All radiation fluxes are in cal cm^{-2} day^{-1}.

The mean daily transmissivity ρ, for the 22 days of measurement, was 0.549, calculated as $\rho = K{\downarrow}/K{\downarrow\downarrow}$ where $K_* = K{\downarrow}(1 - \alpha)$ where $K{\downarrow}$ is global radiation above the canopy and α is the reflectivity of the canopy, here taken as 0.20 from previous measurements above this crop (8).

The standard deviation of the daily values of transmissivity was low, ± 0.0309, or 7% of the mean value, which was the same as that measured previously during the winter at Bet Dagan (8).

Hourly values of solar radiation and water loss showed high correlation almost equal to that found with daily values. Values for 2 contrasted mid-winter days, one cloudless and one overcast, are shown in Fig. 2. The linear regression equations based on 30 hourly values are

$$E_T = .0070\,\underline{K{\downarrow\downarrow}} + 0.05 \text{ mm hr}^{-1},$$
$$r = 0.91, \sqrt{Sy.x^2} = 0.04 \text{ mm hr}^{1}$$
$$E_T = .0165\,\underline{K_*} + 0.04 \text{ mm hr}^{-1},$$
$$r = 0.89, \sqrt{Sy.x^2} = 0.07 \text{ mm hr}^{-1}$$

The positive offset term in the relationships is to be

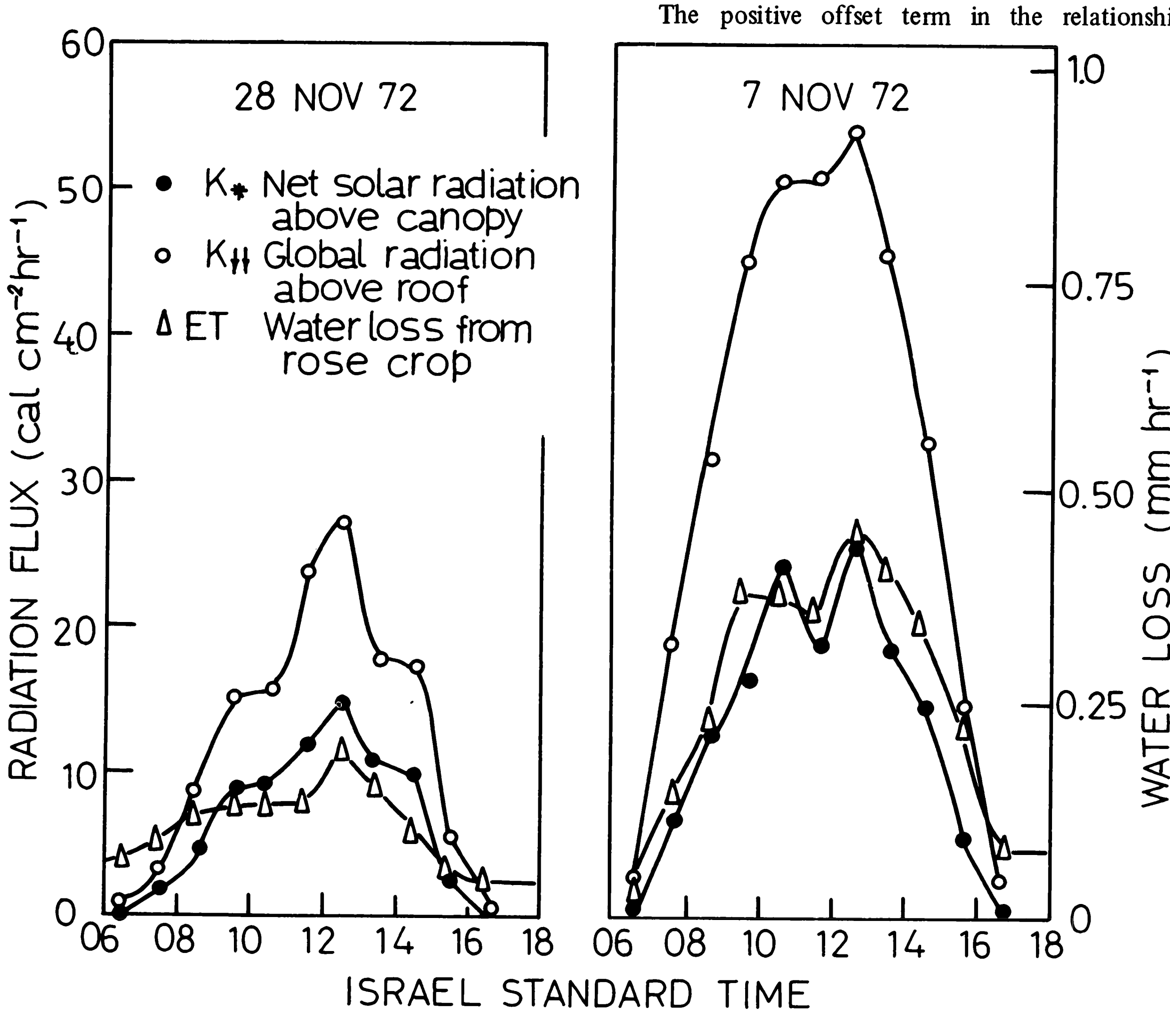

Fig. 2. Relation between hourly totals of solar radiation above a glasshouse roof and above the rose canopy within the glasshouse and water loss from the rose crop. Data are for a cloudy and a cloudless midwinter day at Bet Dagan, Israel. On both days solar time is approximately 30 minutes earlier than Israel Standard Time.

explained by the occurrence of water loss during the night, averaging 0.36 mm for the 13-hr-long night periods. The variation in night-time water losses was somewhat less than that found for the daylight hour values. The standard deviation for the 25 nights measured was 0.07 mm or 21% of the mean, compared with 0.76 mm or 35% of the daylight hour mean.

The effect of increasing soil water deficits on the water loss: radiation relation was studied by comparing average daily ratios of ET/K_* with the soil water deficit, i.e., cumulative water loss from the last irrigation. The data, plotted in Fig. 3, show an apparently linear reduction in the relative rate of water loss as the soil water deficit increases, which amounts to a 25% reduction over the range of water deficits encountered. On the soil type used, the max deficit of 20 mm corresponds to -0.6 atm. water potential[6]. This is close to the inflection point of the moisture release curve, and at lower values the potential increases very sharply with decreasing soil water content.

Discussion

The relationships between both net and global radiation and water loss reported above appear sufficiently constant to serve as a basis for an automatic system of irrigation. In deciding which of the 2 tested radiation parameters to recommend, the advantage of the slightly lower scatter and smaller offset value observed with the net solar radiation measurements has to be weighed against the increased cost and serious sampling problems involved in measurements within the greenhouse as compared with the single pyranometer above the roof needed to measure global radiation.

As the values for mean daily transmissivity appear to show very little day-to-day variation for a given greenhouse, it would appear justifiable to use global radiation measurements to control irrigation. However, the relationship with water loss will need to be corrected when applied to greenhouses of different transmissivities.

For practical purposes, the daily relationship should be used for controlling soil irrigation, as it allows for the small loss during the night hours. Irrigation frequency experiments with this crop (5) have shown that the max flower yield is obtained by watering whenever the soil water potential reaches -0.06 atm., which is equivalent to a soil water deficit of 6 mm in the root zone. The irrigation practice appropriate for the soil moisture characteristics and atmospheric humidity conditions investigated, should therefore supply 6 liters of water per square meter of bed area for each 730 cm^{-2} of global radiation above the greenhouse.

If irrigation is to be applied as a spray or mist to the foliage rather than to the soil, the daylight, hourly relationship should be used. Assuming that the aim is to spray whenever the water held on the foliage of the upper and most exposed third of the canopy has evaporated, the irrigation treatment has been calculated as follows. The measured leaf area of the upper third of a rose canopy of similar height and foliage density to that studied, was previously found to be 2.7 m^2 per m^2 bed area. Measurements with a number of flowering stems of 'Baccara' rose gave an average, max water-holding capacity of 140 g m^2 leaf area; thus, the upper third of the canopy has a max water-holding capacity equivalent to 0.38 mm water depth.

The rate of water loss by evaporation from the wetted leaves, E, is considerably greater than the transpiration rate from similar but unwetted leaves, T. The ratio E/T can be calculated from the following equation given by Monteith (4),

$$E/T = \frac{\Delta + \gamma\,(1 + r_s/r_a)}{\Delta + \gamma}$$

where Δ is the slope of the saturation vapour pressure with temp relationship and is temp-dependent. At 25°C, an average air temp in a rose glasshouse during the winter, $\Delta = 1.9$ mb$^{o}C^{-1}$. γ is the psychrometric constant, 0.66 mb $^{o}C^{-1}$, r_s is the internal, stomatal resistance of the leaf to water vapour diffusion. Previous measurements (8) with 'Baccara' rose leaves in the upper part of the canopy gave values around 2.5 sec cm^{-1} for most of the daylight hours.

r_a is the external, laminar-layer leaf resistance and can be calculated from leaf size and rate of air movement (3). The characteristic dimension of 'Baccara' rose leaflets is 4 cm and under conditions of good natural ventilation, i.e., 30 air changes

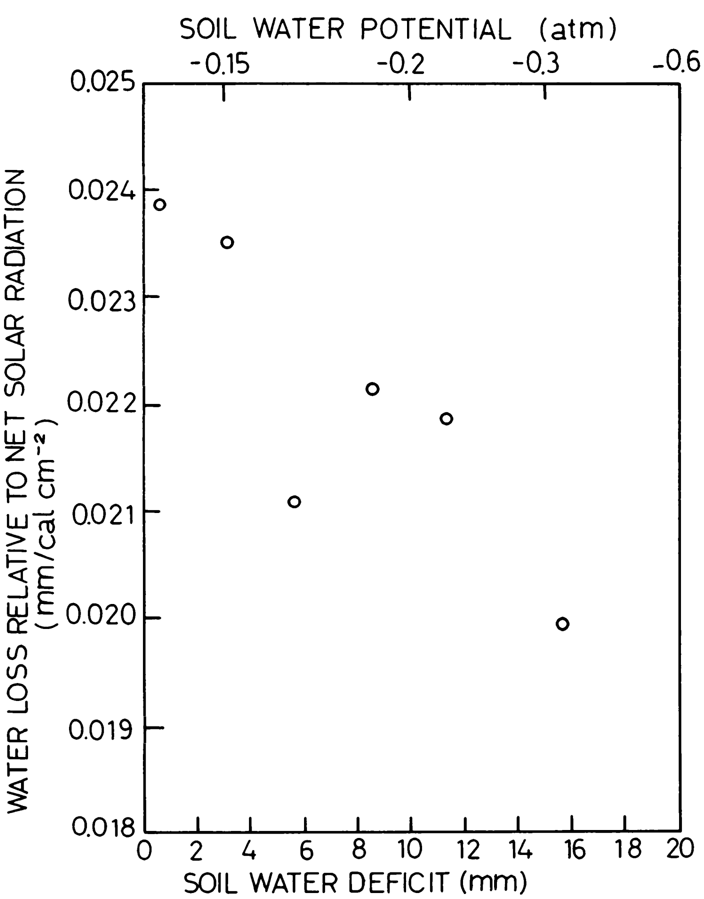

Fig. 3. Effect of soil water deficit on the relative rate of water loss from a glasshouse rose crop. Data from Bet Dagan, Israel.

Table 1. Relation of greenhouse crop water loss to global solar radiation within the greenhouse, LE/K↓.

Crop	Period of measurement	LE/K↓	Reference
Tomatoes	April '53	0.59	(4)
	May '53	0.85	(4)
	June '53	0.99	(4)
	March-April '57	0.70	(7)
	May-June '57	0.98	(7)
	July-Sept. '57	1.06	(7)
	7-13 weeks after planting, '55	0.69	(6)
	7-17 " " " '56	0.67	(6)
	from 50-300-cm height, '57	0.66	(6)
	from 100-250-cm height, '58	0.67	(6)
	May-Sept. '66	0.56	(2)
Lettuce	Feb. '53	0.44	(4)
Carnations	June '54	0.62	(4)
	July '54	0.96	(4)
	March '66	0.98	(1)
Roses	November '72	0.87	This paper

per hour, r_a will average 1.3 sec cm^{-1} for the upper leaves. With forced ventilation leaf fluttering is common and much lower values of r_a, around 0.25 sec cm^{-1}, are to be expected.

Under the above conditions the E/T will vary between 3 for natural ventilation and 11 for forced ventilation. The respective irrigation treatments will be a spray of 0.4 liters per square meter bed for either 15 or for 4 cal cm^{-2} global radiation. The max frequency of spray to be expected under local midwinter conditions has been calculated from the clear-day values of K↓↓ shown in Fig. 2. During midday, when forced ventilation is likely, a spray will be needed every 5 minutes. Clearly the exact interval and the amount of spray needed will depend on factors other than solar radiation, including the position and type of spray nozzles used, and a period of trial will be needed to find the most suitable radiation interval

The fraction of incident solar energy used for transpiration or evaporation, i.e., latent heat transfer, is complexly dependent on a number of plant and microclimatic parameters that are difficult to measure, especially in the horizontally nonhomogeneous situations commonly found with greenhouse crops. However, it has been shown with a number of crops that for a given growth stage and set of environmental conditions, the relationship between the 2 energy fluxes is quite constant. A summary of such comparisons which have appeared in the literature is given in Table 1 with both energy fluxes expressed in the same units by multiplying the water loss E, by the latent heat of vaporization, L.

Reference to the original papers listed in Table 1 shows that in most cases, for a given crop growth stage and planting pattern, very high correlations – often above 0.9, as in this study – were found between daily sums of the 2 energy fluxes. Most of the differences in the ratios of LE/K↓ noted in Table 1 can be explained, at least qualitatively, by the difference in canopy size and hence fraction of incident radiation absorbed by the vegetation. A more quantitative study of the relationship between canopy size and radiation absorption can be found in an earlier study (8).

Literature Cited

1. Hanan, J. J., and R. Huffsmith. 1967. Weighable lysimeter and recording system used in greenhouse evaporation studies. *Proc. Amer. Soc. Hort. Sci.* 91:691-698.
2. Hand, D. W., G. Slack, and D. R. Machin. 1970. Evaporation rates of capillary-watered tomatoes in an east-west glasshouse. *J. Hort. Sci.* 45:3-14.
3. Monteith, J. L. 1965. Evaporation and environment. *In* The State and Movement of Water in Living Organisms. Proc. 19th Symp. Soc. Expl. Biol., Cambridge University Press, 205-234.
4. Morris, L. G., F. E. Neale, and J. P. Postlethwaite. 1957. The transpiration of glasshouse crops and its relationship to the incoming solar radiation. *J. Agr. Eng. Res.* 2:111-112.
5. Plaut, Z., N. Zieslin, and I. Arnon. 1973. The influence of moisture regime on greenhouse rose production in various growth media. *Scientia Horticulturae* 1:239-250.
6. Rothwell, J. B., and D. A. G. Jones. 1961. The water requirements of tomatoes in relation to solar radiation. *Expt. Hort.* 5:25-30.
7. Stanhill, G. 1958. An irrigation gauge for commercial use in field and glasshouse practice. *J. Agr. Eng. Res.* 3:292-298.
8. ——— , M. Fuchs, J. Bakker, and S. Moreshet. 1973. The radiation balance of a glasshouse rose crop. *Agr. Meteorol.* 11:385-404.

Association of Seed Color with Emergence and Seed Yield of Snap Beans[1]

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Abstract. Field tests involving 47 pairs of snap bean breeding lines, near-isogenic except for differences in seed color, demonstrated that colored-seeded sub-lines were superior to their white-seeded counterparts in emergence and seedling vigor. In 11 yield comparisons between colored- and white-seeded isogenic sub-lines, the colored-seeded sub-lines outyielded their white-seeded counterparts by an average of 67%. Covariance techniques were used to adjust yields to remove stand effects. The results suggested that differences in stand based on seed color was a major factor affecting yield.

Many observers have noted that snap bean cultivars with colored seed produced stronger and more vigorous seedlings than those with white seed[3]. Also, cultivars with colored seed appeared to be more vigorous throughout the growing season and were more adaptable to adverse conditions than white-seeded cultivars. According to current standards, white-seeded cultivars are considered superior for canning. Our research suggests, however, that large increases in yields could be obtained by using colored-seeded cultivars.

Damage to snap beans from root rot diseases occurs regularly throughout the U. S. Discovery of resistance to *Rhizoctonia solani* in colored-seeded beans by McLean et al. (5) and subsequent reports by Prasad and Weigle (7, 8) indicated that resistance to this pathogen occurs only in colored-seeded strains. Dickson (1) reported that ability of beans to germinate in cold soils as well as tolerance to *Pythium* root rots was associated with colored seed coats.

Muehlbauer and Kraft (4) extensively studied root rot in peas caused by *Fusarium solani* f. sp. *pisi* and *Pythium ultimum* and reported that resistance to these organisms was associated with several characters, including speckled seed and purple plant color. They reported that resistance was heritable, but they did not state whether all resistant segregates had purple plants or speckled seed. Marx et al. (3) found that tolerance to *Aphanomyces* root rot in peas was also associated with the presence of pigmentation in flowers and seed.

Much evidence indicates that resistance to root rot diseases and seedling vigor is physiologically linked with factors producing colored seed. Even when there is no apparent root rot damage, colored-seeded lines seem to be more vigorous

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[3]Hoffman, J. C. 1960. Twentieth Annual Report of Vegetable Breeding in the Southeastern United States. pp. 6-11.