

Effect of Mulch Surface Color on Root-knot of Tomato Grown in Simulated Planting Beds¹

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Abstract: The effect of different-colored polyethylene mulches on quantity and spectra of reflected light, plant morphology, and root-knot disease was studied in tomato (*Lycopersicon esculentum*) grown in simulated planting beds. Tomato plants were inoculated with *Meloidogyne incognita* at initial populations (Pi) of 0, 1,000, 10,000, or 50,000 eggs/plant, and grown in a greenhouse for 50 days over white, red, or black mulch. Soil temperature was kept constant among the mulch treatments by placing an insulation barrier between the colored mulch and the soil surface. Soil temperature varied less than 0.5 °C between soil chambers at solar noon. Tomatoes grown over white mulch received more reflected photosynthetic light and had greater shoot weights (27%), root weights (32%), and leaf area (20%) than plants grown over black mulch. Plants grown over red mulch received a higher far-red-to-red ratio in the reflected light. Mulch color altered the plant's response to root-knot nematode infection by changing the distribution of mass in axillary shoots. At high Pi, axillary leaf area and leaf weight were greater in tomato grown over white mulch than when grown over red mulch. The root-gall index was lower for plants grown over white mulch than similar plants grown over red mulch.

Key words: host-parasite relationship, light quality, *Meloidogyne incognita*, nematode, photomorphogenesis, plastic mulch, polyethylene, root-knot, tomato.

Plastic mulches are commonly used in the production of vegetables. Benefits from the use of plastic mulch include enhanced water and fertilizer management, and weed control. Soil temperatures can be altered by plastic mulch extending the cropping season into cooler or warmer seasons (black mulch for warming in the spring and white mulch for soil cooling in the summer and early fall). In addition, subtle changes in upwardly reflected light from wavelength-selective mulches have a phyto regulatory role on the growth of young tomato and pepper plants (Decoteau et al., 1989, 1990). Photomorphogenesis in plants is regulated by light in the red (R) and far-red (FR) portion of the spectrum (Kasperbauer, 1988; Kasperbauer et al., 1984, 1986). Colored mulches differ in quantity and spectral bal-

ance (FR/R ratio) of reflected light. The similarities in growth responses of plants grown over reflective films and plants grown in controlled environment R and FR light experiments suggest phytochrome involvement in colored mulch modification of plant growth (Decoteau et al., 1989). Reflective films affect tomato and pepper fruit yield and earliness of fruiting, with plants grown over red mulch producing a greater portion of their fruit earlier in the growing season (Decoteau et al., 1989, 1990).

Root-knot nematodes are common root parasites associated with vegetable and field crops in temperate and tropical regions of the world (Sasser and Carter, 1982; Taylor and Sasser, 1978). Root-knot nematodes (*Meloidogyne* spp.) are one of a variety of root-parasitic nematodes that establish specialized feeding cells in roots, redirecting photosynthate produced in the leaves to supply the energy demands of the nematode in the roots (Bergeson, 1966; Kochba and Samish, 1971). Root weight, as a result of nematode parasitism, increases whereas shoot weight declines, shifting the root-to-shoot balance (Fortnum et al., 1991).

Tomato plants infected with *M. incognita* (Kofoid & White) Chitwood and irradiated with light containing a high FR/R ratio at the end of the day produce fewer eggs and egg masses than plants receiving a low FR/R

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ratio (Fortnum and Kasperbauer, 1992). The fecundity of the nematode in roots was influenced by the light environment of the shoots. Also, the light source used during the photosynthetic period can affect the development of *Meloidogyne javanica* (Treub) Chitwood, suggesting that a combination of irradiance and spectral balance received by the growing shoot might be involved (Bird et al., 1980; Gillard and Van Den Brande, 1956). Colored mulches, which vary in quantity and spectral balance of reflected light, have been shown to alter root-knot nematode development in field trials (Fortnum et al., 1995). Plants grown over white mulch had greater numbers of *M. incognita* eggs per gram dry root weight than similar plants grown over red or black mulch when data were averaged across growing seasons and years. Mulch color did not alter root mass in uninoculated plants. However, root mass in plants grown over white mulch and inoculated with *M. incognita* increased with increasing initial root-knot nematode populations (Pi), whereas root mass of plants grown over black or red mulch plateaued at higher Pi's (Fortnum et al., 1995). Fruit yield, earliness of fruiting, and root-knot disease of *M. incognita*-infected tomato vary with mulch color (Fortnum et al., 1997). In addition to changes in the light environment of the shoots, diurnal soil temperature gradients differed between mulch colors in the field. Soil covered with black mulch at solar noon was 8 °C warmer at a 5-cm depth than soil covered with white mulch (Fortnum et al., 1997). Soil temperature affects root-knot development and egg production (Taylor and Sasser, 1978). Experiments on the effects of colored mulches on root-knot disease have not separated the effects of altered soil temperatures across mulch color from the effects of the mulches on the light environment of the shoots.

The objective of this study was to evaluate the effects of black, white, and red mulches on root-knot of tomato where soil temperature remained constant across mulch colors.

MATERIALS AND METHODS

Inoculum and planting bed preparation: The *M. incognita* race 3 population was isolated

from field plots at the Pee Dee Research and Education Center in Florence County, South Carolina, and was cultured on tomato (*Lycopersicon esculentum* Mill. 'Rutgers'). Nematode eggs from roots of 48-day-old tomato plants were extracted in 0.05% sodium hypochlorite, washed in tap water, and used as inoculum (Hussey and Barker, 1973).

Planting boxes were constructed of wood with soil chambers 80 cm wide, 60 cm long, and 30 cm deep. Chamber size in this greenhouse study was chosen to approximate soil volume per plant in a field planting. Each soil chamber was lined with rigid styrofoam insulation (1.3-cm-thick) on the four walls and bottom of the chamber. The bottom plate was pierced to allow drainage. Varina sandy loam soil (75% sand, 17% silt, 8% clay; pH 6.1; 0.8% organic matter) was placed in each insulated planting chamber. Each planting chamber was covered with a polyethylene tarp and fumigated with methyl bromide (35 g/chamber). The tarps were removed 48 hours after fumigation, and residual fumigant was allowed to escape over a 14-day period. Fertilizer (6 g/chamber of N applied as 63% urea and 37% $[\text{NH}_4]_2\text{HPO}_4$, 2.7 g/chamber of P from $[\text{NH}_4]_2\text{HPO}_4$, and 5 g/chamber of K from KCl) was applied and incorporated into the top 15 cm of soil. Trickle-tubing irrigation tape was placed across the soil surface to simulate irrigation in a field planting. The surface of each soil box was covered with rigid styrofoam insulation 1.9 cm thick. The styrofoam top was then covered with a black polyethylene mulch 0.33-mm thick. A 5-cm hole was cut in the center of each styrofoam chamber cover. The red and white mulch colors were established by application of acrylic enamel paint to the black polyethylene mulch (Decoteau et al., 1989; Fortnum et al., 1995). Non-painted black mulch served as a standard control. The quality and quantity of light reflected from the colored mulches was measured 10 cm above the surface on a cloudless day at solar noon with a Li-Cor spectroradiometer model LI-1800 (Li-Cor, Lincoln, NE). Far-red/red photon ratio (FR/R) of reflected light was determined by dividing values at 735 nm by values at 645 nm. Far-red/red photon ratio was calculated

relative to the ratio in incoming sunlight, which was assigned a value of 1.00. Ratios in upwardly reflected light are means for at least 10 scans. Experiments were conducted in spring 1990 and spring 1991.

Tomato seeds (cv. 'Rutgers') were germinated in plastic seedling trays (5-cm wide, 5-cm long, and 10-cm deep cell size) containing Peat-Lite (Conrad Farard, Springfield, MA) and maintained in a greenhouse until they reached a height of 15 cm. Seedlings were transplanted to the planting chambers on 11 May 1990 and 10 May 1991. Soil moisture was monitored daily, and irrigation was scheduled with tensiometers (irrigation initiated when soil moisture deficit reached 10 centibar). Soil temperatures in chambers covered with black (nonpainted), white, and red-colored mulches were monitored with copper-constantan thermocouple probes placed in the soil 10 cm below the surface of the plastic.

Plant growth and nematode development: Tomato plants were transplanted into the mulch-covered chambers and then inoculated with suspensions of approximately 0, 1,000, 10,000, or 50,000 *M. incognita* race 3 eggs. A root suspension filtrate from nematode-free tomato plants was added to control plants and to inoculated plants, with each plant receiving 50 ml of suspension. Nematode inoculum was pipeted into two 5-cm-deep holes on opposite sides of each tomato plant, and the holes were covered with soil. Plant growth and nematode development were evaluated after 50 days. Plants were excavated from the mulch bed, and the roots were washed free of soil. Each plant was divided into main shoots, axillary shoots, main stems, axillary stems, leaves from the main shoot (petiole detached at the stem), leaves from the axillary shoots, and roots. Plant parts were weighed, and stem lengths were recorded. Leaf area was determined with a Li-Cor model LI-3100 area meter (Li-Cor, Lincoln, NE). Root galling was rated on a 0- to-10 scale: 0 = no galls, 1 = 1–10%, 2 = 11–20%, 3 = 21–30%, 4 = 31–40%, 5 = 41–50%, 6 = 51–60%, 7 = 61–70%, 8 = 71–80%, 9 = 81–90%, and 10 = 91–100% of the root tissue galled (Barker et al., 1986). A 15-g sample of roots was incubated in a ZnSO₄

solution (10 mg/liter) for 4 days, and hatched J2 were collected on a 25- μ m-pore sieve (Bird, 1971).

Mulch treatments were arranged in a factorial design with mulch color as main plots and inoculum level as subplots with four replications/treatment, and the test was repeated. Because results were similar for both years, data were pooled and analyzed using analysis of variance (ANOVA) and regression techniques (Steel and Torrie, 1960). Mean comparisons (LSD) were used to determine the effect of mulch color on mass of specific plant tissues within and across initial nematode population levels (Pi). All calculations were performed with the Statistical Analysis System (SAS Institute, Cary, NC).

RESULTS

Plant microclimate: Mulch surface color influenced the quantity and quality of light reflected into the plant canopy. Photosynthetic photon flux (PPF) of incoming sunlight was 1,555 $\mu\text{mol m}^{-2} \text{s}^{-1}$ at solar noon on a clear day. The quantity of reflected light, obtained by measuring PPF 10 cm above each colored surface, was 732, 275, and 76 $\mu\text{mol m}^{-2} \text{m}^{-1}$ for white (47% of incoming sunlight), red (17%), and black (<5%) surface colors, respectively. Far-red/red photon ratios were calculated relative to the ratio in incoming sunlight, which was assigned a value of 1.00. Far-red/red ratios were 1.0 and 1.16 for white and red mulch surface colors, respectively. Reflection from black mulch was about 5% across the spectrum. Far-red/red ratios were not calculated because very minor differences in measurements of the reflection in R or FR reflectance could result in a large, but meaningless ratio. Soil temperatures recorded 10 cm below the soil surface at solar noon did not differ among the mulch treatments (25 ± 0.5 °C).

Plant growth and nematode development: Significant year \times color interactions were not observed for shoot, leaf, stem, or root weight, or for leaf area, root-galling index, or J2 populations extracted from roots of tomato plants ($P = 0.05$) grown in planting beds; therefore, data were combined over

years. Mulch color and initial *M. incognita* population (Pi) altered total shoot, leaf, and stem weights as well as leaf area and root weight of tomato plants ($P \leq 0.05$) grown in simulated planting beds (Table 1). Mulch color did not alter main shoot stem and leaf weights, or leaf area (Table 1). *Meloidogyne incognita* Pi altered main shoot stem weight ($P \leq 0.05$). Significant mulch color \times Pi interactions ($P = 0.05$) were observed for leaf weight and leaf area but not shoot stem weight in the axillary branches (Table 1). *Meloidogyne incognita* Pi altered the shoot/root ratio ($P \leq 0.01$). Combined over Pi, the total shoot, root, stem, and leaf weight and leaf area were greater ($P \leq 0.05$) in plants grown over white mulch than in plants grown over red or black mulch (Table 2). Axillary shoot and shoot stem weights were also greater ($P \leq 0.05$) in tomato plants grown over white mulch than in plants grown over red or black mulch (Table 2).

A significant color \times Pi interaction was observed for axillary leaf area and leaf weights ($P \leq 0.05$) (Table 1). Axillary leaf area in uninoculated tomato was greater in plants grown over red or white mulch than when grown over black mulch (Fig. 1). Axillary leaf weight in uninoculated tomato was greater in plants grown over red mulch than in those grown over black mulch. At high Pi, axillary leaf area and leaf weight were greater in tomato grown over white plastic than when grown over red mulch.

Plant height, total leaf and stem weight, and total leaf area declined with increasing Pi and were described by quadratic equations when averaged across mulch colors (Fig. 2). The decline in shoot weight was matched by an increase in root weights with increasing Pi (Fig. 2). Root galling increased with increasing Pi and could be described by a quadratic equation (Fig. 2).

Significant color \times Pi interactions were not observed for J2 populations extracted from roots or root-gall index (Fig. 3). Averaged over Pi, nematode J2 per gram dry root weight were greater in plants grown over red mulch than in plants grown over white or black mulch ($P \leq 0.05$) (Fig. 3). Populations

TABLE 1. Sources of variation and *P* values for main effects, and interactions of mulch color and initial nematode population (Pi) on plant growth parameters, in 'Rutgers' tomato grown in simulated planting beds.

Source of variation	Plant height (cm)	Total shoot weight (g)	Main shoot			Axillary shoot			Whole plant			Shoot-to-root ratio	
			Root weight (g)	Leaf area (cm ²)	Leaf weight (g)	Stem weight (g)	Axillary shoot weight (g)	Leaf area (cm ²)	Leaf weight (g)	Stem weight (g)	Leaf area (cm ²)		Leaf weight (g)
Mulch color	ns	0.011*	0.019*	ns	ns	0.080	0.041*	0.076	0.021*	0.019*	0.023*	0.008**	0.088
Pi	0.018*	0.001**	0.001**	ns	ns	0.035*	0.025*	0.055	0.020*	0.010**	0.002**	0.005**	0.001**
Color \times Pi	ns	ns	ns	ns	ns	ns	0.060	0.050*	ns	ns	ns	ns	ns

P > *F* values were calculated for a factorial treatment arrangement with four replications of three mulch colors and four *Meloidogyne incognita* inoculum levels repeated over 2 years.

TABLE 2. Effects of mulch color on growth of 'Rutgers' tomato grown in simulated planting beds over three colors of polyethylene mulch.

Mulch surface color	Total shoot weight (g)	Root weight (g)	Total stem weight (g)	Axillary shoot weight (g)	Axillary shoot stem weight (g)	Total leaf area (cm ²)	Total leaf weight (g)
White	560 a	50 a	233 a	263 a	119 a	5,558 a	326 a
Red	459 b	38 b	179 b	196 b	86 b	4,705 b	274 b
Black	441 b	38 b	171 b	197 b	84 b	4,633 b	269 b

Means are the average of four replications per trial averaged across two trials (spring 1990 and spring 1991). Means in a column with a common letter are not significantly different ($P = 0.05$) according to an LSD test.

of J2 per plant were greater in plants grown over red and white mulch when compared to plants grown over black mulch ($P \leq 0.05$). The root-gall index was greater ($P =$

0.06) for plants grown over red mulch than for plants grown over white mulch.

DISCUSSION

Reproduction of *Meloidogyne* spp. in plant roots can be limited by the ability of the host to provide the necessary energy and habitat for development of the nematode. Root-knot nematodes require a large amount of the plant's energy to support a progression of molts within the root, and an increasing body size culminating in the deposition of a large number of nematode eggs within the root or at the root soil interface. In addition to energy demands, root-knot nematodes alter root structures and mass, increasing susceptibility to soil fungi. Root structure is altered to accommodate nematode development with the production of giant cells. Photosynthate produced in leaves is redirected into nematode-induced giant cells that are metabolic sinks (McClure, 1977). The environment surrounding a host plant, both below and above ground, can play a key role in the development of root-knot disease (Fortnum and Kasperbauer, 1992). Modification of the shoot light and soil temperature environments by colored mulches provides a novel approach to minimizing root-knot nematode damage in tomato (Fortnum et al., 1995, 1997). Previous research in controlled environments has shown that the FR/R ratio received by shoots could affect the numbers of eggs produced on roots (Fortnum et al., 1995). In those studies, all plants received the same amount of photosynthetic light and the same soil temperature. In the present study,

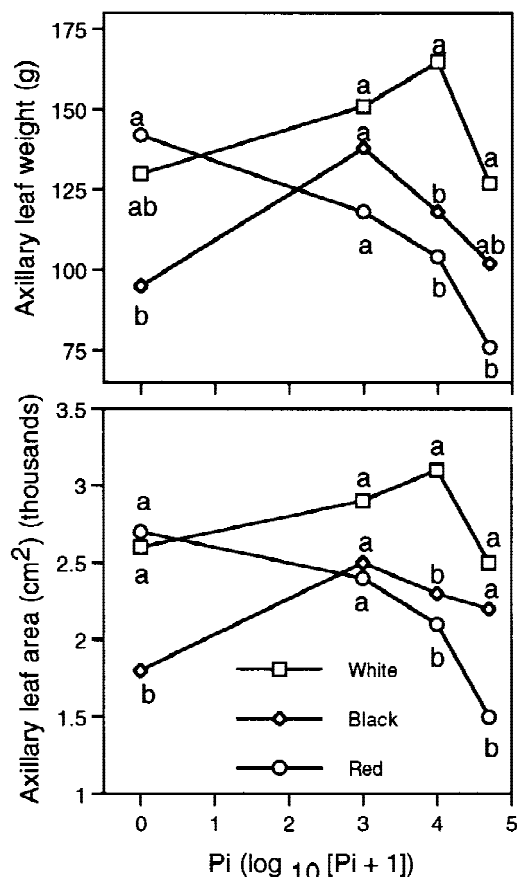


FIG. 1. Effect of initial *Meloidogyne incognita* populations (Pi) on axillary leaf weight and leaf area of 'Rutgers' tomato grown over white, black, or red plastic mulch. Values are the means of eight observations (four replications for each of 2 years). Means within a Pi with a common letter are not significantly different ($P = 0.05$) according to an LSD test.

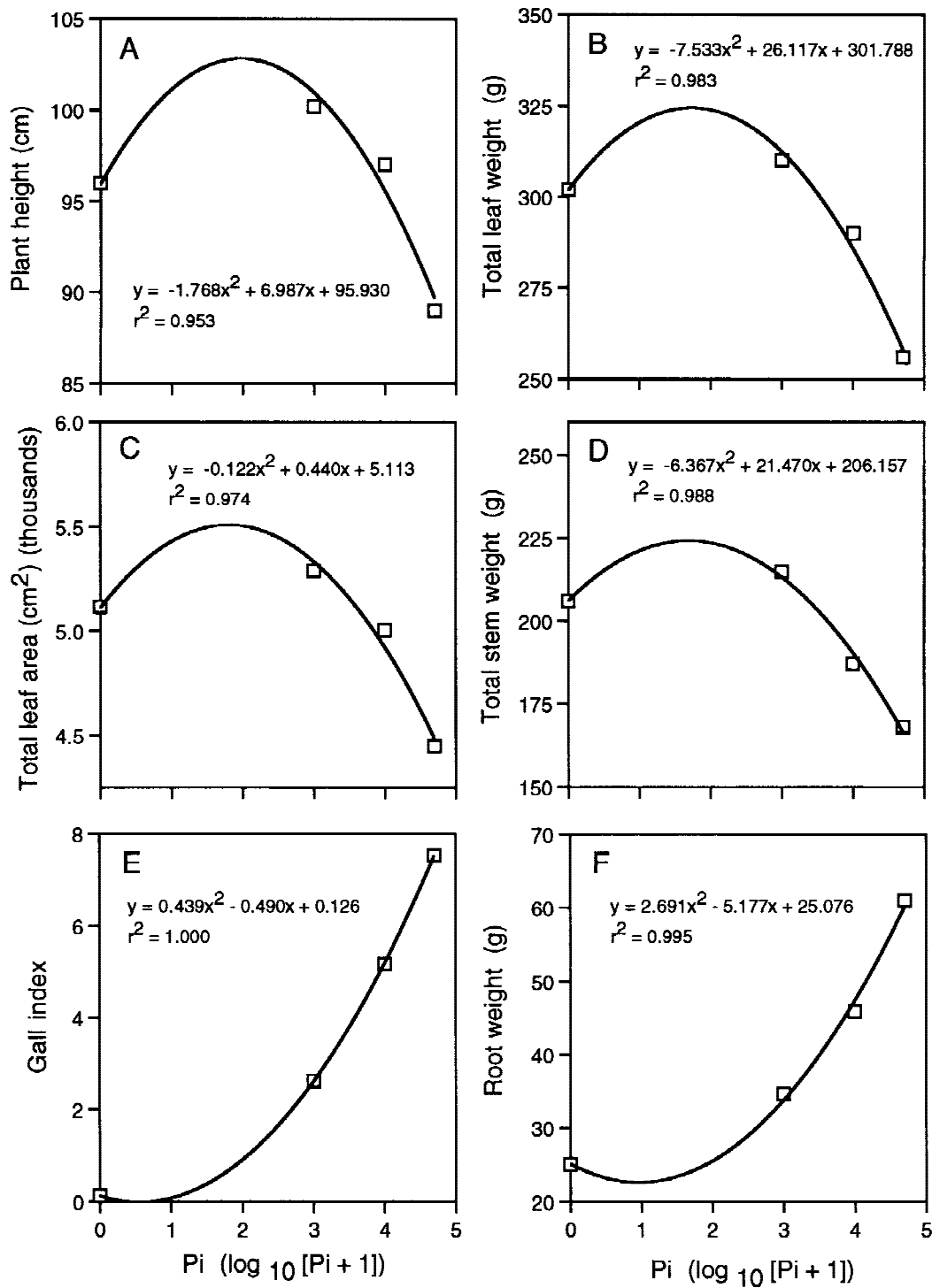


FIG. 2. Effect of initial *Meloidogyne incognita* population (Pi) on biomass (A-D, F) and root-gall index (E) of tomato cv. 'Rutgers' 50 days after inoculation. Values are the means of 24 observations (four replications of three colors for each of 2 years). Regressions are based on treatment means.

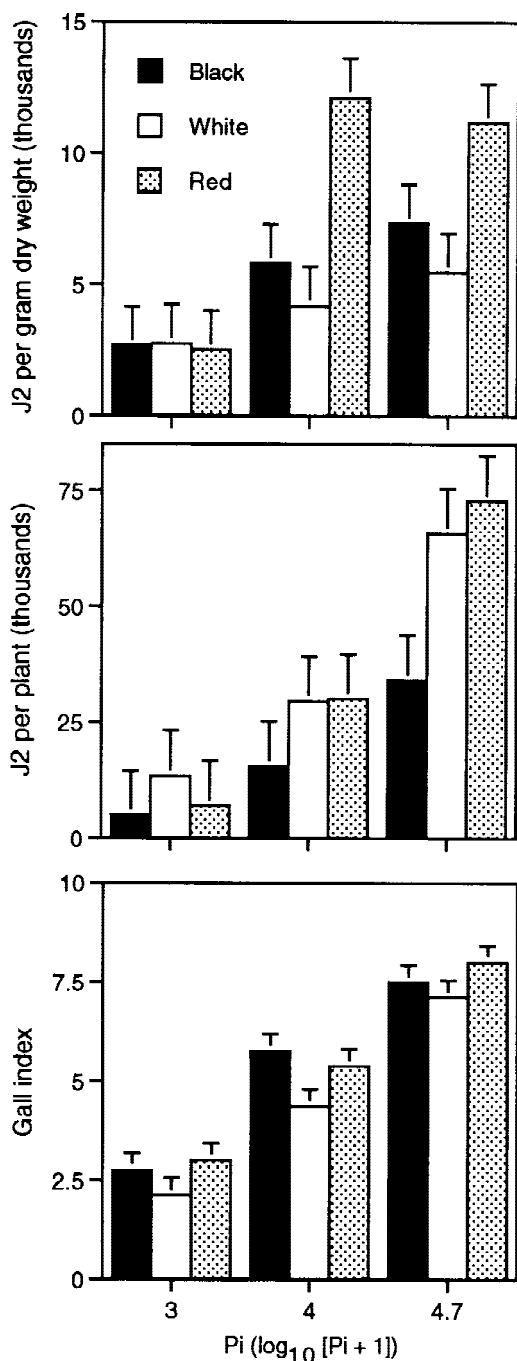


FIG. 3. *Meloidogyne incognita* second-stage juveniles (J2) extracted from roots and root-gall index of 'Rutgers' tomato grown in simulated planting beds over three colors of polyethylene mulch. Lines above bars indicate SE values for four replications per trial averaged across two trials. Root galling was rated on a 0-to-10 scale: 0 = no galls, 1 = 1-10%, 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, 5 = 41-50%, 6 = 51-60%, 7 = 61-70%, 8 = 71-80%, 9 = 81-90%, and 10 = 91-100% of the root tissue galled.

the light reflected from a colored mulch surface altered shoot and root growth and root-knot disease when soil temperature was held constant. The present study illustrates that crop production procedures, such as wavelength-selective mulches, that alter the amount of reflected photosynthetic light and the FR/R ratio in light received by shoots of growing plants can affect nematode development in roots independent of effects caused by changes in soil temperature. Although root and shoot mass differed little between plants grown over black or red mulch, those grown over red had twice the J2 per plant of those grown over black. Although total nematode reproduction over time was not determined, differences in J2 populations extracted from roots suggest differences in the rate of nematode development across mulch colors.

White mulch, as in the previous field trials, had the lowest level of root galling. Plant biomass was greatest in plants grown over white mulch, where the proliferation of axillary shoots contributed to larger shoot mass and greater leaf area. The increase in axillary shoots in plants grown over white mulch was shown in previous field trials and provided more leaf area for photosynthesis (Fortnum et al., 1995). A larger plant may be able to tolerate losses of carbon (fixed by the leaf tissues) to nematode development due to a greater quantity of photosynthetic leaf tissues to support plant growth. Although plants grown over white mulch in the present studies were larger than plants grown over red mulch, nematode J2 populations per plant were not different. The lower root galling in plants grown over white mulch may indicate similar numbers of nematodes distributed over a larger root system. In contrast, plants grown over black mulch had lower J2 populations per plant than plants of similar size grown over red mulch. Field experiments have shown that plants grown over red mulch fruit earlier than similar plants grown over black or white mulch (Decoteau et al., 1989, 1990). Early fruiting may be due to altered growth-regulator levels within the plant. This alteration may influence nematode development

because root-knot nematodes are affected by growth-regulator levels (Fortnum and Lewis, 1983; Glazer et al., 1983; Hussey, 1985).

Typically, plant-growth responses to increasing Pi of *Meloidogyne* spp. are described by quadratic relationships (Fortnum and Kasperbauer, 1992). Similar quadratic relationships were observed for all plant parameters examined in the present studies except axillary leaf area or axillary leaf weight. The effects of colored mulches on plant growth were most pronounced in the axillary shoot growth. Mulch color altered the plant's response to root-knot nematode infection by changing the distribution of mass in axillary shoots (color \times Pi interaction). Although plants grown over red mulch had J2 populations similar to the larger plants grown over white mulch, nematode development may have occurred at the expense of axillary shoot growth. Energy requirements for nematode development increase as each root-knot female undertakes egg-laying. Environmental conditions, such as a red reflective mulch, that accelerate plant maturation (Decoteau et al., 1989) may reduce the impact of nematode parasitism on plant growth. The altered plant maturation rate and architecture may explain the early fruiting and greater fruit yields of tomato infected with root-knot nematodes and grown over red mulch when compared to black mulch in field plantings (Fortnum et al., 1997).

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