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Colored Mulches Affect Yield of Fresh-market Tomato Infected with *Meloidogyne incognita*[1]

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Abstract: The effects of different-colored polyethylene mulches on the quantity and spectra of reflected light, earliness of fruit set, fruit yield and quality, and root-knot disease were studied in field-grown, staked tomato (*Lycopersicon esculentum*). White mulch reflected more photosynthetic light and a lower far-red-to-red ratio than red mulch, whereas black mulch reflected less than 5 percent of any color. Soil temperatures and fruit yields were recorded for tomato plants inoculated with *Meloidogyne incognita* race 3 at initial populations of 0, 1,000, 10,000, 50,000, or 100,000 eggs/plant and grown over black, white, or red plastic mulch in both spring and fall. Soil temperatures were lower under white mulch than under red or black mulch. Tomato yields declined as inoculum level increased. Plants grown over red mulch in the spring and inoculated with 50,000 eggs of *M. incognita* had greater early marketable yields than similarly inoculated plants grown over black or white mulch. Tomato plants inoculated with 100,000 eggs and grown over white mulch or red mulch in the spring had greater total yields per plot than similar plants grown over black mulch (7.39 kg and 7.71 kg vs. 3.65 kg, respectively).

Key words: colored mulch, light quality, *Lycopersicon esculentum, Meloidogyne incognita,* nematode, photomorphogenesis, photospectrum, physiology, root-knot nematode, tomato.

Root-knot nematodes (*Meloidogyne* spp.) are associated with field and vegetable crops in temperate regions of the world (Sasser and Carter, 1982; Taylor and Sasser, 1978). Infection of tomato (*Lycopersicon esculentum* Mill.) by root-knot nematode (*Meloidogyne incognita* (Kofoid & White) Chitwood) increases root weight and decreases shoot and fruit weight (Fortnum et al. 1991; McClure, 1977). Root-knot nematodes function as metabolic sinks similar to a developing fruit (Bergeson, 1966), as nutrients produced in the leaves are redistributed rapidly to the roots and into the bodies of the nematodes. In the southeastern United States, commercial fresh-market tomato fields are treated routinely with a soil fumigant to suppress root-knot nematodes and enhance yields.

Plastic mulches are used commonly in vegetable production. Benefits include enhanced water and fertilizer management, weed control with less herbicide application, and regulation of soil temperatures. Black mulches are used to warm the soil in the spring, and white mulches can be used to keep soil cooler during hot summer days (Decoteau et al., 1986). Upwardly reflected light from colored mulches has been shown to have a phytoregulatory role on the growth of young tomato plants by altering photosynthate allocation to shoots and roots, and on the earliness and quantity of fruit yield (Decoteau et al., 1986, 1988, 1989, 1990).

Subtle changes in the wavelength composition of light reflected from colored mulches alter morphological development in tomato. Photomorphogenesis in plants is regulated by light in the red (R) and far-red (FR) portion of the spectrum, and the FR/R ratios in the plant canopy are altered by reflection from colored mulches. The R-FR reversible pigment, phytochrome, is extremely sensitive to light of low irradiances. The R-absorbing form (Pr) absorbs R and becomes the FR-absorbing form (Pfr) and vice versa. Thus, the FR/R photon ratio in incoming light regulates the photoequilibrium level between the two forms of phytochrome, and this regulates many developmental processes (Kasperbauer, 1971, 1988; Schopfer, 1984). Plants generally respond to an increase in the FR/R ratio by keeping a higher percentage of biomass in the above-ground

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portions of the plant. The phytochrome system may initiate events that modify the balance of endogenous growth regulators (Kasperbauer, 1971), which enables the growing plant to adapt to changing light environments under field conditions (Kasperbauer, 1987; Kasperbauer et al., 1984; Kasperbauer and Karlen, 1986). Similarities between field trials and controlled-environment, end-of-day light experiments suggest that phytochrome initiates the events that modify the differential growth responses in plants grown over colored mulches.

Tomato plants infected with *M. incognita* and irradiated with light containing a high FR/R ratio at the end of the day produced fewer eggs and egg masses than plants receiving a low FR/R ratio in controlled environments (Fortnum and Kasperbauer, 1992). The light source used during the photosynthetic period can affect the development of *Meloidogyne javanica,* suggesting that a combination of irradiance and spectral balance received by the developing shoot might be involved (Bird et al., 1980). Root-knot nematode development is altered by changes in the balance of growth regulators within a plant (Bird and Loveys, 1980; Glazer et al. 1983; Kochba and Samish, 1971), and altered growth regulator levels within the plant may explain the phytochrome-mediated change in nematode development.

Colored mulches, which vary in the quantity and spectral balance of light reflected into the crop canopy, alter nematode development in the field (Fortnum et al., 1995). The objective of this study was to evaluate the effects of colored plastic mulches and the amount of inoculant on earliness and quantity of fresh-market tomato fruit in plants infected with *Meloidogyne incognita* race 3.

Materials and Methods

Field preparation: Two trials were conducted in spring and fall 1989 at the Pee Dee Research and Education Center in Varina sandy loam soil (75% sand, 17% silt, 8% clay; pH 6.0; 0.8% OM). Turn-plowing and disk-harrowing preceded both trials. Fertilizer (90 kg/ha of N applied as 63% urea and 37% $(NH_4)_2HPO_4$, 40 kg/ha of P from the $(NH_4)_2HPO_4$, and 75 kg/ha of K from KCl) was applied broadcast and disked into the upper 15 cm of soil before bedding and mulch application.

Methyl bromide, trickle-irrigation tubes, and polyethylene mulch were applied in one operation. Planting beds were fumigated with methyl bromide (1.7 kg/100-m length of bed) injected 15 cm beneath the soil line with three chisels evenly spaced in an 80-cm-wide by 15-cm-high bed. Bedding disks preceded a bed former that sealed the chisel openings, buried trickle-irrigation tubing 15 cm below the soil line, and covered the bed with a black polyethylene mulch (1.5 m wide by 0.33 mm thick).

The white and the red plastic mulch colors were established by application of outdoor acrylic enamel paint to the black polyethylene mulch. The paint provided a convenient method to obtain different reflective spectra for the small plot studies. Black mulch served as a standard control. The spectra of light reflected from the colored mulches were measured 10 cm above the surface on a cloudless day at solar noon with a spectroradiometer (model LI-1800, LI-COR, Lincoln, NE) after completion of the first trial. The photosynthetic photon flux (400–700nm) was recorded at 5-nm intervals. The FR/R ratio was calculated by dividing the value at 735 nm by the value at 645 nm. FR/R photon ratios were calculated relative to the ratio in incoming sunlight, which was assigned a value of 1.00. Ratios in upwardly reflected light were means of at least 10 scans.

Insect and foliar diseases were controlled with carbaryl (Sevin 80s), malathion (Drexel Malathion 5EC), and chlorothalonil (Bravo 500) as recommended by the Clemson University Cooperative Extension Service. Soil moisture was monitored daily, and irrigation was initiated when soil moisture deficit reached 15 centibars.

Soil temperatures 5 and 10 cm below the black-(unpainted), white-, and red-surfaced

mulches were monitored with a Campbell 21X Micrologger (Campbell Scientific, Logan, UT) with copper-constantan fixed thermocouples. Soil temperature data were averaged for each 60-minute period but reported only every 2 hours. Temperature data were collected from infested (100,000 eggs/plant) and uninfested plots to compare the effects of crop canopy size on soil temperatures. Each temperature value within a mulch color and measured depth is the recorded mean from nine thermocouples distributed over three replications (3 thermocouples/subplot).

Plant growth, yield and nematode development: 'Rutgers' tomato was used in these studies. Tomato seeds were germinated in plastic seedling trays (5- × 5-cm cell size) containing Peat-Lite (Conrad Farard, Springfield, MA) and maintained in a greenhouse until they reached a height of about 15 cm. About 2 weeks after methyl bromide application, seedlings were transplanted to the mulch-covered beds on 17 May and 5 August 1989. An *M. incognita* race 3 population was isolated from field plots at the Clemson Pee Dee Research and Education Center near Florence, South Carolina, and cultured on 'Rutgers' tomato. Nematode eggs from roots of 50-day-old plants were extracted in 0.05% sodium hypochlorite (NaOCl) and washed in tap water (Barker et al., 1986; Hussey and Barker, 1973). Suspensions of 0, 1,000, 10,000, 50,000, and 100,000 eggs were pipetted into two 5-cm-deep holes in the soil on opposite sides of each tomato plant. Nematode-free tomato plant roots were extracted in a similar fashion, and the filtrate of the root suspension was added to control plants and to inoculated plants so each plant received the same total volume (50 ml) of suspension. Holes were filled with soil after adding the suspensions.

Tomato fruit yields were determined biweekly during a 3-week period (total of six harvests). Mature, vine-ripe tomatoes were harvested, sorted by size, and weighed on a subplot (four plants) basis. Yields were divided into early-season (harvest 1–3) and total-season (harvest 1–6) yields. Following the last harvest, plants were excavated and the roots gently washed free of soil. Each plant was separated into stem (including branches) and roots. Fresh plant parts were weighed and recorded. Root galling was rated from 0 to 10 on a linear scale: 0 = no galls and 10 = 100% of the root tissue galled (Barker et al., 1986). Nematode eggs were extracted using the NaOCl treatment, described above, and counted.

Mulch treatments were arranged in a factorial design with mulch colors as main plots and inoculum levels as subplots with six (trial 1) or five (trial 2) replications. Each experimental unit consisted of four plants bordered on each side within a row by an uninoculated plant. Tomato plants were arranged with a 60-cm within-row spacing and 150-cm between-row spacing. Data were analyzed with analysis of variance (Steel and Torrie, 1960).

Results

Plant and soil microclimate: Measurements made at the end of trial 1 demonstrated that mulch surface color influenced the quantity and spectral balance of light reflected into the plant canopy (Table 1). White mulch reflected more photosynthetic light (PPF) than the darker mulches, and red mulch reflected the highest FR/R ratio (Table 1). Soil temperatures were lower under white mulch than under red or black for julian days 156–200 (Fig. 1A–C). Temperatures were cooler at a 10-cm depth than at 5 cm under black plastic, but the difference di-

Table 1. Quantity and quality of light reflected to a point 10 cm above colored mulch surfaces.

Mulch surface color	PPF[a] ($\mu mol \cdot m^{-2} \cdot s^{-1}$)	FR/R ratio[b]
White	898	1.00
Red	273	1.16
Black	94	—[c]

[a] Photosynthetic photon flux (400–700 nm). Light measurements were taken on a cloudless day at solar noon. PPF in incoming sunlight was 1908 $\mu mol\ m^{-2}\ s^{-1}$.

[b] Far-red/red = values at 735 nm divided by values at 645 nm. FR/R photon ratios calculated relative to ratio in incoming sunlight, which was assigned a value of 1.00. Ratios in upwardly reflected light are means for at least 10 scans.

[c] Reflection from black was about 5% across the spectrum. At such low reflectance a very minor difference in reflection in R or FR could result in an apparently large but meaningless ratio.

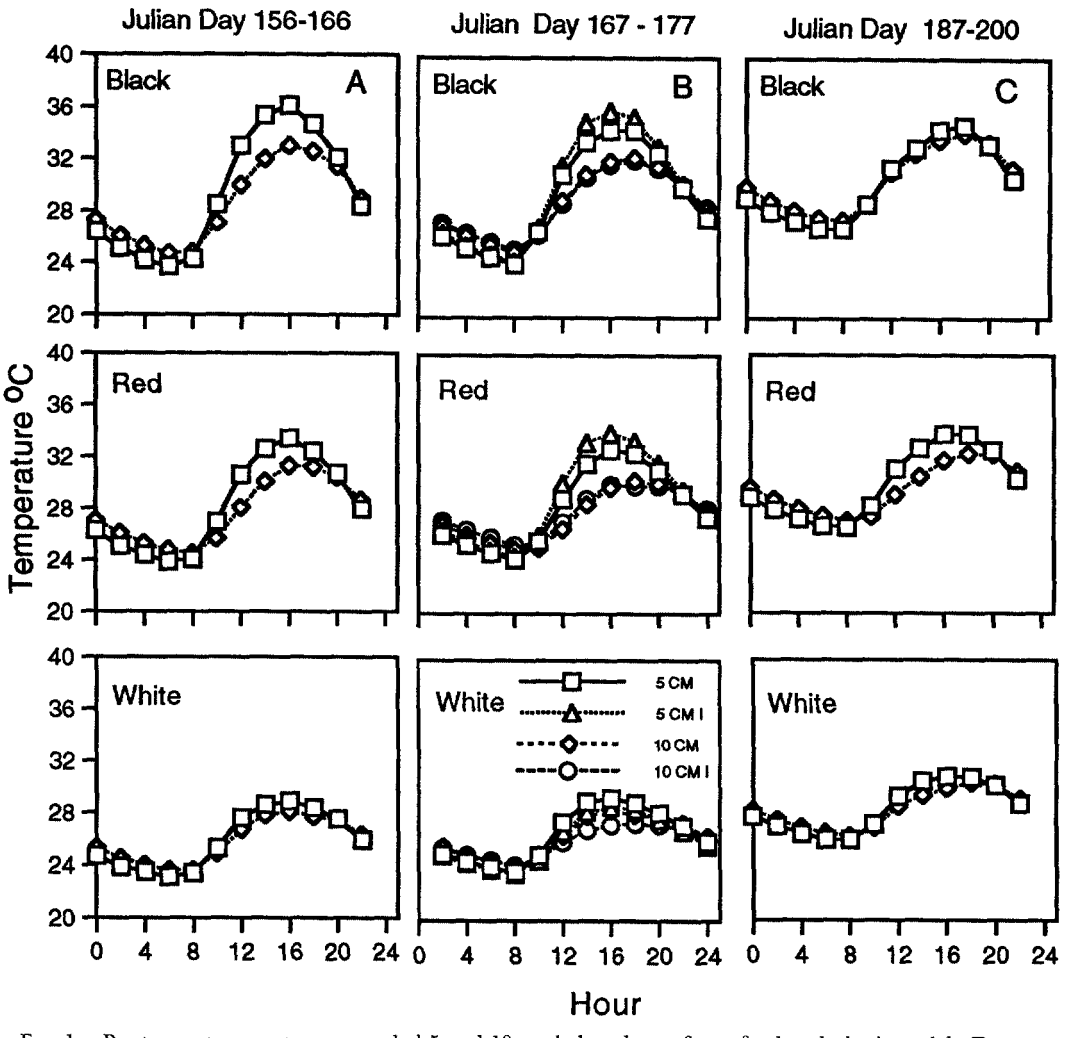

FIG. 1. Root-zone temperatures recorded 5 and 10 cm below the surface of colored plastic mulch. Temperatures were recorded every 5 minutes and averaged each hour during each 24-hour period during julian day 156–166 (A), 167–177 (B), and 187–200 (C). Temperatures were recorded under uninoculated plants and plants inoculated (I) with 100,000 *Meloidogyne incognita* eggs (julian day 167–177).

minished as the season progressed (Fig. 1A–C). Soil temperatures were similar at the 5-cm and 10-cm depths under white mulch. In trial 1, soil temperatures were recorded in infested (100,000 eggs) and uninfested plots. Soil temperatures were warmer (5-cm depth) under plants with smaller canopies (inoculated plants) for black and red mulches than under plants with larger canopies (control plants) (Fig. 1B). In contrast, temperatures under white mulch were cooler for plants with smaller canopies (inoculated plants) than for plants with larger canopies (Fig. 1B).

Plant growth and nematode development: Mulch color altered all parameters used to evaluate the growth and yield of tomatoes ($P \leq 0.10$) except root weight, gall index, early-season average fruit weight (trial 2), and total average fruit weight (Table 2). *Meloidogyne incognita* initial populations (Pi) altered all parameters used to evaluate yield and growth of tomato except for early-season fruit yield and root weight (trial 1), and early-season fruit weight, number of fruit and average fruit weight, and total average fruit weight (trial 2) (Table 2). Significant color × Pi interactions were observed for

TABLE 2. Sources of variation and *P* values for main effects and interactions of mulch color and initial nematode population (Pi) on growth and yield of 'Rutgers' tomato and root galling caused by *Meloidogyne incognita*.

	Early season			Total season						
	Fruit yield			Fruit yield				End of season		
Treatment	Weight	Number	Average fruit weight	Weight	Number	Percentage of control[a]	Average fruit weight	Shoot weight	Root weight	Gall index
Trial 1 (Spring)										
Color	ns	*	*	**	***	***	ns	**	ns	ns
Pi	ns	**	***	***	***	***	***	***	ns	***
Color × Pi	*	ns	ns	ns	ns	ns	ns	*	ns	ns
Trial 2 (Fall)										
Color	**	**	ns	***	***	ns	ns	*	ns	ns
Pi	ns	ns	ns	***	***	***	ns	***	***	***
Color × Pi	*	ns	ns	ns	ns	ns	ns	ns	ns	ns

[a] Fruit yield calculated as a percentage of the uninoculated control.

shoot weight (trial 1, $P = 0.06$) and early-season fruit yield (trial 1, $P = 0.06$; trial 2, $P = 0.10$), but were not observed for any other parameter examined (Table 2).

Combined over Pi, total-season fruit yield and fruit number were greater for tomatoes grown over white mulch than for those grown over black mulch (trials 1 and 2, Table 3). A significant color × Pi interaction was observed for shoot weight (trial 1, $P = 0.06$). Shoot weight declined 71 percent at a Pi of 100,000 eggs when compared to an uninoculated control for white mulch, whereas red and black mulch declined 61 and 62 percent, respectively, at a Pi of 100,000 eggs when compared to the uninoculated control (Fig. 2). The decline in shoot weight plotted as a function of $\log_{10}$ (Pi + 1) was described by quadratic equations for white ($P \leq 0.001$), red ($P = 0.007$), and black ($P = 0.02$) mulch.

Early-season marketable fruit varied across mulch color. A significant color × Pi interaction was observed for fruit yield when fruit weights were totaled over harvests 1–3 (trial 1, $P = 0.06$; trial 2, $P = 0.10$) (Fig. 3). Plants grown over red mulch and inoculated with *M. incognita* (Pi = 50,000 eggs) had

TABLE 3. Fruit yield, root weight, and fruit number of tomatoes grown over mulches of diverse color and averaged across different initial populations of *Meloidogyne incognita*.

			Total season					
	Early season[b]		Fruit yield				End of season	
	Fruit yield (number)	Average fruit weight	Weight	Number	Percentage of control[c]	Average fruit weight	Shoot weight (g)	Root weight (g)
Trial 1 (Spring)								
Color								
White	16 a[a]	119 a	12.2 a	121 a	70 ab	98 a	—	156 a
Red	22 a	113 ab	10.5 ab	108 ab	81 a	96 a	—	110 b
Black	15 a	102 b	8.6 b	89 b	55 b	88 a	—	123 ab
Trial 2 (Fall)								
Color								
White	43 a	131 a	15.0 a	146 a	89 a	103 a	471 a	78 a
Red	35 ab	129 a	12.3 b	125 b	87 a	98 a	401 ab	86 a
Black	28 b	126 a	11.0 b	114 b	92 a	97 a	342 b	83 a

[a] Mean separation based on an LSD test. Values in the same column (within the same trial) followed by the same letter do not differ significantly ($P = 0.05$). Values are averaged across Pi.

[b] Early fruit yields collected from harvest 1–3.

[c] Fruit yield calculated as a percentage of the uninoculated control.

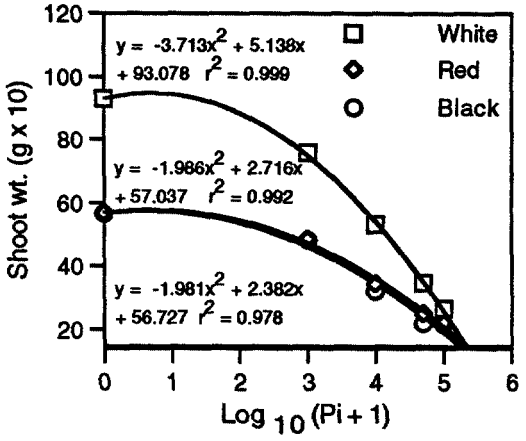

FIG. 2. Effect of initial *Meloidogyne incognita* populations on shoot biomass of Rutgers tomato after the final fruit harvest. Regressions were based on means. Quadratic equations were significant at $P \leq 0.02$.

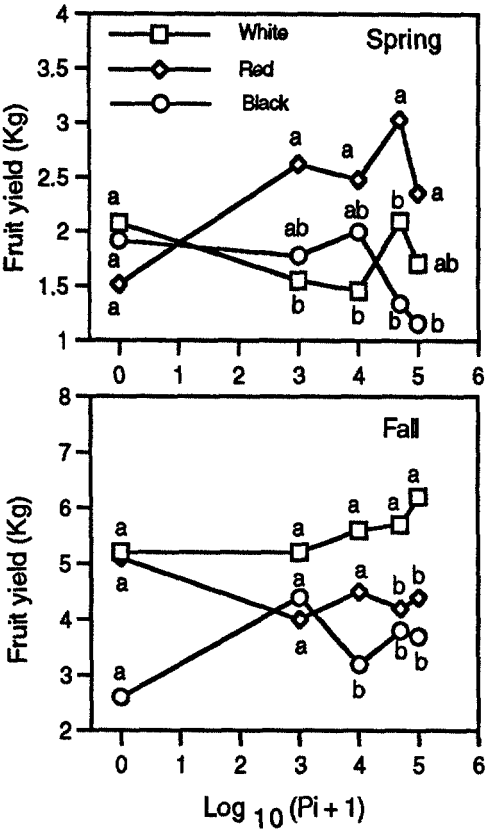

FIG. 3. Effect of initial *Meloidogyne incognita* population on early-season (harvest 1–3) fruit weight of Rutgers tomato grown over several colors of plastic mulch. Mean separation based on LSD test ($P = 0.05$). Values within a Pi followed by the same letter do not differ significantly ($P = 0.05$).

greater early-season fruit yield than plants grown over black or white mulch (trial 1, $P = 0.05$) (Fig. 3). Plants grown over white mulch in the fall had greater early-season yields than plants grown over black mulch with a Pi of 10,000, 50,000, or 100,000 eggs (trial 2, $P = 0.05$). Early-season fruit yields (harvests 1–3) were not altered ($P = 0.05$) by Pi of *M. incognita* (Table 2). Early-season fruit number (harvests 1–3) was higher in plants grown over red mulch than in similar plants grown over white or black mulch ($P \leq 0.10$).

A significant color × Pi interaction was not observed for fruit number, total yield, root weight, or gall index. When averaged across mulch color, fruit number and total yield declined with increasing Pi and could be described by quadratic equations for trials 1 and 2 ($P \leq 0.01$) (Fig. 4). Root galling increased with increasing Pi for trials 1 and 2 ($P \leq 0.01$). Root weights declined with increasing Pi and could be described by a quadratic equation for trial 1 ($P \leq 0.01$). Root weights increased with Pi for trial 2 and could be described by a cubic equation ($P \leq 0.025$) (Fig. 4). Tomato plants inoculated with 100,000 eggs and grown over white mulch or red mulch yielded more (102% and 111%, respectively, $P \leq 0.01$) than similar plants grown over black mulch (7.4 kg and 7.7 kg vs. 3.6 kg/plot, respectively) (trial 1). Tomato plants inoculated with 100,000 eggs and grown over white mulch yielded more (26% and 36%, respectively, $P \leq 0.01$) than similar plants grown over red and over black mulch (13.4 kg vs. 10.6 kg and 9.9 kg/plot, respectively) (trial 2). Total-season fruit yield expressed as a percentage of the uninoculated control was significantly altered ($P = 0.01$) by mulch color and Pi, but a color × Pi interaction was not observed (trial 1, Table 2). Total-season fruit yield averaged across Pi and expressed as a percentage of the uninoculated control was greater for plants grown over red mulch than for similar plants grown over black mulch (trial 1) (Table 3). Total-season fruit yield averaged across Pi and expressed as a percentage of the uninoculated control did not dif-

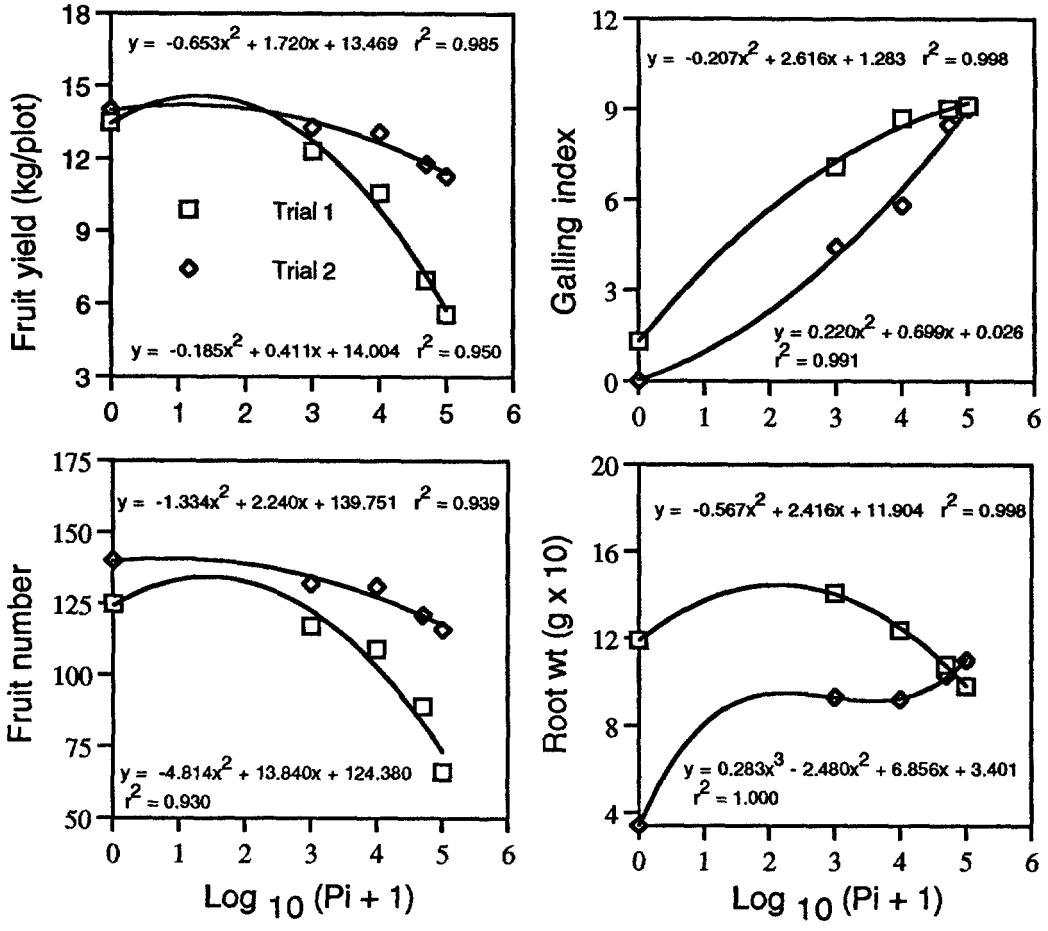

FIG. 4. Root galling, root and fruit weight, and fruit number of Rutgers tomato inoculated with *Meloidogyne incognita*. Regressions were based on means. Values are averaged across mulch colors. Quadratic equations were significant at $P \leq 0.05$.

fer for plants grown over white-, red-, or black-colored mulch in autumn (trial 2) (Table 3).

DISCUSSION

Plastic mulches are used to modify the soil microclimate in production of high-value food crops. Root-knot nematodes are influenced by the environment surrounding a host plant, both below and above ground (Fortnum and Kasperbauer, 1992; Gillard and van Den Brande, 1956; Hussey, 1985). Together, the modified environments influence the amount of root-knot disease. Plastic mulches which differ in color may provide a new tool to modify the environment, thereby affecting plant growth and the development of nematode disease. In our trials mulch color altered root-zone temperatures, plant mass, and fruit yield. Phytochrome has been implicated in the growth responses of tomato grown over different colored mulches, and manipulation of the phytochrome system within the host plant has resulted in altered reproduction of *M. incognita* when root temperatures were held constant across light treatments of the shoot in a controlled environment (Fortnum and Kasperbauer, 1992). In a previous study, we found that mulch color affected early post-transplant tomato plant growth and root-knot nematode reproduction (Fortnum et al., 1995). In the present field experiments, in which root temperatures differed below

the different colored mulches, tomato plants grown over white mulch developed more branches and were heavier than plants grown over black or red mulch. 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. Larger total-season yields were observed in both the spring and fall trials with plants grown over white mulch.

As reported in previous yield trials where colored plastic mulches were evaluated (Decoteau et al., 1986), plants grown over red mulch produced a greater portion of their yield earlier in the season. Earlier fruiting was more pronounced in the spring than in the fall. Accelerating crop maturity may provide an advantage to a producer by providing fruit early in the harvest season when crop value may be highest. Root-knot nematode populations increase with each generation as the eggs hatch and reinfect a plant. The energy demands on the plant are greatest during the later stages of nematode development and the onset of egg laying (Melakeberhan and Ferris, 1988). Increasing the rate of plant maturation may provide an advantage in avoiding the energy demands associated with the late-season increase of nematodes. Plants grown over red mulch in the spring and inoculated with *M. incognita* lost less of their yields than plants grown over black or white mulch when yields were calculated as percentage of an uninoculated control.

Mulch color played a significant role in determining soil temperatures. Canopy structure, as affected by nematode parasitism in terms of amount of shading, altered soil temperatures under the colored plastic mulch in an interactive fashion. Lower soil temperatures under nematode-infected plants grown over white mulch contrasted to the increased temperatures under nematode-infected plants in the darker-colored mulches (black and red). Not only did the soil and light environments affect nematode disease but the nematode-induced disease (reduced canopy size) interacted with the mulch color, affecting soil temperatures.

Typically, plant growth responses to increasing Pi of *Meloidogyne* spp. are described by quadratic relationships (Fortnum et al., 1991). Mulch color did not appear to affect how biomass was partitioned with increasing Pi and agreed with earlier reports (Fortnum and Kasperbauer, 1992; Fortnum et al., 1991). The different responses between spring and fall plantings in these and previous studies suggest factors such as soil temperature and day length may play a role in disease development. Further work will be required to separate the effects of light reflected from the colored mulches from the differences in soil temperatures below these same mulches. Nevertheless, the use of colored mulch allowed us to manipulate both soil temperature and the seedling light environment with the end result being a modified host-parasite relationship and disease development.

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