Effect of Colored Mulches on Root-knot of Tomato

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Technical contribution No. 3519 of the South Carolina Agricultural Experiment Station.

We thank J. Cottingham, T. Matheny, M. Pullen and W. Sanders for technical assistance.

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Accepted for publication 3 October 1994.

ABSTRACT

Fortnum, B. A., Decoteau, D. R., Kasperbauer, M. J., and Bridges, W. 1995. Effect of colored mulches on root-knot of tomato. Phytopathology 85:312-318.

The effect of different colored polyethylene mulches on quantity and spectra of reflected light, plant morphology, and root-knot disease was studied in field grown staked tomato (*Lycopersicon esculentum*). Spring versus fall experiments were conducted in 1987 and 1988 near Florence, South Carolina. Tomato plants were inoculated with *Meloidogyne incognita* at initial populations (Pi) of 0, 10, 50, 100, and 200 ($\times 10^3$) eggs per plant, and grown for 60 days over white, red, and black polyethylene mulch. White reflected more total light, more blue and a lower far-red to red ratio than red, whereas black reflected less than 5% of any color. Soil temperatures were warmer under black and red mulch than under white. Plants grown with white mulch had greater shoot, stem, and leaf weights, and leaf area than plants grown over black mulch ($P \leq 0.004$). Plants grown with red mulch also had greater shoot, leaf, and stem weights, and leaf area, than plants grown over black mulch ($P \leq 0.068$). Treatment interactions were observed for root weight (mulch color $\times$ Pi, $P \leq 0.001$) and root-gall indices (season $\times$ mulch color $\times$ Pi, $P \leq 0.001$). Reductions in shoot weights with increasing Pi coincided with increases in root weight. Linear and quadratic coefficients (absolute values) of the regressions (shoot and root weights on Pi), based on standardized data, were not different ($P = 0.05$) within each color. Although shoot and leaf biomass and leaf area varied among mulch colors, the relationship between biomass or area and Pi was described by quadratic equations for plants grown over white mulch and black mulch but not red mulch ($P \leq 0.057$). The linear and quadratic coefficients of the equations (leaf area, leaf weight or stem weight on Pi) did not differ among tissues ($P = 0.05$) within a mulch color when calculations were based on standardized values.

Additional keywords: colored mulches, far-red light.

Root-knot nematodes are commonly associated with vegetable crops in the southeastern United States (27,30). Root-knot nematodes infect roots, establish polyploid feeding cells, and elicit a metabolic sink reaction in which nutrients produced in the shoots are redirected to the roots (2,24,26). Infection of tomato (*Lycopersicon esculentum* Mill.) by root-knot nematode (*Meloidogyne incognita* (Kofoid & White) Chitwood) can increase root weight and decrease shoot weight (11). Nematode-infected plants have thinner leaves and accumulate proportionately less mass in the stem tissue than in the leaf lamina (11).

Beneficial yield responses of tomato and other crops to plastic mulches have traditionally been attributed to altered soil temperatures, enhanced moisture conservation, and weed control under the plastic. Black plastic is often used in the spring to warm root zone temperatures. In climates where late fall plantings are possible, white-surfaced mulches are used when soil warming is not desirable. Plastic mulches can affect microclimate variables other than soil temperature and moisture. Wavelength selective colored mulches provide a means of altering not only soil temperatures but also the light environment of the growing shoot (5–7). The similarities in response to differences in far-red (FR) to red (R) light ratios associated with mulch color and experiments using different FR/R ratios in controlled environments provide evidence that small changes in the light microclimate, as induced by mulch color, can affect plant growth (5–8,17,19). These growth responses were observed when soil temperatures were held constant among plants that received different FR/R ratios in simulated planting beds (8,17).

Photomorphogenesis in plants is regulated by light in the R and FR portion of the spectrum. The R-FR reversible pigment, phytochrome, is extremely sensitive to light of low irradiances. The R-absorbing form absorbs R and becomes the FR-absorbing form and vice versa. Thus the FR/R ratio in incoming light regulates the photoequilibrium level between the two forms of phytochrome and this regulates many developmental processes (17,28).

Plants growing in a crowded condition or shaded by other plants receive a higher FR/R ratio. Plants generally respond to an increase in the FR/R ratio by growing taller and keeping a higher percentage of biomass in the aboveground portions of the plant. It has been suggested that the phytochrome system initiates events that modify the balance of endogenous growth regulators (17), which enable the growing plant to adapt to changing light environments under field conditions (18–21).

Plant growth regulators also have been implicated in nematode-host responses and disease development (3,12,14,15,22). Tomato plants infected with *M. incognita* and irradiated with light containing a high FR/R ratio in a controlled environment developed fewer eggs and egg masses than plants receiving a low FR/R ratio (10). This was consistent with earlier reports that the light source used during the photosynthetic period can affect the development of *M. javanica* (4,13), suggesting that the combination of irradiance and spectral balance received by the growing shoot might be involved.

The objective of this study was to evaluate the effects of mulch surface color on the light microclimate, soil temperature, and root-knot disease of tomato in the field.

MATERIALS AND METHODS

Inoculum. A *M. incognita* race 3 population was isolated from field plots at the Pee Dee Research and Education Center near Florence, South Carolina and cultured on tomato cv. Rutgers. Nematode eggs from roots of 50-day-old tomato plants were extracted in 0.05% sodium hypochlorite (NaOCl) and washed in tap water as described by Hussey and Barker (16).

Field preparation. Field plots were located at the Pee Dee Research and Education Center on Varina sandy loam soil (75% sand, 17% silt, 8% clay; pH 6.1; 0.8% organic mater). Rye (*Secale cereale* L. 'Abruzzi') had been planted on these sites the previous winter. Turn plowing and disk harrowing preceded all treatments. 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 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 a 80-cm-wide × 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 (1.2-m-wide × 0.33-mm-thick). The white and red 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 spring trials. Experiments were conducted in the spring and fall of 1987 and 1988. 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. Seedlings were transplanted to the field plots (about 2 wk after methyl bromide application) on 12 May and 17 August 1987 and on 19 May and 23 August 1988. Insect and foliar diseases were controlled with carbaryl (Sevin 80 S), malathion (Drexel Malathion 5 EC), 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 centibar. Soil temperatures 5 cm below black (nonpainted), white, and red surfaced mulches were monitored with a Campbell CR7 Micrologger (Campbell Scientific, Logan, UT) with copper-constantan fixed thermocouples. Soil temperature data was collected every 5 min and the data averaged for each 60-min period.

Plant growth and nematode development. Rutgers tomato, which is highly susceptible to root-knot nematodes, was used in these studies. Tomato plants were transplanted into the mulch-covered beds. Suspensions of approximately 0, 10, 50, 100, and 200 (× 10^3) 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 root suspension filtrate 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.

Plant growth and nematode development were evaluated 60 days after infesting the soil. Plants were excavated and the roots gently washed free of soil. Each plant was separated into stem (including branches), leaves (petioles detached at the stem), and roots. Fresh plant parts were weighed, and stem lengths recorded. Leaf areas

TABLE 1. Quality of light reflected to a point 10 cm above colored mulch surfaces

Mulch surface color	PPF[a] (400–700 nm) μmol m^{-2} s^{-1}	Blue (400–500 nm) μmol m^{-2} s^{-1}	Far-red/red ratio[b]
Reflected			
White	898	215	0.95
Red	274	24	1.20
Black	94	21	. . .[c]
Incoming			
Sunlight	1,895	424	0.89

[a]Photosynthetic photon flux.
[b]Far-red/(*FR*) values at 700–795 nm divided by red (*R*) values at 600–695 nm.
[c]Reflection from black was about 5% across spectrum. At such low reflectance a very minor difference in reflection in *R* or *FR* could result in an apparently large, but meaningless, ratio.

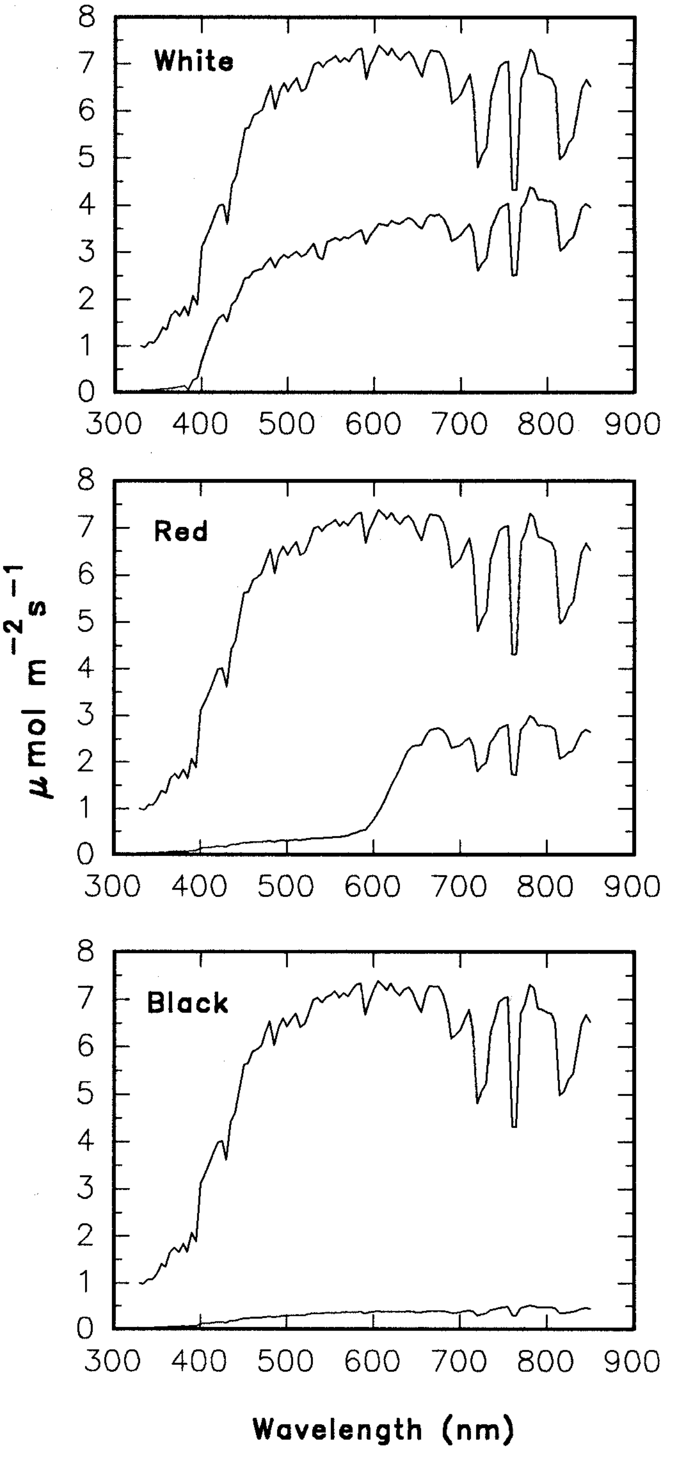

Fig. 1. Effect of mulch color on upwardly reflected light 10 cm above white, red, or black surface colors. Reflected light from each mulch recorded from 330 to 850 nm wavelengths on 5-nm intervals (bottom line) and compared with incoming sunlight (top line).

were determined with an area meter, model LI-3100 (LI-COR, Lincoln, NE). Root galling was rated from 0 to 10 on a linear scale: 0 = no galls and 10 = 100% of the root tissue galled (1). Nematode eggs were extracted using the NaOCl treatment previously described, and counted.

Mulch treatments were arranged in a factorial design with mulch color as main plots and inoculum level as subplots with six replications per trial. Each subplot consisted of two plants. Tomato plants were arranged with 60 cm in-row spacing and 150 cm between-row spacing. Data were analyzed using analysis of variance and regression techniques (29). Least square mean comparisons were used to determine the effect of initial nematode population densities (Pi) on fresh weights of specific plant tissues. Nonlinear regression (quadratic) was used to compare the responses of different plant tissues to Pi. Quadratic regressions were used to compare linear and quadratic coefficients among line equations using a Student's t test. All calculations were performed with the Statistical Analysis System (SAS Institute, Cary, NC) general linear models procedure. For some comparisons, data were converted to a standardized scale (9,11) using equation 1,

$$\text{standardized value} = (\bar{X} - \bar{\bar{X}})/\text{SD} \quad (1)$$

where $\bar{X}$ = the average of 24 replications of parameter X at inoculum level i, $\bar{\bar{X}}$ = the average of parameter X across all inoculum levels, and SD = the standard deviation of the $\bar{X}$s from the $\bar{\bar{X}}$ defined as $\text{SD} = [\Sigma(\bar{X}_i - \bar{\bar{X}})^2/(n-1)]^{1/2}$. Equation 1 centers and scales the responses to a mean of 0 and a variance of 1.

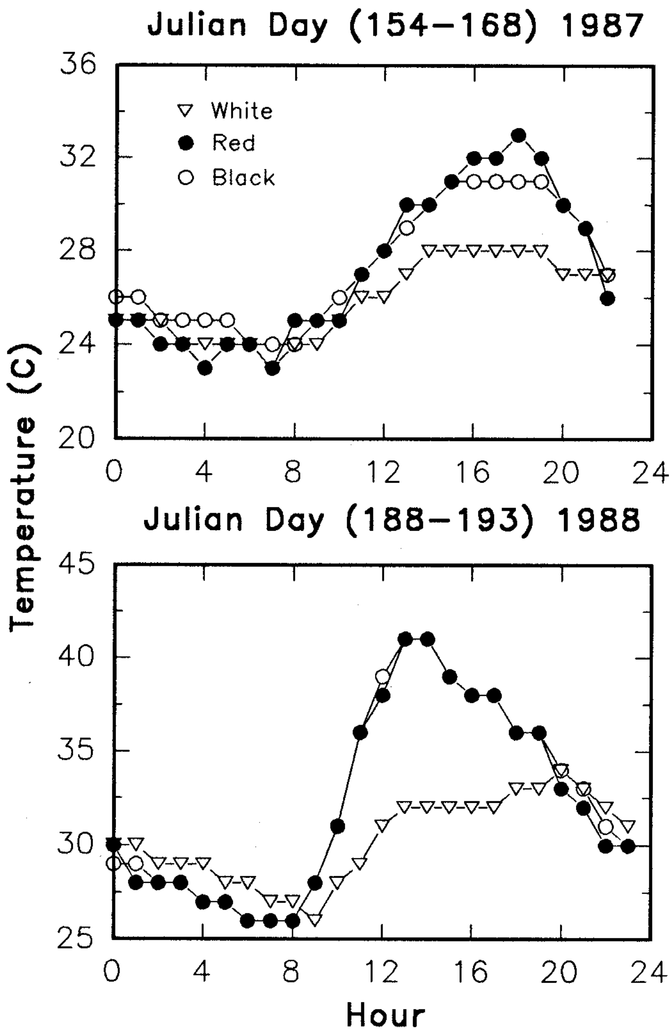

Fig. 2. Mulch color effects on root zone temperatures recorded 5 cm below the plastic mulch. Temperatures recorded every 5 min and averaged each hour during each 24-hr period during the 14 and 5 day periods in 1987 and 1988, respectively. (Soil temperatures 20 cm below surface of colored mulches ranged from 26.1 to 29.5 C across all mulch colors, when temperatures under black mulch reached 38 C at a depth of 5 cm).

RESULTS

Plant microclimate. Mulch surface color influenced the quantity and spectral balance of light reflected into the plant canopy (Table 1, Fig. 1). White mulch reflected more photosynthetic light, more blue light, and had a lower FR/R ratio than the black and red mulches (Table 1, Fig. 1). Soil temperatures recorded 5 cm below the mulch surface were lower under white mulch than under red or black colored mulch (Fig. 2). Soil temperatures 20 cm below the surface of the colored mulches ranged from 26.1 to 29.5 C across all mulch colors, when temperatures under black mulch reached 38 C at a depth of 5 cm.

Plant growth and nematode development. Mulch color and *M. incognita* Pi significantly altered all parameters used to measure the growth and development of tomato plants ($P \leq 0.001$) (Table 2). Significant color × Pi and season × color × Pi interactions ($P = 0.05$) were not observed for shoot, leaf, and stem weights or leaf area (Table 2). Combined over season, years, and Pi, all parameters of plant growth were greater for tomatoes grown over white mulch than for those grown over black mulch ($P \leq 0.004$, Table 3). The fresh shoot, stem, and leaf weights, and leaf area, of tomatoes grown over red mulch were greater ($P \leq 0.068$) than those of plants grown over black mulch (Table 3). Plants grown over red mulch did not differ in leaf area from plants grown over white mulch (Table 3). Nematode egg production per gram of dry root weight was greater in plants grown over white mulch than in plants grown over red or black mulch in the spring ($P \leq 0.013$). Egg production did not differ among mulch treatments in the fall trials (Table 3).

A significant color × Pi interaction was observed for root weight ($P \leq 0.001$, Table 2). Uninoculated plants grown over the three colors of polyethylene mulch did not differ in root weights ($P \leq 0.05$, Table 4). Root weights of plants grown over white mulch increased ($P \leq 0.05$) with each increase in Pi (Table 4,

TABLE 2. Sources of variation and P values for main effects and interactions of season, mulch color, and initial nematode population (Pi) on disease caused by *Meloidogyne incognita* and plant growth parameters in tomato cv. Rutgers

	$P > F$ values							
Source of variation	Shoot wt. (g)	Root wt. (g)	Root gall index	Leaf area (cm^2)	Leaf wt. (g)	Stem wt. (g)	Root/shoot ratio	Eggs per g dry wt.
Season (spring vs fall)	*[a]	***	***	***	***	***	***	***
Mulch color	***	***	***	***	***	***	***	*
Season × color	0.39	0.24	***	0.19	**	0.09	**	*
Pi	***	***	***	***	***	***	***	***
Season × Pi	0.77	***	***	**	**	***	***	***
Color × Pi	0.89	***	***	0.75	0.85	0.64	0.37	0.16
Season × color × pi	0.76	0.31	***	0.42	0.28	0.48	0.43	0.14

[a]One asterisk, significant at $P = 0.05$; two asterisks, significant at $P = 0.01$; three asterisks, significant at $P = 0.001$.

Fig. 3). Root weights of plants grown over black or red mulch increased at low Pi's but plateaued with a Pi of 5×10^4 and 1×10^5 ($\log_{10}$ (Pi + 1) of 5 and 5.3, respectively) (Table 4, Fig. 3).

A significant season × color × Pi interaction was observed for root gall index ($P \leq 0.001$, Table 2). Root gall indices were significantly lower ($P \leq 0.001$) in fall compared with spring planting for tomatoes grown over black or red mulch and inoculated with a Pi of 1×10^4 but were not significantly different between fall and spring at Pi's higher than 5×10^4 (Table 5).

Shoot and leaf weights and leaf area declined with increasing Pi as described by quadratic equations for plants grown over white ($P = 0.011$, $P = 0.017$, $P = 0.005$, respectively), and black mulch ($P = 0.056$, $P = 0.040$, $P = 0.028$, respectively), but not red mulch ($P = 0.09$, $P = 0.21$, $P = 0.22$, respectively) (Fig. 3). Root weight increased with increasing Pi as described by quadratic equations for plants grown over black ($P = 0.026$), white ($P = 0.024$), and red ($P = 0.020$) mulch.

Based on standardized values, the decline in shoot weight and the increase in root mass with increasing Pi were described by quadratic equations for plants grown over black mulch ($P = 0.056$, $P = 0.027$, respectively), white mulch ($P = 0.011$, $P = 0.024$, respectively), and red mulch ($P = 0.090$, $P = 0.021$, respectively). Linear and quadratic coefficients (absolute values) of regressions (shoot and root weights on Pi) within a color, based on standardized data, were not different ($P = 0.05$, Fig. 4). Based on standardized values, leaf area, leaf weight, and stem weight declined with increasing Pi as described by quadratic equations for plants grown over black mulch ($P = 0.028$, $P = 0.040$, $P = 0.113$, respectively) or white mulch ($P = 0.006$, $P = 0.018$, $P = 0.010$, respectively), but not for those grown over red mulch ($P = 0.226$, $P = 0.208$, $P = 0.153$, respectively) (Fig. 5). The linear and quadratic coefficients of the equations (leaf area, leaf weight or stem weight on Pi) within a mulch color did not differ among tissues ($P = 0.05$) when calculations were based on standardized values.

TABLE 3. Tomato plant development and *Meloidogyne incognita* reproduction over white, red, and black mulches averaged over seasons, years, and initial nematode populations (Pi)

Mulch[a] surface color	Shoot wt. (g)	Leaf area (cm^2)	Leaf wt. (g)	Stem wt. (g)	Eggs per gram dry root wt. (× 1,000)[b]
White (W)	1,137	7,803	643	430	312
Red (R)	992	7,093	544	357	170
Black (B)	796	6,000	464	306	201
Probability[c]					
W vs R	0.095	0.229	0.021	0.004	0.002
W vs B	0.001	0.004	0.001	0.001	0.013
R vs B	0.026	0.068	0.056	0.035	0.460

[a]Means are average of six replications per trial averaged across four trials (spring and fall of both 1987 and 1988).
[b]Data are from trials planted in the spring (two trials).
[c]Probability calculated with least square means.

DISCUSSION

Biomass accumulation by *M. incognita*-infected tomato plants is controlled by the efficiency of the parasite-altered host to capture light energy and to allocate that energy to growth of the plant or to the parasitic nematode (23,25,26). Root-knot nematodes, due to their body size and egg laying capacity, require large amounts of energy for synthesis (23,25,26). In addition to energy demands, root-knot nematodes have pathogenic effects on the host such as altered root structures and mass, increased susceptibility to soil fungi (15), and altered photosynthetic efficiency (25,26). The environment surrounding a host plant, both below and above ground, plays a key role in the development of root-knot disease. Environmental conditions alter the growth of the host, the pathogen, and possibly the ability of the host to compensate for damage by the nematode to root structures and the reallocation of nutrients to giant cells located within the roots (15). Modification of the shoot light and soil temperature environments by colored mulches provides a novel approach to minimizing root-knot damage.

The light environment surrounding young seedlings can be modified by reflection from different colored mulches and this can have a phytoregulatory role in the growth of young tomato plants (5–7). In our trials, mulch color altered the quantity and spectral balance of light reflected into the plant canopy, soil temperatures, and the accumulation of plant mass. Mulch color altered root-knot disease by affecting root galling and egg production. 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 (10). In the present field experiment, in which root temperatures differed below the different colored mulches, tomato plants grown over white 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

TABLE 4. Root weights of tomatoes grown over different colored mulches and inoculated with different initial populations (Pi) of *Meloidogyne incognita*

Mulch surface color	Nematode populations $\log_{10}$ (Pi + 1)	Root wt. (g)	Treatment code	$P > F$[a] 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Black	0	73	1	...														
	4	134	2	***	...													
	4.7	187	3	***	***	...												
	5.0	197	4	***	***	NS[b]	...											
	5.3	200	5	***	***	NS	NS	...										
White	0	90	6	NS	**	***	***	***	...									
	4	128	7	***	NS	***	***	***	**	...								
	4.7	173	8	***	*	NS	NS	NS	***	**	...							
	5.0	226	9	***	***	*	NS	NS	***	***	***	...						
	5.3	281	10	***	***	***	***	***	***	***	***	***	...					
Red	0	79	11	NS	***	***	***	***	NS	***	***	***	***	...				
	4	138	12	***	NS	**	***	***	***	NS	*	***	***	***	...			
	4.7	203	13	***	***	***	NS	NS	***	***	NS	NS	***	***	***	...		
	5.0	256	14	***	***	NS	***	***	***	***	***	NS	NS	***	***	***	...	
	5.3	260	15	***	***	***	***	***	***	***	***	*	NS	***	***	***	NS	...

[a]Probability calculated with least square means: one asterisk, significant at $P = 0.05$; two asterisks, significant at $P = 0.01$; three asterisks, significant at $P = 0.001$.
[b]Not significant at $P = 0.05$.

growth. The increased egg production in plants grown over white mulch may reflect a greater nutrient supply for the nematode. Root size was unaffected by mulch color in the absence of nematodes. The increased potential to support nematode development and tolerate nematode parasitism could be seen in the capacity of the plant root system to enlarge with increasing Pi in plants grown over white and red mulch, but not over black mulch. At lower Pi's, root mass and available nutrients were not limiting factors, and a different response emerged (season × color × Pi interaction). The lower temperatures in the spring under white mulch may have contributed to lower galling indices.

In plants infected by root-knot nematodes, root weights typically increase with increasing Pi due to the biomass of the galled tissue; conversely, shoot weights decrease (11). Typically growth responses to increasing Pi of *Meloidogyne* spp. are described by quadratic relationships (11). A strong relationship was observed in our trials between the decline in shoot weight and the increase in root weight when data were standardized. The use of standardized data allowed the change in plant mass due to root-knot nematodes to be viewed from a different perspective. When responses were centered and scaled to a mean of zero with a variance of 1, comparisons were made between the shapes

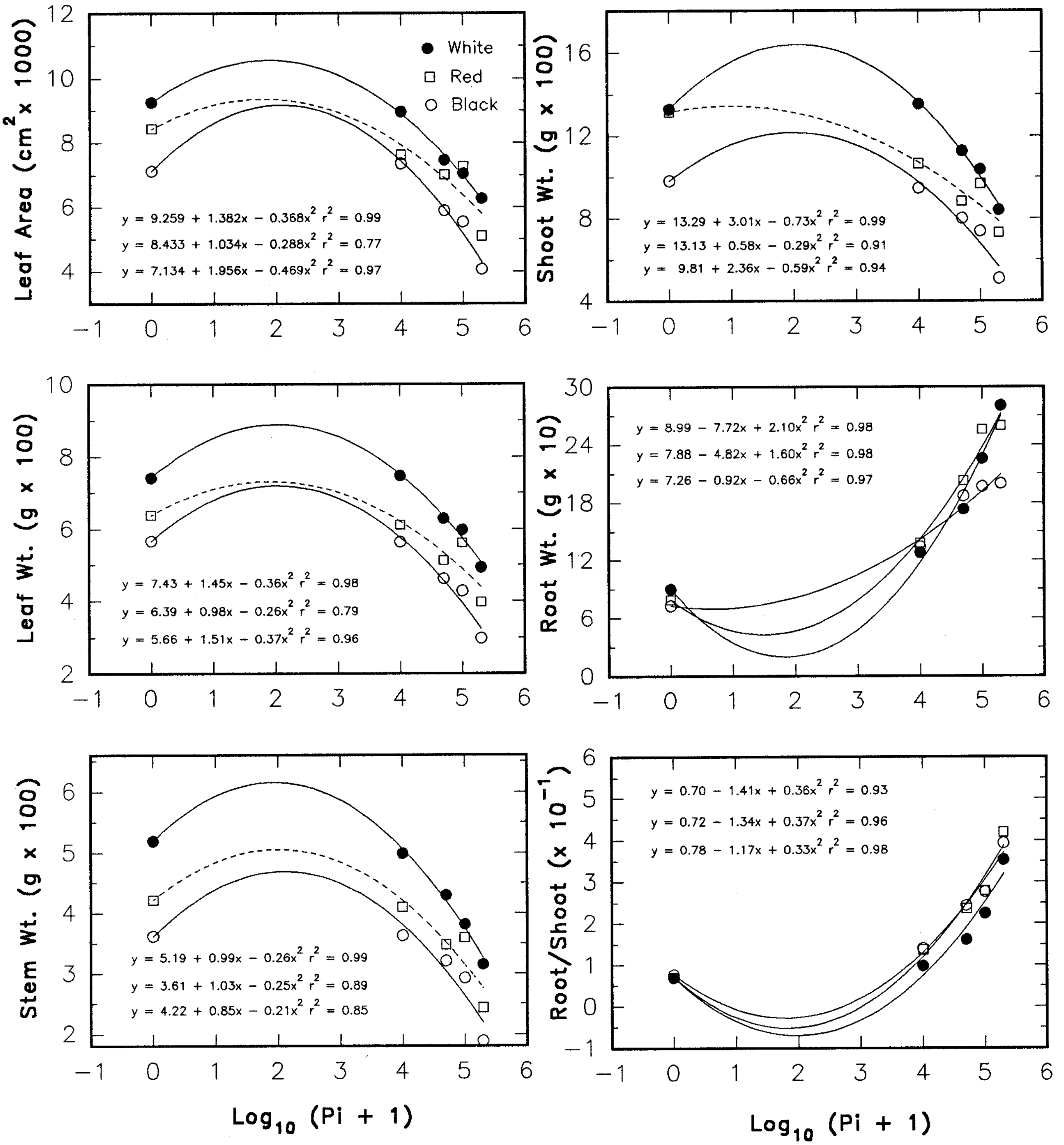

Fig. 3. Effect of initial *Meloidogyne incognita* populations on biomass of tomato cv. Rutgers 60-days-after inoculation. Values are means of 24 replications collected over two seasons (spring and fall, 1987 and 1988). Regressions based on means. Dashed lines indicate quadratic equations not significant at $P \leq 0.06$.

of the response curves independent of the magnitude of the response. The relationship (equal but opposite growth patterns) between root and shoot tissues on Pi, based on standardized data, was observed across all mulch colors. Mulch color did not appear to affect the change in biomass partitioning caused by *M. incognita.* The mirror image effect illustrates the strong link between altered root mass and the decline in shoot weight that is not apparent from nontransformed data. This data confirms under field conditions this root-knot nematode/host relationship that was previously reported in a controlled environment study (11).

Nematode reproduction differed among mulch colors and between seasons; however, with the present data the effects of an altered light environment could not be separated from the effects of altered soil temperatures. 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 modified disease development. Further work will be required to quantify the effects of mulch color on fruit yield, earliness of fruit set, and fruit quality in nematode-infected tomato.

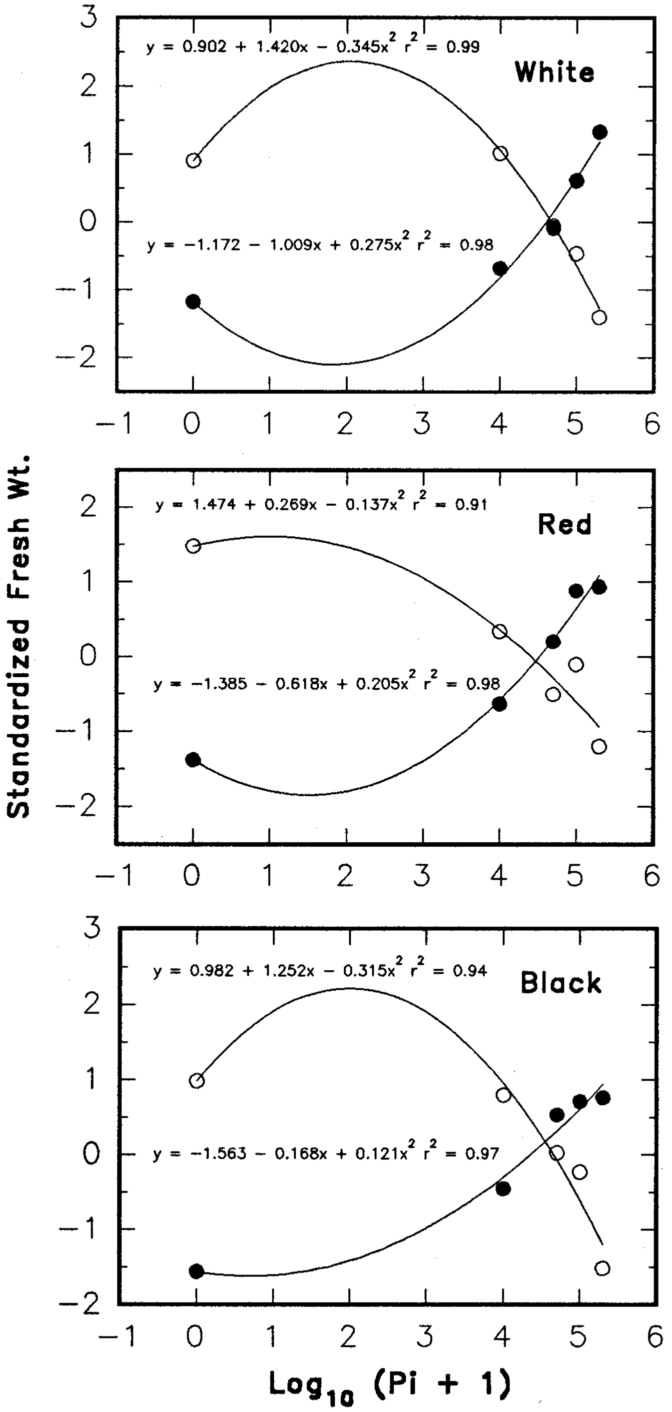

Fig. 4. Effect of initial *Meloidogyne incognita* populations (Pi) on shoot (hollow circles) and root (filled circles) biomass of tomato cv. Rutgers 60- days-after inocultion. Standardized growth paramenters plotted as log function of Pi, $\log_{10}$ (Pi + 1). Values are mean of 24 replications collected over two seasons (spring and fall, 1987 and 1988). Regressions based on means. Responses centered and scaled to mean of 0 and variance of 1.

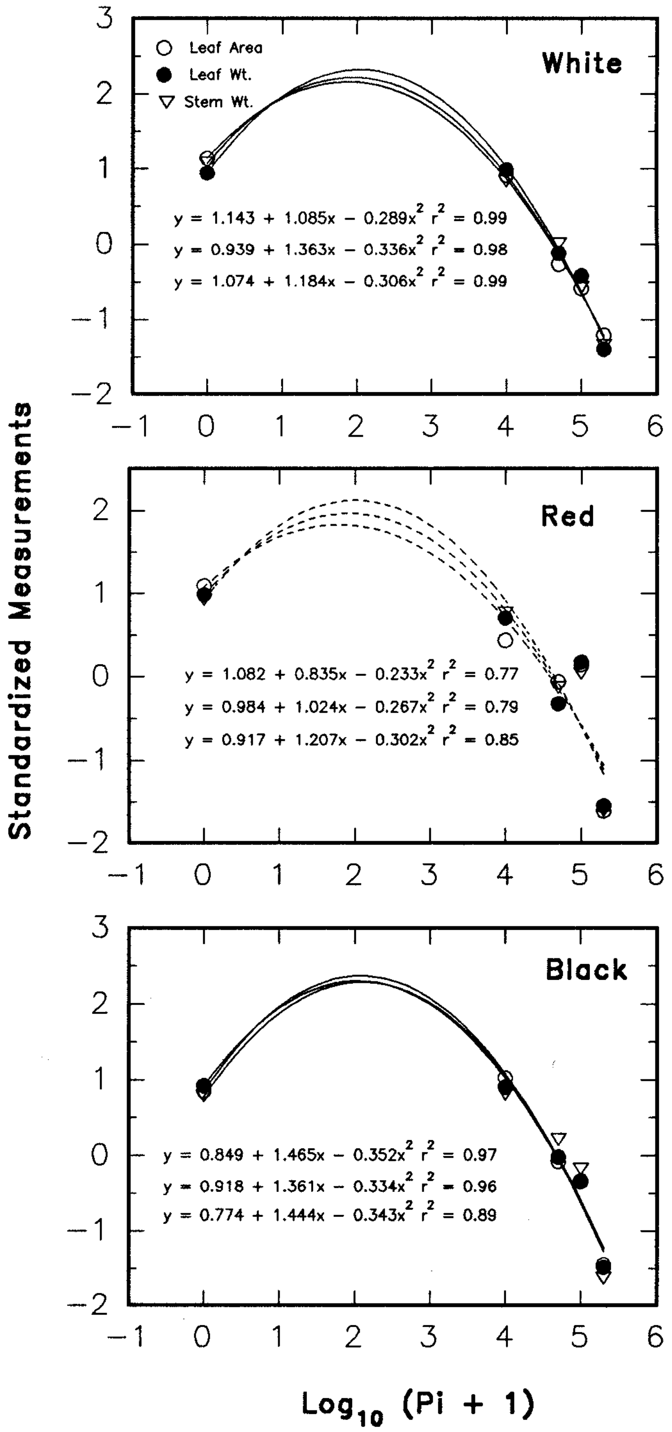

Fig. 5. Standardized growth paramenters plotted as a log function of the initial nematode population, Pi, $\log_{10}$ (Pi + 1). Responses centered and scaled to mean of 0 and variance of 1. Regressions based on means. Values are mean of 24 replications collected over two seasons (spring and fall, 1987 and 1988).

TABLE 5. Root gall indices of tomatoes grown over white, red, and black mulches and inoculated with *Meloidogyne incognita* in spring and fall plantings

Mulch surface color	Nematode populations $\log_{10}(Pi + 1)$	Gall index[a] Spring	vs	Fall	$P > F$[b]
White	0	0		0	NS[c]
	4.0	3.9		3.9	NS
	4.7	7.0		7.8	NS
	5.0	8.1		8.8	NS
	5.3	9.4		9.8	NS
Red	0	0		0	NS
	4.0	7.3		5.0	***
	4.7	7.6		7.9	NS
	5.0	9.4		8.9	NS
	5.3	9.9		9.9	NS
Black	0	0		0	NS
	4	7.3		4.5	***
	4.7	8.6		7.8	*
	5.0	9.6		9.0	NS
	5.3	9.6		9.6	NS

[a]Means are average of two trials per season with six replications per trial. Root-galling was rated from 0 to 10 on a linear scale: 0 = no galls and 10 = 100% of the root tissue galled.
[b]One asterisk, significant at $P = 0.05$; two asterisks, significant at $P = 0.01$; three asterisks, significant at $P = 0.001$.
[c]Not significant at $P = 0.05$.

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