EVALUATION OF SOIL TREATMENTS FOR CONTROL OF *MELOIDOGYNE ARENARIA* IN CALADIUM TUBERS (*CALADIUM* × *HORTULANUM*) AND NEMATODE SUSCEPTIBILITY OF SELECTED CULTIVARS

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ABSTRACT

Kokalis-Burelle, N., E. N. Rosskopf, and R. D. Hartman. 2010. Evaluation of soil treatments for control of *Meloidogyne arenaria* in Caladium tubers (*Caladium* × *hortulanum*) and nematode susceptibility of selected cultivars. Nematropica 40:177-189.

Field and greenhouse studies were conducted to assess the efficacy of soil fumigants for control of *Meloidogyne arenaria* on harvested caladium (*Caladium* × *hortulanum*) tubers, to determine the susceptibility of five commonly grown caladium cultivars to *M. arenaria*, and to evaluate effects of fumigation of previously uncultivated land on caladium production. In the fumigant effectiveness study, root condition was better and gall ratings were lower on caladium and tomato indicator plants for the dimethyl disulfide product, Paladin than for several Telone treatments and the untreated control. Of the two cultivars planted in the fumigant study, galling and *M. arenaria* J2 isolated from roots were both higher in 'White Delight' than 'Moonlight'. Evaluation of additional cultivars for susceptibility to *M. arenaria* showed that the standard hot water treatment employed by the grower as a pre-plant seed treatment was equally effective in disinfesting all caladium cultivars tested, with low numbers of viable root-knot nematode juveniles isolated from tubers following the treatment. Fumigation of previously fallow land with methyl bromide compared to non-fumigated land in the same field resulted in caladium shoot weights and root weights that were greater in methyl bromide treated soil than in untreated soil. However, root health was better in untreated soil, with no differences in galling or nematodes isolated from roots in the methyl bromide treated soil compared to the untreated soil. Evaluation of weeds as alternate hosts for root-knot nematodes in this field study revealed lower levels of galling in untreated soil compared with methyl bromide fumigated soil.

Key words: caladium, dimethyldisulfide, DMDS, *Meloidogyne arenaria*, methyl bromide Paladin, root-knot nematodes, soil fumigants, Telone.

RESUMEN

Kokalis-Burelle, N., E. N. Rosskopf, and R. D. Hartman. 2010. Evaluación de tratamientos para el control de *Meloidogyne arenaria* en tubérculos de caladio (*Caladium* × *hortulanum*) y susceptibilidad de cinco cultivares. Nematropica 40:177-189.

En estudios de campo e invernadero, se midió la eficacia de fumigantes para el control de *Meloidogyne arenaria* en tubérculos de caladio (*Caladium* × *hortulanum*), se determinó la susceptibilidad a *M. arenaria* de cinco cultivares de caladio comúnmente cultivados, y se evaluó el efecto de la fumigación sobre terrenos nunca antes usados para el cultivo de caladio. En el estudio para evaluar la efectividad de los fumigantes, se observaron mejores raíces y menos agallamiento en plantas de tomate y de caladio sembradas en suelo tratado con dimetildisulfuro (Paladin) que con los tratamientos de Telone y que en los controles no tratados. Tanto el agallamiento como los juveniles en el suelo fueron mayores en 'White Delight' que en 'Moonlight', los dos cultivares usados para el estudio de fumigación.

La evaluación de la susceptibilidad de cultivares a *M. arenaria* demostró que el tratamiento con agua caliente usado por los cultivadores de caladio como método de control presiembra es igualmente efectivo en todos los cultivares para la desinfestación de semilla. La fumigación con bromuro de metilo de tierras no cultivadas produjo mayor peso de raíces y de partes aéreas, comparado con plantas sembradas en suelo no fumigado del mismo lote. Sin embargo, la salud de la raíz fue mejor en el suelo no fumigado, sin observarse diferencias en agallamiento o en densidades de población en la raíz. La evaluación de malezas como hospedantes alternos del nematode reveló niveles de agallamiento más bajos en el suelo no tratado que en suelo fumigado con bromuro de metilo.

Palabras claves: bromuro de metilo, caladio, dimethildisulfuro, DMDS, fumigantes, *Meloidogyne arenaria*, nematodos agalladores, Paladin, Telone.

Caladium (*Caladium* × *hortulanum* Birdsey) is an ornamental foliage plant grown from tubers and planted extensively in the landscape, especially in the southeastern U.S. Commercial production of caladium tubers is highly concentrated in Highlands County in central Florida, which produces approximately 85% of the world's supply of tubers. The majority of caladium production occurs in a highly organic, muck soil but a small percentage (10-20%) of production occurs in sandy soil in Hardee County, Florida. Both soils have high root-knot nematode (*Meloidogyne* spp.) populations. Symptoms of root-knot nematode infestation on caladium include leaf dieback, stunted plants, galling on roots, and low tuber yields due to small sized tubers. Tubers also become highly infested with root-knot nematodes but may remain either symptomless or produce fairly nondescript corky lesions. Nematode infestation of tubers is highly problematic both for shipping of tubers for retail sale and replanting of seed tubers for commercial propagation. Caladium varieties have been reported to differ in their resistance to some species of *Meloidogyne* (McSorley *et al.*, 2004).

Caladium growers have relied on methyl bromide for nematode, weed, and pathogen control, but their access to methyl bromide is ending as final phase-out of the chemical progresses (Rosskopf *et al.*, 2005). Currently, caladium growers have access to quarantine/pre-shipment (QPS) stocks of methyl bromide; however, this availability is short-term (Rosskopf *et al.*, 2005). Growers rely on variations of pre-plant hot water treatments to kill residual nematodes in tubers (Rhoades, 1961; 1964).

There is no known root-knot nematode resistance in caladium; however, cultivars differ in their level of susceptibility (McSorley *et al.*, 2004). Currently only the University of Florida and one private grower have caladium breeding programs. In addition to identifying levels of resistance in existing cultivars, and breeding new cultivars, alternative soil chemical treatments have been investigated to provide nematode, weed, and pathogen control (Gilreath and West, 1996; Gilreath *et al.*, 1999). To successfully manage production of numerous caladium cultivars without methyl bromide, it will be necessary to have a better understanding of the effects of available fumigants on nematodes in soil and in tubers harvested from treated soil. Knowing the relative susceptibility of caladium cultivars to different *Meloidogyne* spp. may also enable growers to manage nematode infested fields.

The biological buffering capacity of non-fumigated soil is a well-known phenomenon (Westphal and Becker, 1999; 2000; 2001). Aggressive and stable populations of *Meloidogyne* spp. are most easily

established by fumigating fields with methyl bromide (personal observations, N. Kokalis-Burelle). This phenomenon is due to elimination of the biological buffering capacity of the soil and is well established in nematology literature (Borneman and Becker, 2007). The first year of caladium production in previously uncultivated soil often produces the highest yields and does not require fumigation for root-knot nematode control (personal observations, R. Hartman).

The objectives of this research were to assess 1) two soil fumigants for control of *M. arenaria* in caladium tubers harvested from treated field soil, 2) the relative susceptibility to *M. arenaria* of several caladium cultivars, including two recent releases, 3) the ability of uncultivated, nonfumigated soil to buffer nematode infestation on caladium compared to soil fumigated with methyl bromide, and 4) weeds in untreated and methyl bromide treated field plots as hosts for *M. arenaria*.

MATERIALS AND METHODS

Commercial field production of caladium tubers

Field production was located in a nematode infested area of a commercial caladium farm in Hardee County, Florida. Soil type was Myakka fine sand. For the first study, planting beds were formed in late summer by a prebedder, followed by a final bed press and fumigation rig which injected methyl bromide:chloropicrin (67:33) at 403 kg/ha, followed by application of standard black high barrier film to fumigated beds. Two cultivars of caladium tubers, 'Moonlight' and 'White Delight', were planted and fertilized according to the grower's standard practices for commercial production. Fertilization consisted of an in-furrow application of Florikan (Florikan E.S.A., Sarasota, FL) controlled release fertilizer at 1569 kg/ha (298 kg N/ha), followed at three weeks after planting with 6-2-7 plus minor nutrients applied at 1120 kg/ha (67 kg N/ha). During the season five applications of 7-0-9 liquid fertilizer were applied at 112 liters/ha/application for a total of 49.9 kg N/ha. Total N applied during the season was 415.3 kg/ha. At midseason, additional soil fumigant treatments were applied through drip chemigation to test the potential to reduce nematode infestation of harvested tubers. Supplemental drip treatments were: untreated, Telone® II EC (1.3-Dichloropropene) at 500 ppm (T-500), Telone II EC at 750 ppm (T-700), Telone II EC at 1000 ppm (T-1000), Telone II EC at 1500 ppm (T-1500), Paladin™ (Dimethyldisulfide) at 1500 ppm (DMDS-1500). Following caladium harvest, 'Moonlight' and 'White Delight' tubers from the fumigant test area were sent to the USDA, ARS lab in Ft. Pierce, Florida where a series of greenhouse trials (described below) were conducted to assess nematode infestation levels in harvested tubers.

The second study was conducted to determine the relative susceptibility of caladium cultivars 'Moonlight', 'White Delight', 'Candidum Senior', 'White Christmas', 'John Peed', 'Pink Beauty', and 'Sweetheart', to *Meloidogyne arenaria,* and to determine the effectiveness of the grower's standard pre-plant hot water treatment for disinfesting tubers of different cultivars. The production area was fumigated in February with methyl bromide:chloropicrin (67:33) at 392 kg/ha applied with a bed press under plastic and covered with a standard 1ml black polyethylene film. Prior to planting, beds were formed by a pre-bedder followed by a final bed press and covered with standard black high barrier film. Prior to planting, tubers from all cultivars were dipped into 50°C water for 30 minutes. Tubers were then cut into seed pieces

with a custom built mechanical cutter, and seed pieces were coated with pecan hull dust to prevent sticking. Following caladium harvest, the seven cultivars listed above from the methyl bromide treated production area were sent to the USDA, ARS lab in Ft. Pierce, Florida where a series of greenhouse trials (described below) were conducted to assess nematode infestation levels in harvested tubers.

Greenhouse assessments of Telone and DMDS post-plant field treatments for nematode control in harvested caladium tubers

Tubers of two cultivars of caladiums were planted in 20 cm-diam. plastic pots and arranged in a completely randomized design on the greenhouse bench. One tuber seed piece was planted per pot, and each seed piece contained at least one auxiliary bud. Ten replicate pots were planted for each caladium cultivar and field soil treatment. Each pot was also planted with one approximately 3 week old 'Tiny Tim' tomato transplant. Tomato plants were used because of the ease of assessing nematode infestation of tomato roots compared with caladium tubers (McSorley *et al.*, 1999). Pots were maintained in the greenhouse, watered daily and fertilized once a week by hand with Peters 20-20-20 (J. R. Peters, Inc., Allentown, PA). After 8 weeks, the 'Tiny Tim' tomatoes were removed from pots and assessed for growth, root disease and galling, and nematode infestation of roots (described below). Caladium tubers and roots were removed from soil after 13 weeks and plants were assessed for growth, root disease and galling. Nematodes were extracted from both tomato and caladium roots using the Baermann funnel technique. Both tomato and caladium plants were also evaluated for root weight, stem weight, and nematodes/g root. Root condition was used as a general indicator of root disease and was assessed using a subjective scale of 0 to 4 with 0 = 0% to 20% discolored roots, 1 = 21% to 40%, 2 = 41% to 60%, 3 = 61% to 80%, and 4 = 81% to 100%. Root galling was assessed using a root gall index based on a scale of 0 to 10, with zero representing no galls and 10 representing severe (100%) galling (Bridge and Page, 1980).

Greenhouse evaluation of susceptibility of seven selected caladium cultivars to Meloidogyne arenaria

Tubers of seven field-grown (described above) caladium cultivars were planted in 20 cm-diam. plastic pots and arranged in a completely randomized design on the greenhouse bench. Ten replicate pots were planted for each caladium cultivar. Each pot was also planted with one 'Tiny Tim' tomato plant. Pots were maintained in the greenhouse, watered daily and fertilized weekly as previously described. After 8 weeks the 'Tiny Tim' tomatoes were removed from pots and assessed as previously described. Caladium tubers and roots were removed from soil after 13 weeks and assessed for root disease and nematodes were extracted from roots.

Effects of first year soil fumigation with methyl bromide on nematode infestation of tubers

A field trial was conducted to investigate nematode infestation of caladium tubers produced in previously uncultivated soil that was both fumigated with methyl bromide and non-fumigated. Methyl bromide:chloropicrin (98:2) was applied to preformed 46 m long beds at 448 kg/ha and covered with Canslit brand metalized plastic mulch. Untreated beds were formed and also covered with metalized mulch. Both methyl bromide and untreated soil plots were replicated four times and arranged in a randomized complete block

design. Each bed was planted with two rows of caladium tubers in March 2008. Each 46 m bed was planted with two varieties of caladium, 'Candidum Senior' and 'Sweetheart', which were each randomly assigned to one half (23 m section) of each 46 m row. One drip irrigation line was placed in the center of each bed between rows of caladiums. Caladiums were harvested in September 2008 and evaluated for plant growth, root disease, and nematodes in soil and roots. Soil cores were taken in each plot using a 1.75-cm internal diameter soil probe. A 100-cm^3 subsample was used for nematode extraction. Twenty composited soil cores were sampled from each block for nematode analysis prior to establishment of the experiment. Nematodes were extracted from both soil and roots using the Baermann funnel technique. Plants were also evaluated for root weight, stem weight, root galling, root condition, and nematodes/g root. Root condition and root galling were assessed as previously described.

Following assessment of caladiums at the end of the season, common weeds found in both soil treatments were identified and evaluated as alternative hosts for nematode infestation of roots. Nematodes were extracted from roots using the Baermann funnel technique. Plants were also evaluated for root weight, root galling, root condition, and nematodes/g root. Root condition and root galling were assessed as previously described.

Statistical Analysis

Data were statistically analyzed according to standard procedures including SAS (SAS Institute, Cary, NC) analysis of variance (ANOVA), least significant difference (LSD), and mixed models analysis of variance using the PROC MIXED procedure in SAS for a split-plot design ($P \geq 0.05$) (Schabenberger, no date). Calculations for mean separations for split-plot designs were performed by the macro designed by Saxton (1998). Unless otherwise stated, all differences referred to in the text were significant at the 5% level of probability.

RESULTS

Greenhouse assessments of Telone and DMDS post-plant field treatments for nematode control in harvested caladium tubers

Tomato plant growth was reduced with caladium tubers treated with Paladin compared to some of the Telone treatments. Tomato plants in soil with Paladin treated tubers did not differ from the control with regard to plant growth and nematode variables measured (Table 1). However, galling was lower in Paladin treated tubers and fewer *M. arenaria* J2 were isolated from roots of the Paladin treatment when compared to the Telone 500 treatment (Table 1). All plant growth parameters measured for caladiums grown in soil previously treated with Paladin were higher than all Telone treatments, which did not differ from the control (Table 2). Caladium root condition ratings were better and galling was lower for Paladin than for the control and several Telone treatments (Table 2).

Data from the chemical treatments was sorted by the two varieties grown in the test and there were no differences in the effects of caladium cultivars 'White Delight' and 'Moonlight' with respect to tomato plant growth, disease, or nematodes isolated from tomato roots (Table 3). The effects of field treatments on nematodes in caladium tubers of the two varieties revealed that both galling and *M. arenaria* J2 isolated from roots were higher in 'White Delight' than 'Moonlight' (Table 4). There was no difference in the number of non-parasitic nematodes isolated from roots of the two

Table 1. Growth and disease of tomato indicator plants in chemical fumigant trial after eight weeks of exposure to caladium bulbs.

In-field soil treatment	Stem diameter (mm)	Root weight (g)	Shoot weight (g)	Height (cm)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Untreated	9.19 ab[z]	25.35 bc	135.82 ab	30.00 b	0.70 a	1.17 ab	3.09 b	42.71 ab
Telone EC 500 ppm	8.97 ab	29.98 ab	140.45 a	36.50 a	0.70 a	2.42 a	26.16 a	64.53 a
Telone EC 750 ppm	8.97 ab	20.50 c	115.25 ab	32.08 ab	0.66 a	1.78 ab	1.52 b	31.69 ab
Telone EC 1000 ppm	9.25 a	23.63 bc	137.54 ab	33.33 ab	0.58 a	1.69 ab	2.55 b	43.04 ab
Telone EC 1500 ppm	8.97 ab	34.58 a	146.17 a	32.17 ab	0.75 a	0.62 ab	2.45 b	16.79 b
Paladin EC 1500	8.33 b	21.98 bc	107.08 b	29.50 b	0.65 a	0.03 b	0.19 b	22.10 b
LSD (0.05)	0.86	8.38	31.4	6.19	0.56	2.22	12.06	37.58

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

Table 2. Growth, disease, and nematode isolated from roots of caladiums in chemical fumigant trial after 13 weeks in the greenhouse.

In-field soil treatment	Root weight (g)	Shoot weight (g)	Height (cm)	Tuber dry weight (g)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Untreated	53.97 b[z]	31.50 b	31.03 c	16.16 c	2.01 a	2.79 bc	4.68 a	154.34 a
Telone EC 500 ppm	80.86 b	49.06 b	38.48 bc	32.06 b	1.56 ab	5.43 a	10.24 a	58.04 bc
Telone EC 750 ppm	70.97 b	47.52 b	37.39 bc	30.94 bc	1.16 abc	1.88 bcd	10.78 a	90.66 abc
Telone EC 1000 ppm	68.73 b	47.52 b	37.55 bc	25.33 bc	1.56 ab	3.70 ab	11.35 a	69.62 abc
Telone EC 1500 ppm	77.66 b	42.36 b	39.10 b	28.80 bc	0.56 bc	0.90 cd	0.22 a	28.20 bc
Paladin EC 1500	132.18 a	84.82 a	49.06 a	61.90 a	0.28 c	0.07 d	0.19 a	13.38 c
LSD (0.05)	37.06	31.35	7.86	15.75	1.16	2.48	13.57	88.63

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

Table 3. Growth, disease, and nematodes isolated from roots of tomato indicator plants in chemical fumigant trial after eight weeks of exposure to caladium tubers.

Cultivar	Stem diameter (mm)	Root weight (g)	Shoot weight (g)	Height (cm)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Moonlight	8.91 a[z]	25.75 a	129.43 a	32.24 a	0.72 a	1.20 a	6.69 a	38.21 a
White Delight	9.32 a	25.24 a	131.32 a	32.21 a	0.52 a	1.70 a	3.19 a	33.96 a
LSD (0.05)	0.42	4.12	15.44	3.04	0.28	1.09	5.92	18.45

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

Table 4. Growth, disease and nematodes isolated from roots of caladiums in chemical fumigant trial after 13 weeks in the greenhouse.

Cultivar	Root weight (g)	Shoot weight (g)	Height (cm)	Tuber dry weight (g)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Moonlight	76.79 a[z]	47.41 a	38.84 a	32.96 a	1.19 a	1.82 b	4.09 b[1]	79.33 a
White Delight	70.46 a	47.55 a	35.15 a	21.15 b	1.38 a	4.17 a	12.61 a	81.27 a
LSD (0.05)	18.04	15.26	3.83	7.67	0.57	1.21	6.60	43.14

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P > 0.05$).

cultivars, or in most plant growth variables measured with the exception of an increase in tuber dry weight in 'Moonlight' (Table 4), which could be related to lower numbers of *M. arenaria* isolated from tubers of that cultivar. Based on personal observations, root-knot nematode infested tubers tended to be corky and less dense than healthy tubers (Robert Hartman, personal communication).

Greenhouse evaluation of susceptibility of seven selected caladium cultivars to M. arenaria

Tomato plants grown in pots with the seven different caladium cultivars all had similar root weight, root condition, galling, and nematodes isolated from roots (Table 5). Although galling levels on tomato were moderate and were similar for pots containing all caladium cultivars, the number of juveniles isolated from tomato roots was very low and also did not differ among caladium cultivars (Table 5). With regard to caladium roots, 'Pink Beauty' harbored more free-living nematodes than 'Candidum Senior'. As expected, the plant growth variables differed among the cultivars in the study (Table 6). Root condition in 'Sweetheart' was better than 'Candidum Senior' (Table 6). No galling was detected on any caladium cultivars and negligible numbers of root-knot nematode J2 were isolated from caladium roots at the end of the experiment (Table 6).

Effects of first year soil fumigation with methyl bromide on caladium growth and nematodes isolated from caladiums and weeds

Nematode populations did not differ among the blocks prior to establishment of the experiment (data not presented). Caladium growth, as reflected in fresh shoot and root weights, was greater in methyl bromide treated soil than in untreated soil (Table 7). However, root health was better in untreated soil. Galling on weeds was also lower in untreated soil compared with methyl bromide fumigated soil (Table 7). Root galling was higher in 'Sweetheart' than 'Candidum Senior' regardless of soil treatment (Table 7). In both the untreated and methyl bromide fumigated soil galling was high in only two weeds, *Aeschynomene americana* (Aeschynomene) and *Zornia* sp. Overall, galling on all other weeds was very low in the untreated soil (Table 8). The number of root-knot nematode juveniles isolated from roots was also very low in untreated soil and did not differ among the weed species (Table 8). In methyl bromide fumigated soil, *Zornia* sp. harbored higher numbers of juveniles than *Cyperus surinamensis* (Surinam sedge) and *Eragrostis ciliaris* (gophertail lovegrass) (Table 8).

DISCUSSION

Research was initiated to address the important issue of nematode management confronting caladium growers following the completion of the methyl bromide phase-out. Regardless of the effectiveness of methyl bromide in providing growers with increases in yield, crop production methods must be developed that do not rely on this fumigant. In addition, other soil fumigants such as chloropicrin, dazomet, and metam sodium/potassium are also facing new use restrictions as safety measures are increased to protect agricultural workers and the public under current fumigant re-registration requirements (U.S.E.P.A., 2010).

Although standard cultural practices for commercial caladium production currently include high application rates of fumigants, high levels of root-knot nematode infestation of tubers still occur, with reports of up to 52% of tubers from methyl bromide treated soil infested (Overman and Harbaugh, 1982; 1983). This is partic-

Table 5. Growth, disease, and nematodes isolated from tomato indicator plants after exposure to caladium tubers for eight weeks in caladium variety trial.

Cultivar	Stem diameter (mm)	Root weight (g)	Shoot weight (g)	Height (cm)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Candidum Senior	8.11 b[z]	22.99 a	82.28 c	36.95 a	0.79 a	2.32 a	0.33 a	9.16 a
White Christmas	8.94 ab	16.50 a	107.73 b	32.89 b	0.73 a	2.13 a	0.44 a	10.56 ab
John Peed	9.40 a	22.91 a	142.66 a	35.19 ab	1.02 a	2.18 a	0.11 a	10.11 ab
Pink Beauty	8.42 b	18.80 a	88.10 bc	32.31 b	1.08 a	2.67 a	0.44 a	24.50 b
Sweetheart	8.41 b	24.55 a	106.78 b	34.64 ab	1.01 a	2.86 a	0.00 a	9.95 ab
LSD (0.05)	0.89	10.43	19.89	3.57	0.54	0.83	0.55	14.60

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

Table 6. Growth, disease, and nematodes isolated from roots of caladium tubers after 13 weeks in the greenhouse.

Cultivar	Root weight (g)	Shoot weight (g)	Height (cm)	Tuber dry weight (g)	Root condition[x]	Gall rate[y]	*M. arenaria* J2/g root	Free-living No./g root
Candidum Senior	63.71 b[z]	38.14 c	28.47 b	14.90 a	1.03 a	0.01 a	0.00 a	83.60 a
White Christmas	87.18 ab	59.31 bc	39.57 a	19.12 a	0.39 ab	0.00 a	0.22 a	75.27 a
John Peed	89.59 ab	49.03 bc	39.54 a	19.16 a	0.09 ab	0.00 a	1.12 a	54.67 a
Pink Beauty	131.33 a	64.25 ab	32.48 b	21.75 a	0.86 ab	0.00 a	0.28 a	47.55 a
Sweetheart	105.61 ab	86.38 a	34.65 ab	13.15 a	0.04 b	0.00 a	0.00 a	32.80 a
LSD (0.05)	45.75	22.47	6.22	8.85	0.97	0.00	1.16	66.77

[x]Root condition is a scale of 0 to 4, 0 = 0-20% discolored, 1 = 21-40%, 2 = 41-60%, 3 = 61-80%, and 4 = 81-100%
[y]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[z]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

Table 7. The effect of soil treatment and variety on growth and disease of caladiums from Picos Farm.

Soil treatment	Shoot weight (g)	Root weight (g)	Height (cm)	Root condition[W]	*M. arenaria* No./100 cc soil	Free-living No./100 cc soil	*M. arenaria* No./g root	Free-living No./g root	Gall rate[X] caladium	Gall rate weeds
Untreated Control	20.54 b[Y]	37.49 b	14.68 a	1.07 b	4.25 a	146.47 b	19.03 a	87.59 a	1.40 a	0.63 b
Methyl Bromide	63.27 a	82.67 a	16.46 a	1.25 a	8.98 a	313.27 a	4.21 a	87.85 a	1.90 a	1.43 a
LSD (0.05)	16.92	16.89	3.86	0.17	5.61	94.50	18.47	54.54	0.71	—[Z]
Caladium variety										
Candidum Senior	41.72 a	73.99 a	16.96 a	1.20 a	7.09 a	265.07 a	14.60 a	82.32 a	1.24 b	0.76 a
Sweetheart	42.09 a	46.17 a	14.18 a	1.12 a	6.14 a	194.67 a	8.64 a	93.13 a	2.06 a	1.31 a
LSD (0.05)	16.92	16.89	3.86	0.17	5.61	94.50	18.47	54.54	0.71	—

[W]Root Condition is defined as 1 = 0-20%, 2 = 21-40%, 3 = 41-60%, 4 = 61-80%, 5 = 81-100% discolored.

[X]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).

[Y]Means with the same letter are not significantly different according to least significant difference procedures (LSD) ($P \geq 0.05$).

[Z]Means with the same letter are not significantly different according to mixed models analysis of variance using the PROC MIXED procedure in SAS for a split-plot design ($P \geq 0.05$) (Schabenberger, no date). Calculations for mean separations were performed by the macro designed by Saxton (1998).

Table 8. The effect of fumigation on weeds within each soil treatment.

	Gall rate[w]	Root condition[x]	*M. arenaria* No./g root	Free-living No./g root
Untreated Control[y]				
Aeschynomene americana	3.37 a[z]	3.24 a	2.91 a	43.19 a
Zornia sp.	4.04 a	2.00 abcd	0.00 a	40.78 ab
Oenothera laciniata (cutleaf evening primrose)	0.14 b	0.20 d	0.00 a	13.75 b
Cyperus spp. (sedge)	0.11 b	3.56 a	1.35 a	31.91 ab
Polypremum procumbens (rustweed)	0.04 b	0.52 cd	0.00 a	10.63 b
Cyperus surinamensis (Surinam sedge)	0.15 b	1.30 bc	1.66 a	35.51 ab
Eragrostis ciliaris (gophertail lovegrass)	0.01 b	2.00 b	1.31 a	17.88 ab
Methyl Bromide				
Aeschynomene americana	3.88 a	2.34 ab	0.03 ab	0.00 b
Zornia sp.	2.72 ab	0.46 de	9.37 a	203.55 a
Oenothera laciniata (cutleaf evening primrose)	0.36 cd	0.92 cde	3.06 ab	40.96 ab
Cyperus spp. (sedge)	0.20 cd	3.90 a	1.20 ab	71.23 ab
Polypremum procumbens (rustweed)	0.02 d	0.36 e	0.18 ab	0.00 b
Cyperus surinamensis (Surinam sedge)	0.04 d	1.42 bcde	0.00 b	51.79 ab
Eragrostis ciliaris (gophertail lovegrass)	0.74 cd	1.72 bcd	0.00 b	23.34 ab

[w]Gall rate index (0-10): 0 = no galling and 10 = root system completely galled (Bridge and Page, 1980).
[x]Root condition is on a scale of 0 to 4, with 0 = healthy roots and 4 = rotted roots.
[y]Data are sorted by soil treatment and caladium variety because no significant interaction occurred between these factors.
[z]Means with the same letter are not significantly different according to mixed models analysis of variance using the PROC MIXED procedure in SAS for a split-plot design ($P \geq 0.05$) (Schabenberger, no date). Calculations for mean separations were performed by the macro designed by Saxton (1998).

ularly problematic in caladiums because of the nature of the commercial product, which is the tuber harvested from field soil. In order to control any residual nematode inoculum present in seed tubers, growers routinely use a pre-plant hot water dip treatment. However, if hot water treatments are not effective in eliminating all nematode inoculum in tubers, planting infested tubers into fumigated soil can exacerbate nematode infestations in production fields (Rhoades, 1961; Brcka *et al.*, 2000; Borneman and Becker, 2007).

In the experiments presented here several aspects of production were evaluated to determine the potential for improving root-knot nematode management in fields and in harvested tubers. These included evaluation of different post plant chemical treatments, cultivar differences with respect to nematode carrying capacity of tubers, and comparison of fumigation with methyl bromide to untreated soil. Interestingly, the greenhouse assessments of Telone and Paladin (DMDS) post-plant field treatments for nematode control in harvested caladium tubers, revealed that Paladin had greater nematicidal activity than Telone. Greenhouse evaluation of susceptibility of seven selected caladium cultivars to *M. arenaria* showed that the standard hot water treatments employed by

the grower were equally effective in disinfesting all caladium varieties tested. Although tubers from the different varieties differed in general morphological characteristics, they all had similarly low numbers of root-knot nematode juveniles in tubers following the grower's standard hot water seed treatment.

To make informed decisions regarding nematode management, it is necessary to determine how soil nematodes respond to chemical applications compared to how they behave when no chemicals are applied. Methyl bromide has profound effects on soil microbiology that can be detrimental to crop production, and which may cause further reliance on chemical fumigants by destroying the natural buffering capacity of soil (Borneman and Becker, 2007). Results of the study to determine the effects of first year soil fumigation with methyl bromide on nematode infestation of tubers revealed that the effects of fumigation with methyl bromide are often contrary to expected outcomes with respect to phytoparasitic nematodes. Growers have reported the best yields of caladiums from fields during the first year of production with no fumigation following a fallow period (Robert Hartman, personal communication). Our results support these observations for first year field production in previously uncultivated soil. However, plant growth increases following methyl bromide fumigation are well documented in a variety of other crops including strawberry (Wilhelm and Paulus, 1980; Duniway, 2002) and were observed to a certain degree in our studies on caladium.

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