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Evaluating *Brassica* species as an alternative control measure for root-knot nematode (*M. incognita*) in Georgia vegetable plasticulture

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Abstract

Multiple *Brassica* species commonly grown in Georgia were evaluated as a potential alternative to methyl bromide for management of root-knot nematode in vegetables. *Brassica* species produce general biocides called glucosinolates and were grown as cover crops and incorporated as green manures prior to transplanting of vegetable crop. Nematicidal activity of the *Brassica* species was based on net changes in nematode population and root damage caused by root-knot infection and feeding. Plant growth and crop yield was also evaluated to determine the response of the subsequent vegetable crop to the incorporated *Brassica* species. Incorporation of select *Brassica* species reduced root-knot populations and root damage caused by root-knot infection comparable to non-*Brassica* species cover crops with metam sodium in most years; however, the level and consistency of the nematicidal activity varied between and within *Brassica* species. Variations in plant growth and yield were also observed among and with *Brassica* and non-*Brassica* species. Generally, increased growth and yield corresponded with cover crop treatments that had the lowest levels of root-knot nematode populations at planting of the subsequent crop. Several cover crop treatments had a negative affect on the growth and yield potential of the vegetable crops. Therefore, a producer will need to choose a *Brassica* species cover crop that can significantly reduce nematode populations without adversely affecting the growth/yield of the subsequent vegetable crop.
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1. Introduction

Vegetable producers in Georgia lost an estimated $ 44.3 million from diseases in 2004 (Langston, 2005). One of the economically important disease organisms producers are faced with on an annual basis is plant parasitic nematodes. In Georgia, many nematode species infect and cause damage to vegetables including *Meloidogyne* species, *Rotylenchulus reniformis*, *Pratylenchus thornei*, *Belonolaimus longicaudatus*, and *Paratrichodorus* species (Thies, 1996). Of the nematode species that feed on and cause damage to vegetables, *Meloidogyne* species, is considered to be the most problematic and widely distributed (Potter and Olthof, 1993).

For the last 50 years, producers have used methyl bromide, a broad-spectrum fumigant that is efficacious on fungi, nematodes, insects and weeds, and have effectively controlled nematodes in vegetable plasticulture systems. However, methyl bromide was identified as a contributor to the depletion of the stratosphere ozone layer in 1992 and was scheduled for worldwide phase out by 2005 (Noling, 2002; Schneider et al., 2003). With plasticulture vegetable production continuing to increase in both total area planted and economic value over the last decade in Georgia, producers are concerned with the potential impact the loss of methyl bromide will have on their input costs as it relates to controlling nematode pests.

The phase out of methyl bromide has spawned cooperative research efforts to identify and evaluate

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potential chemical, biological, and/or cultural alternatives that give comparable control of the many fungal, nematode, insect, and weed pests that producers are faced with on an annual basis. One potential cultural alternative to methyl bromide for management of nematode pests is the use of cover crops, particularly *Brassica* species, as green manure amendments prior to planting. Past research has demonstrated that many *Brassica* species have nematicidal activity on multiple plant parasitic nematode species including *Meloidogyne incognita*, *Meloidogyne javanica* (Johnson et al., 1992), *Heterodera schachtii* (Thierfelder and Friedt, 1995) and *Pratylenchus neglectus* (Potter et al., 1998) when used as a green manure amendment. Currently in Georgia, cover crops are mainly utilized as a control measure for erosion rather than a pest management strategy with a majority of the cover crop acres being planted to either rye (*Secale cereale* L.) or wheat (*Triticum aestivum* L.). For this type of cultural control strategy to be utilized in Georgia, producers will need to observe and understand the potential impacts both positive and negative on their cropping system beyond that of just erosion control. Unfortunately, there is little information available on the utilization of cover crops as green manure amendments for control of nematode and other pests in Georgia's vegetable production practices. The objective of this study was to evaluate the affects of select *Brassica* species as cover crops, commonly available in Georgia, as a biological control measure for *M. incognita* in vegetables. A second objective was to determine affects of the *Brassica* species as cover crops on the growth and yield of subsequent vegetable crops.

2. Materials and methods

Trials were conducted at the Blackshank Farm in 2003 and 2005 and at the Gibbs Farm, Coastal Plain Experiment Station, Tifton, GA, in 2004. The area had a history of soybeans, tobacco, and assorted vegetables. Plot areas consisted of primarily a Tifton Loamy Sand (88% sand, 8% silt, 4% clay) and is known to have reoccurring disease and nematode problems. The plot design each year was a randomized complete blocks consisting of single bed plots replicated five times. Each plot was 9.14 m long and 0.76 m wide.

2.1. Cover crop treatments

Cover crop treatments studied in this experiment in 2003 were: two cultivars of mustard greens (*Brassica juncea*), Florida Broadleaf and Curly Leaf; two turnip cultivars (*Brassica rapa*), Purple Top White Globe and White Egg; Rutabaga (*Brassica napus*), cv. American Purple Top; Kale (*Brassica oleracea*), cv. Dwarf Blue Curled Scotch; Radish (*Raphanus sativus*), cv. Scarlet Globe; spinach (*Spinacia oleracea*), cv. Bloomsdale; and wheat (*T. aestivum*), cv. Pioneer 2684, with and without a metam sodium (Vapam; Amvac Chemical Corporation, Los Angeles, CA) (468 l ha^{-1}) application prior to planting of vegetable crop.

Cover crop treatments evaluated in 2004 were: two Australian mustard cultivars (*B. juncea*), Fumus L71 and Fumus E75; two mustard cultivars from the Pacific US, (*Sinapsis alba*) Pacific Gold and (*B. juncea*) Ida Gold; Ethiopian mustard (*B. carinata*); turnip (*B. rapa*), cv. Purple Top White Globe; rutabaga (*B. napus*), cv. American Purple Top; radish (*R. sativus*), cv. White Icicle; collards (*Brassica oleracae* var. *acephala*), cv. Vates; rapeseed (*B. rapa*), cv. Dwarf Essex; and a rapeseed cv. Dwarf Essex + rye (*S. cereale*), cv. Elbon mixture. Two more treatments consisted of a rye, with and without Dazomet (Basimid G, Certis USA, Columbia, MD) application (280 kg ha^{-1}) prior to laying plastic.

Cover crop treatments evaluated in 2005 were: cabbage (*B. oleracea* var. *Capitata*), cv. Bravo and Red Dynasty; broccoli (*B. oleracea* var. *Italica*), cv. Pacman; collards (B. oleracea var. *Acephala*), cv. Top Bunch; mustard (*B. juncea*), cv. Florida Broadleaf; turnip (*Brassica campestris* var. *Rapifera*), cv. Purple Top White Globe; rapeseed (*B. rapa*), cv. Dwarf Essex; raddish (*R. Sativus*), cv. White Icicle; rutabaga (*B. napus*), cv. American Purple Top; and carrot (*Daucus carota*). The other treatments were bare fallow ground with and without a metam sodium (468 l ha^{-1}) application after laying plastic, rye, and vetch.

2.2. Research plot maintenance

Plots received 560 kg $ha^{-1}$of a 10-10-10 blend fertilizer prior to planting of cover crop treatments. Cover crops treatments were seeded on 25 February (2003), 22 October (2003), and 8 October (2004) for the 2003, 2004, and 2005 growing seasons, respectively, at an average density of 5 kg ha^{-1}. Cover crops were cut with a flail mower and incorporated with a rototiller on 11 June, 3 March and 28 February for 2003, 2004, and 2005, respectively. Prior to incorporation each year, plots were fertilized with a 5-10-15 blend at a rate 840 kg ha^{-1}. After incorporation, plots were shaped into 0.76 m beds. Beds were then covered with 1 mil black polyethylene with drip tape applied in the centre of the bed approximately 2.54 cm deep.

Vegetable crops evaluated in this study were zucchini squash (*Cucurbita pepo*) cv. Seneca, cantaloupe (*Cucumis melo*) cv. Athena, and tomato (*Lycopersicon esculentum* L.) cv. BHN 640 for the 2003, 2004, and 2005 growing seasons, respectively. Transplant seedlings were purchased from Lewis Taylor Farms in Tifton, GA. Plants were transplanted using a mechanical type transplanter, which cuts holes in the plastic just ahead of the planters in the centre of the plastic bed adjacent to the drip tape. Vegetables were transplanted on 7 July 2003 (zucchini squash), 31 March 2004 (cantaloupe), and 29 March 2005 (tomato). Plant spacing was approximately 30.5 cm for zucchini squash and tomato and 61 cm for cantaloupe. Additional fertilizer on zucchini and tomato was added in the form of liquid fertilizer (NPK 20-20-20 and 8-0-4 alternated) injected through the irrigation tubing during the growing season. For cantaloupe, urea (46-0-0) at a rate of 224 kg ha^{-1} was applied as a side-dress application 3 weeks after planting.

Zucchini squash plots were sprayed on a 4–7 day interval with Maneb (Manex; Dupont, Wilmington, DE) with Zinc (5.60 l ha^{-1}) plus Copper Hydroxide (Kocide LF; Dupont, Wilmington, DE) (4.66 l ha^{-1}) and Chlorothalonil (Bravo Weatherstik; Syngenta Crop Protection, Inc., Greensboro, NC) (2.36 l ha^{-1}) for control of foliar diseases, and Permethrin (Ambush; Syngenta Crop Protection, Inc., Greensboro, NC) (0.74 l ha^{-1}) alternating with Permethrin (Pounce 3.2; FMC Corporation, Philadelphia, PA) (0.44 l ha^{-1}), Esfinvalerate (Asana XL; Dupont, Wilmington, DE) (0.44 l ha^{-1}) and Indoxacarb (Avaunt; Dupont, Wilmington, DE) (0.22 l ha^{-1}) for insect control beginning after transplanting.

Cantaloupe plots were sprayed with Chlorothalonil (Bravo Weatherstik; Syngenta Crop Protection, Inc., Greensboro, NC) (2.36 l ha^{-1}) on 16, 28 April and 14 May, 2004, and Azoxystrobin (Quadris; Syngenta Crop Protection, Inc., Greensboro, NC) (0.82 l ha^{-1}) on 7 May, 2004 for control of foliar diseases; and Indoxacarb (Avaunt; Dupont, Wilmington, DE) (0.22 l ha^{-1}) on 16 April, 2004, Methomyl (Lannate; Dupont, Wilmington, DE) (1.75 l ha^{-1}) on 28 April and 7 May, 2004 and Esfinvalerate (Asana XL; Dupont, Wilmington, DE) (0.44 l ha^{-1}) on 14 May 2004 for insect control. Weeds were sprayed with Glyphosate (Round-Up; Monsanto, St. Louis, Missouri) (2.35 l ha^{-1}) on 22 April 2004, using a hooded sprayer between mulched beds and Sethoxydim (Poast Plus; Micro Flo Company LLC, Memphis, TN) (1.16 l ha^{-1}) on 14 May 2004.

Tomato plots were sprayed with Chlorothalonil (Bravo Weatherstik; Syngenta Crop Protection, Inc., Greensboro, NC) (2.36 l ha^{-1}) on 5, 11, and 21 April, 13, 20, and 27 May, and 17 and 24 June 2005; Azoxystrobin (Quadris; Syngenta Crop Protection, Inc., Greensboro, NC) on 21 April, 2005 (0.033 l ha^{-1}) and on 10 May, 2005 (0.74 l ha^{-1}) for foliar diseases. Esfinvalerate (Asana XL; Dupont, Wilmington, DE) (0.73 l ha^{-1}) on 11, 21 April, 2, 20 May, and 3, 24 June 2005 and Methomyl (Lannate; Dupont, Wilmington, DE) (1.16 l ha^{-1}) on 13, 27 May and 10, 17 June, 2005 were applied to all plots for insect control.

2.3. Disease collection and analysis

Stand counts and plant vigour ratings were conducted to determine potential affects of the cover crop treatments on plant health and growth. Plant vigour was rated based on a 1–10 scale, where 10 = a vigorous and healthy growing plant and 1 = a dead plant. Plots were rated for plant stand and plant vigour on 21 and 28 July, 2003 for zucchini; 28 April and 12 May, 2004 for cantaloupe; and 28 April and 18 May, 2005 for tomato.

Twelve cores of soil, 2.5-m-diam × 25-cm-deep, were collected from the centre of each plot prior to planting cover crops (24 February), at harvest of cover crops (11 June), and at planting (7 July) and harvest (25 August) in 2003; prior to planting cover crops (22 October, 2003), at harvest of cover crops (3 March), and at planting (31 March) and harvest (28 June) of cantaloupe in 2004; and planting cover crops (8 October, 2004), at harvest of cover crops (28 February), and at planting (31 March) and harvest (18 July) of tomatoes in 2005 for *M. incognita* nematode identification and quantification.

Nematodes were extracted from the samples using the semi-automatic elutriator (Byrd et al., 1976) followed by centrifugal flotation (Jenkins, 1964), and nematodes were identified and quantified with a stereoscope at 40–60 × magnification. On 24 May an early root gall evaluation was done on three plants per plot using a 0–10 scale, whereby, 0 = no galls, 1 = very few small galls, 2 = numerous small galls, 3 = numerous small galls of which some are grown together, 4 = numerous small and some big galls, 5 = 25% of roots severely galled, 6 = 50% of roots severely galled, 7 = 75% of roots severely galled, 8 = no healthy roots but plant is still green, 9 = roots rotting and plant dying, 10 = plant and roots dead. Again following final harvest on 18 July five plants per plot were evaluated for root galls using that same scale.

All tomato fruits were hand harvested from the 4.6 m centre area of each bed (15 plants per plot). Each harvest was separated into marketable and cull fruits, counted and weighed. Harvest dates were 4, 7, 13 and 18 August 2003 for zucchini; 14, 22, and 28 June 2004 for cantaloupe; and 16 and 27 June, and 5 July, 2005 for tomato. Treatment comparisons for soil nematode population densities were analysed based on their net change from one sampling date to the next sampling date. Evaluation of the net changes in populations allowed for standardization of the results due to variations in natural population levels between and among treatments. Data were analysed by ANOVA and mean comparison by Fisher LSD test ($P = 0.05$) using SAS statistical software (SAS Institute, Inc., Cary, NC).

3. Results

3.1. *Brassica* trial (2003)

Plant vigour ranged from 6.1 to 9.4 and 5.4 to 9.5 for 21 and 28 July evaluations, respectively. Plant vigour was significantly greater in the wheat cover crop treatment with metam sodium compared to the mustard "Fl Broadleaf", turnip "PTWG" and "White Egg", and kale "DBCS" cover crop treatments for both evaluations (Table 1). Plants grown in plots with spinach "Bloomsdale", mustard "Curly Leaf", radish "Scarlet Globe", and rutabaga "AMPT" cover crop treatments showed a numeric increase in plant vigour compared to other *Brassica* species (Table 1). There were no differences observed in plant stand counts among the cover crop treatments (data not shown).

Initial results from the nematode sampling and analysis showed a large variation in populations among the treatments, which was not a direct affect of the cover crops. Therefore, to evaluate the potential affects of the cover crops the nematode populations were analysed based on their net change from 25 February to 11 June, 11 June to 7 July, and 7 July to 18 August for each treatment.

The net change in populations at planting of the cover crops to harvest of the cover crops indicated that all cover crop treatments increased populations during their establishment and harvest (Table 2). The two mustard, turnip "White Egg", and wheat with and without metam sodium cover crop treatments had the smallest increase in populations with the radish cover crop treatment having the greatest net increase in population densities (Table 2). The net impact of the cover crop on populations shifted from positive to negative between cover crop harvest and planting of zucchini. The results of this evaluations indicated that the radish significantly reduced the nematode populations from cover crop harvest to at planting of zucchini compared to a majority of the other cover crop treatments with mustard "FL Broadleaf", kale, wheat with and without metam sodium having the lowest negative effect on nematode populations (Table 2). Unfortunately, radish even with the large reduction in nematode populations after harvest and incorporation had the highest level of nematode populations compared to the other cover crop treatments. The net change in populations between the last two sampling dates (zucchini planting and zucchini harvest) showed dramatic increases in populations in all treatments except for the mustard "FL Broadleaf" and the wheat with metam sodium cover crop treatments which were significantly lower compared to most of the evaluated cover crop treatments (Table 2).

Root gall ratings (0–10 scale) were also conducted on 1 and 25 August to further examine the affects of the cover crop treatments on root-knot infection and damage on zucchini. Root gall ratings ranged from 0.4 to 7.9 and 2.1 to 9.3 for 1 and 25 August, respectively (Fig. 1). Root galling was significant lower in the wheat with metam sodium and radish cover crops compared to kale, spinach,

Table 1
Evaluation of select *Brassica* and non-*Brassica* species cover crop affects on total number and weight of marketable fruits of zucchini squash in 2003

Cover crop treatments	Plant vigour[a] (0–10 scale)		Total number of fruit per plot	Total weight of fruit per plot (kg)
	21 July	28 July	Marketable	Marketable
Mustard "FL Broadleaf"	7.0bc[b]	6.9cde[b]	18bc[b]	23.3ab[b]
Mustard "Curly leaf"	8.7ab	8.7abc	22abc	27.9ab
Turnip "PTWG"	6.2c	5.4e	16c	16.7b
Turnip "White Egg"	7.0bc	7.4bcd	24abc	26.0ab
Radish "Scarlet Globe"	8.1ab	8.9abc	31a	34.3a
Rutabaga "AMPT"	8.1ab	8.4abc	29a	31.0a
Kale "DBCS"	6.1c	6.0de	15c	15.2b
Spinach "Bloomsdale"	8.5ab	9.2ab	33a	35.7a
Wheat "Pioneer 2684"	8.2ab	9.0ab	27abc	31.4a
Wheat and metam sodium	9.4a	9.5a	31a	32.8a

[a]Plant vigour was rated based on a 1–10 scale, where 10 = a vigourous and healthy growing plant and 1 = a dead plant.
[b]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

Table 2
Evaluation of nematicidal activity of select *Brassica* and non-*Brassica* species cover crops on *Meloidogyne incognita* populations[a] on Zucchini Squash in 2003

Cover crop treatments	Pre-plant cover crop (25 Feb)	Harvest cover crop (11 June)	Net change[b] (HCC–PPCC)	At plant zucchini (7 July)	Net change[b] (PZ–HCC)	Harvest zucchini (18 Aug)	Net change[b] (HZ–PZ)
Mustard "FL Broadleaf"	34	56	22b[c]	116	70ab[c]	313	197c[c]
Mustard "Curly leaf"	130	168	38ab	128	−65ab	1248	1120bc
Turnip "PTWG"	152	374	222ab	178	−283bc	2525	2348ab
Turnip "White Egg"	172	250	78ab	106	−144ab	1774	1668abc
Radish "Scarlet Globe"	176	668	492a	303	−530c	1853	1550abc
Rutabaga "AMPT"	110	324	214ab	478	154a	2782	2304ab
Kale "DBCS"	90	392	302ab	374	−18ab	3494	3120a
Spinach "Bloomsdale"	76	410	334ab	190	−220ab	1986	1796abc
Wheat "Pioneer 2684"	58	172	114ab	150	−50ab	1410	1260bc
Wheat + metam sodium	76	122	46ab	200	78ab	298	98c

[a]*M. incognita* populations based on number juveniles extracted from 150 cm^3 soil.
[b]Net change represents the change in *M. incognita* populations (juveniles per 150 cm^3 soil) from pre-plant cover crop on 25 February to cover crop harvest on 11 June, harvest cover crop on 11 June to zucchini planting on 7 July, and Zucchini planting on 7 July to zucchini harvest on 18 August, 2003.
[c]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

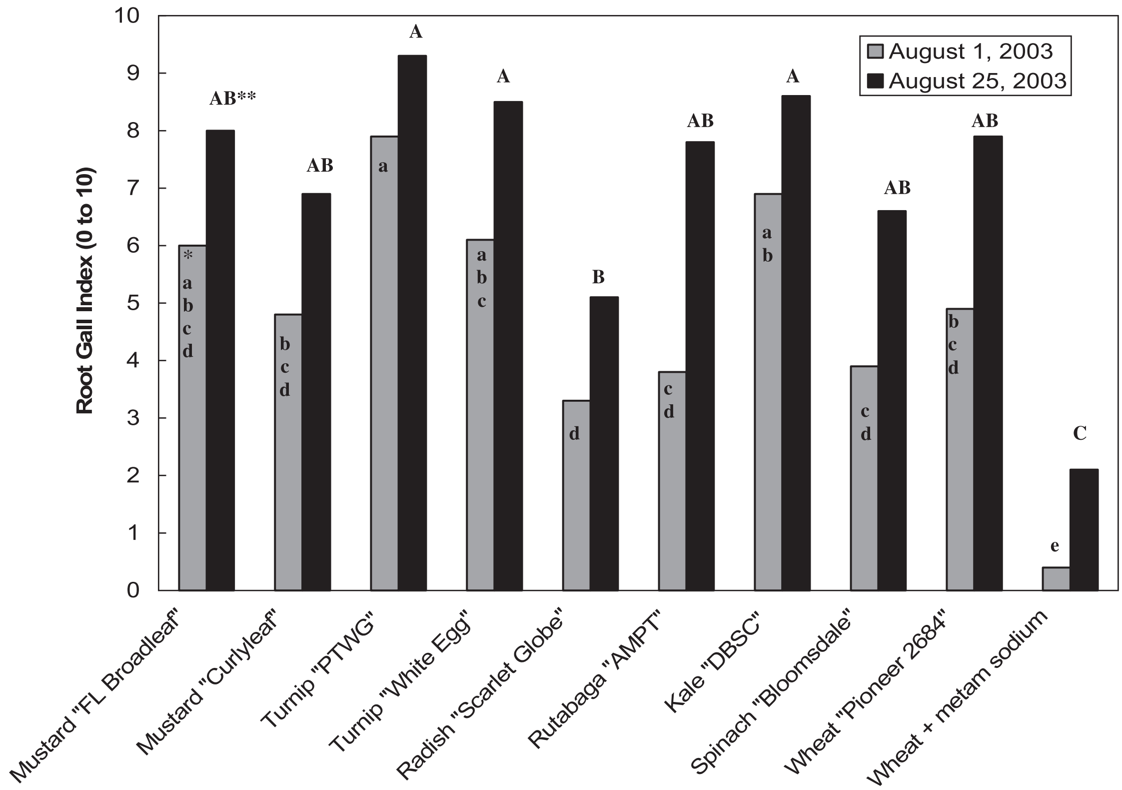

Fig. 1. Effects of *Brassica* and non-*Brassica* species cover crops on root damage caused by *M. incognita* on Zucchini in 2003. Root Gall evaluations were based on a 0–10 scale, whereby, 0 = no galls, 1 = very few small galls, 2 = numerous small galls, 3 = numerous small galls of which some are grown together, 4 = numerous small and some big galls, 5 = 25% of roots severely galled, 6 = 50% of roots severely galled, 7 = 75% of roots severely galled, 8 = no healthy roots but plant is still green, 9 = roots rotting and plant dying, 10 = plant and roots dead. Root gall evaluations were conducted on three plants on 1 August and five plants on 25 August. *Means followed by same capital letters are not statistically different ($P<0.05$) among cover crop treatments according to Fishers LSD for August 1, 2003. **Means followed by same capital letters are not statistically different ($P<0.05$) among cover crop treatments according to Fishers LSD for 25 August 2003.

and the two turnip cover crops with the wheat cover crop with metam sodium having the lowest overall root damage at both evaluation dates (Fig. 1).

Zucchini was harvested on 4, 7, 13, and 18 August in which the total number of marketable fruit and total weight were evaluated. For all sampling dates mustard "FL Broadleaf", turnip "PTWG", and kale cover crop treatments had the lowest number of total marketable fruit and the turnip "PTWG", and kale cover crop treatments had the lowest total weight compared to the other cover crop treatments (Table 1). Radish, rutabaga, spinach, and the two wheat cover crop treatments had a significantly higher number and weight of total fruit compared to the turnip "PTWG" and kale cover crop treatments (Table 1).

3.2. *Brassica trial (2004)*

Early observations (28 April) of plant vigour showed a reduction in plant vigour in the rye cover crop with Dazomet compared to all cover crop treatments except for rye, mustard "Fumas E75" and mustard "Ida Gold" (Table 3). Plant vigour ratings on 12 May showed no significant differences among the treatments. Numerically, the most vigorously growing plants were observed in the plots where turnip, rutabaga, and radish were previously planted and incorporated (Table 3). There were no differences observed in plant stand counts among the cover crop treatments (data not shown).

Like with the evaluations of nematode population in 2003, the initial results from the nematode sampling and analysis showed variation in populations among the treatments, which may not have been a direct affect of the cover crops. Therefore, to evaluate the potential affects of the cover crops nematodes were analysed based on their net change from 3 October (cover crop planting) to 3 March (cover crop harvest), 3 March to 31 March (cantaloupe planting), and 31 March to 28 June (cantaloupe harvest) for each treatment.

The evaluations of nematode populations at cover crop planting and harvest suggested that some of the cover crops had benefited nematode reproduction. This was evident in the analysis of the net change between the planting and harvest of the cover crops where rape and rye, radish, and rye cover crops significantly reduced nematode populations compared to mustard "Pacific Gold" and turnip which increased nematode populations (Table 4). The evaluation of the net change in nematode populations between cover crop harvest and planting of cantaloupe showed that incorporation of a majority of the cover crop treatments reduced nematode populations (Table 4). The greatest net reduction in nematode populations were noted in the mustard cover crops "Fumus E75", "Pacific Gold", and "Ida Gold" and the turnip cover crop treatments along with the rye cover crop treatment with Dazomet (Table 4). These results were similar to the previous year where the above-mentioned *Brassica* treatments, even after a large reduction in nematode populations were observed, remained higher than the rye cover crop treatment with Dazomet at planting of the vegetable crop.

The examination of the change in nematode populations between planting and harvest of cantaloupe indicated an overall net increase in population in all cover crop treatments. The largest net increase in populations by harvest of the cantaloupe was observed in the turnip cover crop which was significantly higher than the mustard "Fumus E75", mustard "Ethiopian", rape, and rye with Dazomet cover crop treatments (Table 4). Root damage evaluations associated with nematode infection and feeding showed little differences among the cover crop treatments on 20 May or 28 June. Root gall ratings ranged from 5.5 to 7.9 and 9.4 to 10 for 20 May or 28 June, respectively. On 20 May, there was a small, however significant, reduction in root galling in the rape cover crop compared to mustard "Ida Gold" cover crop (Fig. 2).

Cantaloupe yield results were similar among the treatments. The analysis of the total number of marketable fruit

Table 3
Evaluation of select *Brassica* and non-*Brassica* species cover crop affects on total number and weight of marketable fruits of cantaloupe in 2004

Cover crop treatments	Plant vigour[a] (0–10 scale)		Total number of fruit per plot	Total weight of fruit per plot (Kg)
	28 April	12 May	Marketable	Marketable
Mustard "Fumus L71"	8.6abc[b]	8.8a[b]	21bcd[b]	122ab[b]
Mustard "Fumus E75"	7.5abcd	8.3a	25abc	148ab
Mustard "Pacific Gold"	8.3abc	8.5a	16d	82b
Mustard "Ida Gold"	7.9abcd	8.0a	20bcd	112ab
Mustard "Ethiopian"	8.2abc	8.3a	22bcd	124ab
Turnip "PTWG"	9.2a	9.2a	25abc	141ab
Rape "Dewarf Essex"	8.3abc	8.7a	22bcd	126ab
Rape + Rye	8.6abc	8.8a	21bcd	125ab
Rutabaga "AMPT"	9.1ab	9.1a	18cd	97b
Radish "White Icicle"	8.7abc	9.3a	22bcd	187a
Collards "Vates"	8.3abc	8.6a	24bcd	133ab
Rye "Elbon"	7.5cd	8.0a	26ab	148ab
Rye + Dazomet	6.8d	8.4a	31a	182a

[a]Plant vigour was rated based on a 1–10 scale, where 10 = a vigorous and healthy growing plant and 1 = a dead plant.
[b]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

Table 4
Evaluation of nematicidal activity of select *Brassica* and non-*Brassica* species cover crops on *Meloidogyne incognita* populations[a] on cantaloupe in 2004

Cover crop treatments	Pre-plant over crop (22 Oct. 2003)	Harvest cover crop (3 March)	Net change[b] (HCC–PPCC)	At plant antaloupe (31 March)	Net change[b] (PC–HCC)	Harvest antaloupe (28 June)	Net change[b] (HC–PC)
Mustard "Fumus L71"	120	58	−62abc[c]	136	78ab[c]	1534	1398ab[c]
Mustard "Fumus E75"	356	394	38abc	74	−320d	1672	1598b
Mustard "Pacific Gold"	132	422	290a	56	−366d	1330	1274ab
Mustard "Ida Gold"	262	434	172ab	120	−314cd	1916	1796ab
Mustard "Ethiopian"	307	394	87ab	106	−288bcd	660	554b
Turnip "PTWG"	122	408	286a	68	−340d	2716	2648a
Rape "Dewarf Essex"	222	242	20abc	80	−162abcd	678	598b
Rape and Rye	236	84	−152bc	218	134a	2024	1806ab
Rutabaga "AMPT"	118	238	120ab	106	−132abcd	1542	1436ab
Radish "White Icicle"	350	80	−270bc	132	52abc	1596	1464ab
Collards "Vates"	222	176	−46abc	94	−82abcd	844	750ab
Rye "Elbon"	322	174	−148bc	30	−144abcd	1162	1132ab
Rye and Dazomet	320	276	−44abc	10	−266bcd	534	524b

[a]*M. incognita* populations based on number juveniles extracted from 150 cm^3 soil.
[b]Net change represents the change in *M. incognita* populations (juveniles per 150 cm^3 soil) from pre-plant cover crop on 22 October, 2003 to cover crop harvest on 3 March, harvest cover crop on 3 March to cantaloupe planting on 31 March, and cantaloupe planting on 31 March to cantaloupe harvest on 28 June, 2004.
[c]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

showed the mustard "Fumus E75", turnip and rye with Dazomet had a significant higher number of marketable fruit compared to the mustard "Pacific Gold" and rutabaga cover crop treatments (Table 3). The total weight of marketable fruit ranged from 82 to 187 kg with radish and rye with Dazomet having a significant higher total fruit weight than the rutabaga and mustard "Pacific Gold" cover crops (Table 3).

3.3. *Brassica* trial (2005)

Plant vigour rating conducted on 28 April showed little differences among the treatments in their affects on plant growth. Plant vigour rating ranged from 5.8 to 9.2. The plant growth rate in the bare fallow cover crop with metam sodium applied was significantly higher than a majority of the other cover crops on 28 April with the rate of plant growth among cover crop treatments becoming more similar to the bare fallow cover crop with metam sodium by 18 May (Table 5). Plant vigour ratings on 18 May indicated that the plant vigour was significantly lower in the Mustard, Rape, Rutabaga, and the bare fallow cover crop treatments compared to the bare fallow cover crop treatment with metam sodium (Table 5). There were little differences observed in plant stand counts among the cover crop treatments on 28 April or 18 May. There was a slight advantage in plant stands in the broccoli and carrot cover crop treatments compared to cabbage "Bravo" (Table 5).

The trial area in 2005 was found to have low to undetectable populations of root-knot nematode. Populations were not detected in any cover crop treatment until tomato planting in which only one cover crop treatment, cabbage "Red Dynasty", had a measurable numbers of juveniles detected (Table 6). However, by the end of the season root-knot nematodes were detected in all of the cover crop treatments except cabbage "Bravo", broccoli, collards, and rape cover crop treatments (Table 6). In all treatments with nematodes present at the end of the season, the cabbage "Red Dynasty" cover crop was the only treatment to have a decrease in populations (Table 6). Like with root-knot populations, root gall damage was not detected in the early season evaluations. The harvest evaluation of root galling showed a dramatic increase in damage in several treatments with the root gall ratings ranging from 0.4 to 4.4. The highest level of damage was noted in two cabbage, turnip, and vetch cover crop treatments (Fig. 3).

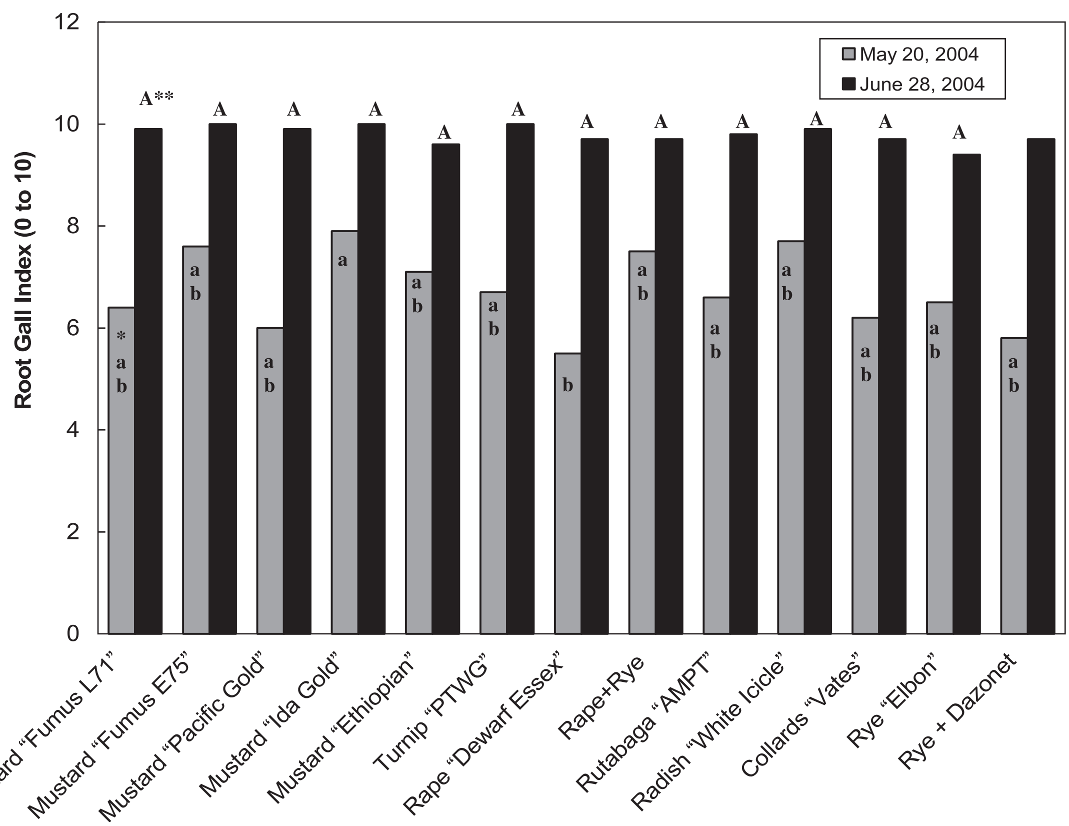

Fig. 2. Effects of *Brassica* and non-*Brassica* species cover crops on root damage caused by *M. incognita* on cantaloupe in 2004. Root Gall evaluations were based on a 0–10 scale, whereby, 0 = no galls, 1 = very few small galls, 2 = numerous small galls, 3 = numerous small galls of which some are grown together, 4 = numerous small and some big galls, 5 = 25% of roots severely galled, 6 = 50% of roots severely galled, 7 = 75% of roots severely galled, 8 = no healthy roots but plant is still green, 9 = roots rotting and plant dying, 10 = plant and roots dead. Root gall evaluations were conducted on three plants on 20 May and five plants on 28 June. *Means followed by same capital letters are not statistically different ($P < 0.05$) among cover crop treatments according to Fishers LSD for 20 May 2004. **Means followed by same capital letters are not statistically different ($P < 0.05$) among cover crop treatments according to Fishers LSD for 28 June 2004.

Table 5
Evaluation of select *Brassica* and non-*Brassica* speciescover crop affects on plant growth and yield of tomato in 2005

Cover crop treatments	Plant stand[a] counts	Plant vigour[b] (0–10)		Total number of fruit per plot	Total weight of fruit per plot (kg)
	18 May	28 April	18 May	Marketable	Marketable
Cabbage "Bravo"	10.4b[c]	7.2bc[c]	8.4abc[c]	259bc[c]	108.5abc[c]
Cabbage "Red Dynasty"	11.0ab	6.6bc	7.9abc	350abc	153.6a
Broccoli "Pacman"	11.2a	6.2bc	8.0abc	230c	96.8bc
Collards "Top Bunch"	10.8ab	7.2bc	8.6abc	267bc	108.9abc
Mustard "Florida Broadleaf"	11.0ab	6.5bc	7.6c	401a	132.4abc
Turnip "PTWG"	11.0ab	6.9bc	8.4abc	378ab	142.4ab
Rape "Dwarf Essex"	11.0ab	6.5bc	7.4c	362ab	147.3a
Radish "White Icicle"	10.8ab	7.1bc	8.5abc	298abc	117.2abc
Rutabaga "AMPT"	11.0ab	5.8c	7.7bc	292abc	117.6abc
Carrot	11.2a	7.8ab	9.2ab	329abc	132.1abc
Rye "Elbon"	10.8ab	7.3bc	8.1abc	378ab	148.9a
Vetch "Harry Vetch"	11.0ab	7.3bc	8.6abc	353ab	127.5abc
Bare Fallow	11.0ab	6.8bc	7.8bc	299abc	91.6c
Bare Fallow and metam sodium	10.8ab	9.2a	9.4a	295abc	117.1abc

[a]Plant stand counts represents the total number of live plants in the entire plot for each treatment.
[b]Plant vigour was rated based on a 1–10 scale, where 10 = a vigorous and healthy growing plant and 1 = a dead plant.
[c]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

Table 6
Evaluation of nematicidal activity of select *Brassica* and non-*Brassica* species cover crops on *Meloidogyne incognita* populations[a] on tomato in 2005

Cover crop treatments	At plant tomato (31 March)	Harvest tomato (18 July)	Net change[b] (HC–PC)
Cabbage "Bravo"	0	0	0ab[c]
Cabbage "Red Dynasty"	120	60	−60b
Broccoli "Pacman"	0	0	0ab
Collards "Top Bunch"	0	0	0ab
Mustard "Florida Broadleaf"	0	20	20ab
Turnip "PTWG"	0	120	120a
Rape "Dwarf Essex"	0	0	0ab
Radish "White Icicle"	0	20	20ab
Rutabaga "AMPT"	0	20	20ab
Carrot	0	20	20ab
Rye "Elbon"	0	20	20ab
Vetch "Harry Vetch"	0	120	120
Bare Fallow	0	20	20
Bare Fallow and metam sodium	0	60	60

[a]*M. incognita* populations based on number juveniles extracted from 150 cm^3 soil.
[b]Net change represents the change in *M. incognita* populations (juveniles per 150 cm^3 soil) from tomato planting on 31 March to tomato harvest on 18 July, 2004.
[c]Means in same columns followed by the same letter are not different ($P<0.05$) according to Fishers LSD.

Tomato yields in total number of fruit were similar among most of the cover crop treatments except for the cabbage "Bravo", broccoli, and collards cover crop treatments which were significantly lower than the mustard cover crop treatment (Table 5). Yield (total weights) affects were also similar among cover crop treatments. Cabbage "Red Dynasty", rape, and rye cover crop treatments were found to have the highest total fruit weight of all the cover crop treatments and were found to be significantly higher than the broccoli and bare fallow cover crop treatments (Table 5).

4. Discussion

Results from these studies showed that *Brassica* species when incorporated as green manures do have a moderate level of nematicidal activity. However, the level of nematode control from *Brassicas* was found to be inconsistent between and within *Brassica* species (Morra and Kirkegaard, 2002; Zasada et al., 2003; Hartz et al., 2005). Based on the evaluations in *M. incognita* populations from planting to harvest of the cover crops, *M. incognita* was capable of reproducing on a majority of the *Brassica* species during their growing period which could explain some of the variation observed in the population densities among the treatments.

The largest net reductions in nematode populations were noted between incorporation of the *Brassica* species and the vegetable crop planting in most years. The large net reduction in nematode populations after incorporations does support previous research that *Brassica* soil amendments do have potential as a biological control measure for *M. incognita* compared to the commercial standard (Potter et al., 1998; Lazzeri et al., 2004; Zasada and Ferris, 2004). Unfortunately, one of the major obstacles observed in this study was the increase in nematode populations prior to harvest and incorporation in several of *Brassica* cover crop treatments. This increase in population densities in several of the treatments, even after large reductions after incorporation, translated into higher populations at planting of the vegetable crops. In most cases, the treatments

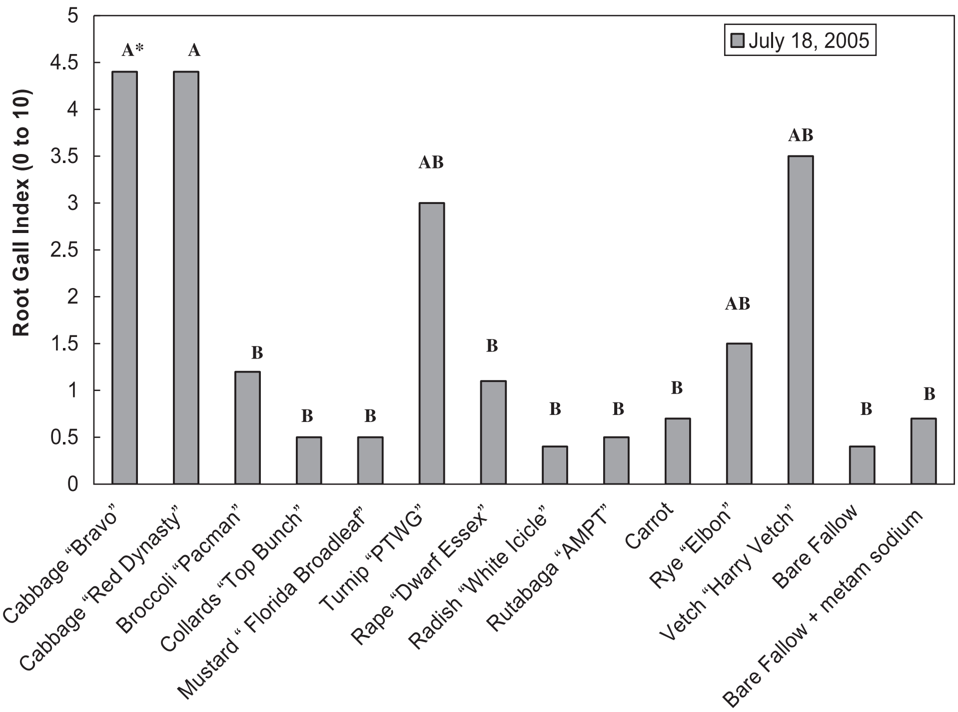

Fig. 3. Effects of *Brassica* and non-*Brassica* species cover crops on root damage caused by *M. incognita* on tomato in 2005. Root Gall evaluations were based on a 0–10 scale, whereby, 0 = no galls, 1 = very few small galls, 2 = numerous small galls, 3 = numerous small galls of which some are grown together, 4 = numerous small and some big galls, 5 = 25% of roots severely galled, 6 = 50% of roots severely galled, 7 = 75% of roots severely galled, 8 = no healthy roots but plant is still green, 9 = roots rotting and plant dying, 10 = plant and roots dead. Root gall evaluations were conducted on five plants on 18 July. *Columns means followed by same capital letters are not statistically different ($P<0.05$) among cover crop treatments according to Fishers LSD.

with higher population densities at planting of the vegetable crop resulted in lower growth and yield. Overall, radish, turnip, some mustard varieties, and the non-*Brassica* species cover crops with a nematicide had the highest level of nematode control in the early part of the vegetable growing season each year with the non-*Brassica* species treatment plus a nematicide have the best suppression of the nematode population densities through each season.

Root galling ratings were also conducted to evaluate the potential suppression of damage resulting from nematode infection and feeding in the vegetable root system of the select cover crop treatments. Results of the root gall ratings indicated that the highest level of variations in damage suppression within and among *Brassica* species was noted in the mid-season gall ratings with damage becoming more similar across treatments by harvest each year. Although there was damage suppression in most of the cover crop treatments evaluated, the highest level of nematode damage suppression was observed in the cover crop treatment with metam sodium. Again, this may be the result of the increased populations in many of the *Brassica* species cover crops prior to incorporation compared to the non-*Brassica* species with the nematicide. Along with the variations in the mid season gall ratings among the cover crops, nematode damage also seemed to vary among the vegetable crops potentially indicating differing levels of susceptibility to *M. incognita* infection and feeding.

The affects of the *Brassica* species amendments were also noted in crop growth and yield each year. Radish, rutabaga, spinach, some mustard varieties, and cover crops with metam sodium had the highest rate of growth compared to the other cover crops. The increased rate of growth also translated into improved yields in total marketable fruit and total marketable fruit weight for the above mention cover crop treatments. Based on the results of this study, there was no correlation between net change in nematode population densities (between cover crop harvest and incorporation and planting of the vegetable crop) and increased yields. In most situations, increased yields were observed in treatments with low population densities at planting and/or in treatments that appeared to have beneficial affects on the vegetable crop other than nematode control, perhaps an increase in available nutrients from the cover crops.

In conclusion, this study allowed for a broad examination of the potential affects of many *Brassica* and non-*Brassica* species cover crops commonly grown in Georgia on *M. incognita* and on several subsequent vegetable crops. The results of this trial, although variable, did show some promise of *Brassica* species as a biological control option in vegetable production in Georgia. Therefore, as previously stated by Kirkegaard and others, to achieve the maximum benefit from utilizing *Brassica* species as a green manure for control of soilborne pathogens a producer will need to choose a *Brassica* species with a high potential of glucosinolate production and also one that produces large quantities of biomass in the select geographic location or environment (Kirkegaard and Sarwar, 1998; Morra and Kirkegaard, 2002; Zasada et al., 2003). Along with determining the suitable *Brassica* species cover crop based on its biofumigation characteristics and adaptation in a select area, important care needs to be taken in determining the overall affects of the cover crop on the various vegetable crops grown in Georgia. This is important based on the growth and yield responses noted from the differing vegetable crops to the incorporated cover crops and *M. incognita* infection and feeding.

Further research is needed to determine which *Brassica* species are more effective in Georgia's environment as a biological control option and determine the level of susceptibility of the various *Brassica* species to *M. incognita*. There is also a need for more studies to examine the effects of seeding rates, timing of incorporation, and types of incorporation on the nematicidal activity of select *Brassica* species. Furthermore, there is a need to evaluate the level of control for nematodes achieved with the incorporation of select *Brassica* amendments in combinations with varying rates of commercially available nematicides to determine if reductions in these pesticides can be accomplished in this type of management system.

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