Integrated control of the nematode *Meloidogyne incognita* infecting eggplant and effects on associated weeds and crop yield: a field study

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Abstract: Integrated regimes were conducted during the season 2015-2016 at kafre Hakim village Giza Governorate. The aim was to evaluate the protective efficiency of combinations of different environment- friendly compounds; indole acetic acid (IAA), Furfural, urea as well as the herbicide pendimethalin to control root knot nematode. Meloidogyne incognita infecting eggplant and associated annual broad leaf and annual grasses weeds, and their effects on crop production. Data revealed that all the tested treatments resulted in variable significant decrease in root knot nematode reproductive parameters, associated weeds and improvement in eggplant production. The tested parameters were; initial and final populations, number of galls, number of egg masses, fresh and dry weight of weeds after 120 days from planting and yield of eggplant. The authors recommend the use of the organic fertilizer urea for controlling the nematode M. incognita infecting eggplant and increase the crop yield. However, application of integrated protocols including, urea, IAA combined with the herbicide pendimethalin deserves consideration in the future tactics to maximize the efficiency of nematode control, associated weeds infestation and promoting the yield. Detailed data are presented in the text.

Keywords: rRoot–knot nematode, *Meloidogyne incognita*, eggplant, IAA, organic fertilizer, furfural, pendimethalin control

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1 Introduction

Eggplant (*Solanummelongena* L.) is a widely adaptive and highly productive crop of tropical and subtropical rejoins. It is one of the most popular solanaceous plants produced in Egypt for local consumption, medicinal properties and exportation. It's flesh contains carbohydrate, protein, minerals and vitamins (Shukla and Naik, 1993). Vegetables in general are known to be susceptible to nematode infection and in Egypt eggplant is known to be extremely susceptible to nematode infection (Abd- elgawad, 2014).

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Eggplants suffer also from weeds which are considered a major problem, through its competition with the plants for light, carbon dioxide, moisture and soil nutritive (Zoran, 2004). The use of chemical nematicides and/ or herbicides is one of the primary means of plant protection. However, their potential negative impact on the environment and human health hasled to restricted use of most of them. Therefore, research efforts have been continued to develop an alternative environment friendly management tactics for plant parasitic nematodes and weeds control (Nolling and Barker, 1994; Subhra and Dipack, 2015).

Protection of plants against nematodes could be feasible by manipulation of the internal environment of the plants by changing the non toxic chemicals to toxic metabolites making the plant unfavorable host. Plant

growth hormones increase the endogenous auxins and alter plant metabolism (Sirear and Kundu, 1960, Nelmes, 1971) and influence the nematode- plant relationships. Indole-3-acetic acid (IAA) is the most common naturally occurring plant hormone of the auxin class and it has been a subject of extensive studies by plant physiologists (Simon and Patrasek, 2011), as well as nematologists (Abdel-Momen etal,2005; Templeman and Marmoy, 2008).

Pendimethalin is an herbicide of the dinitroalanine class. It has been used as pre- emergence and post emergence application to control annual grass and certain broad leaf weeds. It inhibits cell division and cell elongation of root and shoots growth. Pendimethalin is an efficient herbicide regarding to cost environmental impact and weed control efficacy (Gehring et al., 2009).

An alternative to application of chemical nematicides is the use of naturally occurring compounds such as furfural which provides protection against broad spectrum of disease- causing pathogenic microorganisms (Rodriguez-Kabana, 2005, El-Mougy et al., 2012). Furfural is a natural bactericide, herbicide, fungicide, insecticide, and nematicide. The efficacy of furfural as a nematicide has been recorded (Rodriguez-Kabana et al., 1993; Mohamed, 2005; Burelle, 2007) Furfural has been investigated for the control of nematodes in turf, peanut, and fruits (Anonymous, 2006). Due to its low toxicity, application can be made post planting as well as pre-planting of the crops. This property allows for in-season application to provide long nematode control.

The role of urea in controlling nematodes and improving the plant growth was reported by many investigators (Ismail, et al., 2012, Osman, et al., 2014, Abddel- Kader et al., 2015).

The use of organic fertilizers such as urea combined with other bioactive compounds has become one of significant research areas in integrated control of nematodes (Osman et al., 2014).

The objective of this study was to evaluate the efficacy of environment- friendly compounds; Indole-3 acetic –acid (IAA), furfural, urea as well as the herbicide pendimethalin, single or combined treatments to control root knot nematode Meloidogyne incognita infecting eggplant cv. Baladi and associated weeds and their effects on crop production under field conditions.

2 Materials and methods

A field experiment was conducted during one season 2015-2016 to study the effects of application of IAA as plant growth regulator, furfural as natural nematicide, urea as an organic fertilizer and pendimethalin as herbicide for controlling *Meloidogyne incognita* infecting eggplant cv Baladi at Kfre hakim district, Giza Governorate Egypt. The experimental field was divided into plots each containing rows of (10 m×50 cm Length× Width), and the distance between each plant was 50 cm. The experiment was set up in completely randomized block design. Twelve treatments with 100 replicates (plant) for each one. The proposed treatments and methods of application are presented in Table 1.

Table 1 Treatments and methods of application.

Group	Dose and time of application
1. Control	Untreated plants
2. Pendimethalin (PMT)	1.7 L/ feddan added pre-emergence of the eggplant seedlings as soil drench.
3. Furfural(FUR)	7 mL /L three days before planting as soil drench.
4. urea	120-150 nitrogen unit/feddan at planting.
5. Indole acetic acid (IAA)	50 ppm as spray six weeks from planting.
6. PMT + FUR	PMT (1.7 L/feddan) + FUR (7mL/L)
7. PMT + Urea	PMT (1.7 L/feddan) + Urea 120-150 nitrogen unit/feddan.
8. PMT + IAA.	PMT (1.7 L/feddan) + IAA (50 ppm).
9. IAA + FUR	IAA (50 ppm) + FURl (7 mL/L). IAA (50 ppm).
10. IAA + Urea.	IAA (50ppm) + Urea 120-150 nitrogen unit/feddan.
11. PMT + FUR + Urea	PMT (1.7 L/ feddan) + FUR (7ml / L) + Urea 120-150 nitrogen unit/feddan.
12. PMT + IAA+Urea	PMT (1.7 L/ feddan) +IAA (50ppm) + Urea 120-150 nitrogen unit/feddan.

Initial population densities of *M.incognita* were determined prior to planting time from 250g subsamples of well mixed soil from each row according to Barker, 1985. After four months eggplants were harvested for yield estimation. Final nematode populations were extracted as previously (Barker, 1985). The final nematode population densities of *M.incognita* juveniles in soil were determined and expressed as number/250 g soil. Data was subjected to analysis of variance and means were compared according to Duncan, 1951. Percentage nematode reduction in soil was determined according to Henderson and Tilton formula (Puntener, 1981) as follows:

$$\text{Nematode reduction (\%)} = [1-(\text{PTA}/\text{PTB}\times\text{PCB}/\text{PCA})]\times 100$$

where, PTA= Population in the treated plot after application; PTB= Population in the treated plot before application; PCB= Population in the check plot before application; PCA= Population in the check plot after application.

Data recorded for weeds associated with eggplants:

After 60 days from planting samples of weeds were hand pulled from the middle ridge of each plot and classified into two groups as follow:

1) Annual broadleaf weeds: Amaranthuspariculatus Lois, Potulacaoleracea L., Urticaurens L., Medicagohispida L., Amiranthusviridis L.

2) Annual grasses weeds: Echinochloacolonum L., Cyperusrotundus L.,Phalaris minor, Retz.,Setariaglauca L.

Fresh and dry weights of each group as well as total weeds weights were estimated at harvest time 120 days from planting.

Data was statistically analyzed according to Snedecor and Cochran (1967) using LSD at 5% level of significance.

3 Results and discussion

A field experiment was set up to evaluate the efficacy of applying furfural, pendimethalin, urea and IAA alone or in combined applications for controlling M. incognita infecting eggplant, associated weeds and their effects on crop production.

3.1 Effects on nematode population

Data presented in Table 2 revealed that all the tested treatments resulted in variable significant decrease in root- knot nematode M. incognita in soil compared to control untreated. Moreover, the yield of the crop was significantly improved in all the treatments. The recorded data indicated that the combined application of IAA plus furfural resulted in the greatest percent reduction 86.3%, 74.1%, and 82.6% in M. incognita juveniles in soil, root galls and egg masses respectively as compared to untreated control. Followed by combined application of urea plus pendimethalin, which recorded percentage decrease of 85.9%, 59.4%, and 78.9% in M. incognita j_2 in soil, root galls, and egg masses respectively as compared to untreated control. When IAA was combined with pendimethalin, the percentage reduction were 82.2%, 53.5% and 59.8% for M. incognita j_2 in soil, root galls, and egg masses respectively as compared to untreated control. While, other single or combined applications of urea, pendimethalin and IAA resulted in relatively less efficiency in controlling M incognita compared to untreated control (Table 2).

Table 2 Effect of Pendimithlin herbicide, Furfural, Urea, Indoleacctic acid IAA, on eggplant cv. baladi infected with root knot nematode *Meloidogyneincognita* under field conditions

Traetmant	*No. of J_2 in 250 g soil			*No. of Root galls in 5 g roots		*No. of Egg masses in 5 g roots		Eggplant- production	
	Initial Pop.**	Final Pop.**	***% Red.	*No.	***% Red.	*No.	***% Red.	Weight, kg	% increase
Control	310	1100a	-	70a	-	152d	-	1500	-
Pendimithalin	330	420 d	–64.1	90 bc	–47.06	65 b	–57.24	3210 f	114.0
Furfural	210	350f	–53.0	82 bc	–51.76	31 e	–79.61	3820 e	154.0
Urea	245	405 e	–53.4	57 ef	–66.47	22 e	–85.53	4500 a	200.0
Indoleacctic acid IAA	150	240 h	–54.9	52 fg	–69.41	43 cd	–71.71	2950 h	96.0
Pendimithalin+furfural	170	310 g	–48.6	87 bc	–48.82	44 cd	–71.05	4200 b	180.0
Pendimithalin+urea	300	150 i	–85.9	69 de	–59.41	32 de	–78.95	4000 c	166.
Pendimithalin+IAA	365	230 h	–82.2	79 cd	–53.53	61 b	–59.87	2750 j	83.0
IAA+Furfural	290	140 i	–86.3	44 g	–74.12	26 e	–82.89	2260 L	50.0
IAA+urea	220	567 b	–27.3	96 b	–43.53	56 b	–57.24	3000 g	100.0
Pendimithalin+furfural+Urea	340	320 g	–73.4	63 ef	–62.94	44 cd	–71.05	2890 i	92.0
Pendimithalin+IAA+Urea	280	544 c	–45.2	87 bc	–48.82	55 bc	–63.82	3890 d	159.0

Note: Each value represents mean of five replicates. Means followed by the same letter (s) within a column are not significantly ($P\leq 0.05$) different according to Duncanu'smultible range Test. ***% Red. =% Reduction. **Initial pop. = Initial population. **Final pop. = Final population. *No. Number.

3.2 Eggplant yield

Data in Table 2 showed that all treatments significantly increased eggplant production compared to untreated control.

The urea single treatment produced the highest percentage increase in eggplant yield. The percentage increase was 200% compared to the untreated control. Followed by furfural plus pendimethalin combined treatment which showed the percentage increase of 180% compared to the untreated control. The combined treatment of urea plus pendimethalin plus IAA resulted in 159% percentage increase in eggplant yield compared to the untreated control. While furfural plus IAA application exhibited the least percentage increase of 50 % compared to the untreated control (Table 2).

3.3 Effects on dry weight of weeds associated with eggplant

Data presented in Table 3 indicated that the highest percentage reduction of dry weight of total weeds was 65.9% by application of combined treatment with urea, pendimethalin and IAA. However, the lowest percentage reduction was 23.6% by application of urea plus IAA. As for annual grasses, application of pindimethalin alone produced 63.6% reduction in dry weight, however addition of furfural and urea to pindimethalin produced the highest reduction in dry weight of 72.5% compared to control group. Concerning broadleaf weeds, pendimethalin application alone recorded percentage decrease in dry weight of 49.3% compared to untreated control. However addition of either furfural, IAA or urea to pendimethalin did not show any significant difference from pindimethalin alone on dry weight of broadleaf weeds at the time of harvest of eggplant.

Table 3 Effect of Pendimithalin herbicide, Furfural, Urea and Indole acetic acid on fresh and dry weight of eggplant associated weeds after120 days from planting (At harvest)

Treatments	Annual grasses				Annual broadleaf				Total weeds			
	Fresh weight, g/m^2	% change	Dry weight, g/m^2	% change	Fresh weight, g/m^2	*% Red.	Dry weight, g/m^2	*% Red.	Fresh weight, g/m^2	*% Red.	Dry weight, g/m^2	*% Red.
Control	420	-	165	-	955	-	320	-	1475	-	485	-
Pendimithalin	200	–52.3	60	–63.6	520	–45.5	162	–49.3	720	–51.1	222	–54.2
Furfural	600	+42.8	220	+33.3	690	–27.7	230	–28.0	1290	–12.5	350	–27.8
Urea	150	–64.2	67	–59.3	530	–64.8	189	–40.8	720	–51.1	256	–47.2
Indole-3- acetic acid IAA	300	–28.5	112	–32.1	500	47.1	236	–27.5.	1250	–15.2	348	–28.6
Pendimithalin+Furfural	200	–52.3	62	–62.4	500	–47.6	160	–50.0	700	–52.5	222	–54.2
Pendimithalin+Urea	130	–69.8	45	27.7	490	–48.6	168	–47.5	620	–57.9	213	–56.0
Pendimithalin+IAA	–	–	–	–	600	–37.1	189	–42.0	660	–55.2	185	–61.8
IAA+Furfural	200	–52.3	65	–60.6	590	–38.2	181	–43.4	790	–46.4	246	–49.2
IAA+Urea	300	–28.5	139	–15.7	550	–42.4	170	–46.8	850	–42.0	369	–23.9
Pendimithalin+Furfural+Urea	100	–76.1	37	–72.5	510	–46.5	173	–45.9	610	–58.6	210	–56.7
Pendimithalin+IAA+Urea	–	–	–	–	600	–37.1	165	–48.4	600	–59.3	165	–65.9
L.S.D$_{5\%}$	40.2		21.3		300/0		90.5		400.8		70	

Note: Values are mean of five replicates. Non significant ≥0.05, - highly significant ≤ 0.05 using Snedecor and Cochran (1967). *% Red. % Reduction. **% Change of control.

The present study emphasized that all the treatments exhibited variable activities against the root knot nematode disease incidence, associated weeds, and improved eggplant production. The most nematode-suppressive treatment was application of combined IAA, pendimethalin plus urea.

Concerning furfural either alone or combined treatments the data in (Tables 2, 3) indicated significant reduction in M. incognita, total dry weeds, and significant increase in eggplant yield production. Regarding the effects on nematode development, our results are in harmony with Rodreguez-Kabana, 2005, 2006, Burger 2005, and Abdel-Kader et al. 2015, who reported that the application of furfural reduced the number of M. incognita juveniles in soil, number of galls, and egg masses in roots of cucumber plants under greenhouse conditions. Furfural is recorded as a natural nematicide, bactericide and herbicide. Furfural interacts with the cuticle of nematode, effectively stripping the protective layers which results in swelling and disintegration. Nematode movement is embedded and subsequently dies through dehydration or attack by parasitic organisms

(Rodreguez-Kabana, 2006 and Steyn, 2006).

However, Burelle (2007) studied the effects of furfural on parasitic nematode population in roots and soil, plant growth and galling in tomato and bell pepper plants infected by Meloidogyne incognita. He suggested that furfural increase many beneficial and nematode antagonistic microorganisms including Pseudomonas spp., chitinolytic bacteria and increase non parasitic nematode populations. The author argued that the varied effects of furfural on M. incognita population depend on the host plant, and rate of treatment, and may indicate influences on soil microorganisms, on which microbivorous nematodes feed, or a direct effect on the host plant such as induced resistance response to parasitic nematodes, resulting in reduced gall formation.

Our data indicated that pendimethalin alone or in combined treatments significantly decreased the total dry weights of weeds and M. incognita population and increase the crop yield. The nematicidal effects of pendimethalin could be explained by direct toxicity on nematode reproduction.

Weeds dry matter is a good parameter to measure the completion than the weed number (Chnnappagouclas et al., 2013). In the present study, the control treatment recoded significantly higher weed dry matter after 120 days from planting, the time of harvest. The lower weed dry matter may be ascribed to the less number of weeds, rapid depletion of the carbohydrate reserves of weeds through rapid respiration (Dakshinadas, 1962) and may be due to reduced photosynthetic activity (Hilli and Sankeemann, 1969). The herbicide pendimethalin alone produced significant reduction in annual grasses dry weight after 120 days from implanting (63.6%). However, combination of other compounds with pindimeithalin did not show synergistic effects in dry weight reduction of annual grasses except when furfural and urea were added which improved the efficiency to –72.5%. As for annual broad leaf no synergistic effects over pendimethalin (–49.35%) were observed by combination with other test compounds .However synergistic effects were observed over pindimethalin alone (–54.2%) in the dry weight of total weeds by combined treatment of pendimethalin and IAA (–61.8%) as well as pedimethalin plus urea and IAA (–65.9%). Thus, the last combination may be beneficial to better control the total weeds associated with eggplant crops.

Data presented in Table 2 revealed that the eggplant yield was significantly influenced by weed control. Subhra and Dipak (2015) in their studies on the number of eggplant, individual fruit weight, and total fruit yield, indicated significant increase due to herbicide treatments. Similar findings were also reported by (Shivalingappa et al., 2014).

In our study application of urea alone or combined with other tested compounds not only increased fertility of the soil, but also caused considerable stress on the root knot nematode M. incognita, decreased associated weeds and increased eggplant crop yield. These results are in harmony with the findings of (Osman et al., 2014). These authors revealed that under field condition three doses of urea alone at 250, 200, and 150 kg N/F were able to cause a remarkable decrease in root knot nematode population in soil, roots and improved yield of sunflower plant.

The exact mechanism of action of organic fertilizers may be due to secondary metabolic products which are directly toxic to the nematode (Mahmood and Saxena 1992), or their beneficial ingredients for plant growth (Oteifa et al., 1964). The reduction of nematode population obtained by urea may be due to the liberation of ammonia which may inhibit giant cell formation and suppress nematode development (Oteifa, 1955).

Regarding the combined treatments of urea plus pendimethalin , the reduction of nematode M.incognita juveniles infecting eggplant, decreasing weeds and increasing yield production may be due to the synergistic action of both urea and pendimethalin, each of them has suppressive effects on the nematodes, weeds and increasing effects on yield production.

IAA either single or combined application showed a potential effects in suppressing root knot nematode M.incognita j_2 in soil and increasing eggplant yield. These results are in agreement with the findings of (Abdel-Momen et al., 2005). These authors argued that IAA is a growth regulator that may enhance accumulation of metabolites that resist pathogenic organisms. Prasad

and Raot (1976) in their study on the physiology of rice plant against the root knot nematode M. graminicolagolden and birch field, they found that accumulation of growth regulators in root helped in reduction of nematode activity. These growth regulators appear to act physiotherapeutically by changing the internal environment of plant by conversion of non- toxic chemicals into metabolites toxic to nematode. Phenolic acids as well as IAA were increased in most cases after nematode infection in different plant parts of rice as compared to control. HPLC analyses of rice plant parts indicated that the IAA is synthesized in lower leaves and then after it is translocated to the site of infection (Singh et al., 2013). IAA binds to the chemosensory organs of M. incognita and it is possible that IAA act as a signal that orients the nematode on the root surface in the rhizosphere and or inside the root tissue and thereby promotes nematode infection (Curitis, 2008).

Our results go in the same direction with Mohamed, 2004, on his study on the effect of IAA alone and combined with the herbicide Bezagran on yield of soybean plant and its associated weeds. He came to conclusion that IAA alone treatment was the least effective in total dry weight. Whereas, the combined application of Bazagran plus IAA significantly decreased the total dry weight of the weeds.

As for application of IAA plus furfural, the highest reduction on *M. incognita* reproduction criteria and significant reduction in total dry weeds were recorded. Moreover, positive effects of either furfural or IAA alone on decreasing nematode development, their least effects alone on decreasing total dry weights of the weeds at harvest and their positive effects on increasing yield were recorded. Surprisingly, the least increase in eggplant yield in the combined application of IAA plus furfural was recorded. The authors hypothesized that IAA plus furfural combined application may enhance some toxic metabolites which affect eggplant vegetative growth characters and consequently decrease in eggplant yield occurred. This point needs further investigations.

In conclusion the authors recommend the use of organic fertilizer urea for controlling *Meloidogyne incognita* infecting eggplant cv. baladi and increase the crop yield. However, application of integrated protocols including urea, IAA combined with herbicide such as pendimithalin deserves consideration in the future tactics to maximize the efficiency of nematode control, and associated weeds as well as promoting the crop yield.

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