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Effect of Water of Tilapia Pond on Reproduction of *Meloidogyne incognita* and Growth of Eggplant in Relation to Soil Type

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Key words
Nematode management, Eggplant, *Meloidogyne incognita*, Tilapia effluents, Soil type

ABSTRACT

Plant-parasitic nematodes particularly the genus *Meloidogyne* are a primary limiting factor in the production of many plants and is a major problem in organic systems. This study was carried out to examine the influence of irrigation with different effluent water sources, including semi-intensive tilapia pond (STP), intensive tilapia biofloc (ITB) systems, and well water (WW), on the reproduction of *Meloidogyne incognita* infecting eggplants7 or 45 days after planting in sandy loam or sandy soils. Each irrigation source was applied daily at 150 mL/pot. The STP source was more suppressive to nematode development than ITB irrigation source in the two inoculation times of treatments either in sandy soil or sandy loam soil. Also, the produced eggs were highly influenced by the STP source achieving half of the produced eggs in the ITB after 45 days of inoculation time. The plant growth was enhanced. The efficiency percentage (%) of STP in both soil types was more than ITB. The growth parameters of the plants (length and fresh and dry weights) in both soil types also significantly increased when compared with WW. The STB and ITB irrigation sources improved the plant content regarding the total protein, total amino acids, and total carbohydrates in both tested soil types. These results suggest that aquaculture effluents from tilapia production could be utilized to manage *M. incognita* in different soil types.

INTRODUCTION

In Egypt, the efficient use of water for irrigation is becoming increasingly important with limited irrigation resources and a gradual increase in the population (Abdrabbo *et al*., 2015). Therefore, the use of aquaculture effluent sources under the integration system has become frugal and beneficial because fish wastes and algae can reduce the nematode population and/or improve plant growth (Kesba *et al*., 2013). Also, Kesba *et al*. (2013) stated that *M. incognita* and *R. reniformis* development on 5 strains of cowpea under greenhouse conditions was reduced differently according to the cowpea strains and the percentages of organic and inorganic fertilizers in tilapia ponds and they found that all treatments failed to reduce nematode criteria on one of the cowpea strains (strain 5). Root-knot nematodes (RKN), *Meloidogyne* spp. are the most economically important phytopathogenic nematode (PPN) groups worldwide (Koenning *et al*., 1996). Grown plants and any agricultural crop may be a host to one or more root-knot nematode species (Koenning *et al*., 1996). *Meloidogyne incognita* causes major losses in the yield of vegetable crops (Kesba *et al*., 2013).

Eggplant (*Solanum melongena* L.) is an important vegetable crop in Egypt that is grown in most cultivated areas and generally enlisted as a classical commodity for both local consumption and export (Rakha, 2014). Environmental safety, the hazards of chemical nematicide toxicity, and residues have shifted the research in nematode management toward environmentally friendly alternatives (Hassan *et al*., 2010). The incorporation of the organic amendment (with or without biocontrol agents) has been used for nematode management (Kesba and Al-Shalaby, 2008; Rashad *et al*., 2011; Abolusoro *et al*., 2015).

The effect of soil type and texture on the infectivity of

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Meloidogyne species was evaluated in many investigations. For examples, sandy loam soil was more favorable for *M. javanica* than sandy soil (Kim *et al*., 2017), *M. incognita* occurred in high density in sandy loam soil (David, 1980), in coarse-textured soil more than fine-textured soil (Koenning *et al*., 1996). The soil properties have a considerable effect on the communities of plant-parasitic nematodes in different farming systems (Ardakani *et al*., 2014; Krif *et al*., 2020).

An increase in organic matter in soil encourages the growth of numerous fungi, bacteria, and beneficial nematodes that may provide some level of biological control for root-knot nematodes and promote soil aggregations, which impede the nematode juveniles movement (Mbah and Onweremadu, 2009). Biofloc systems contain bacteria, cyanobacteria, algae, microalgae, organic matter, protozoa, and rotifers (Hargreaves, 2006; Martínez-Córdova *et al*., 2015). The high-nitrogen-containing organic amendments suppress plant-parasitic nematode populations as a result of ammonia and formulations nitrogen in the soil after the initiation of microbial decomposition (Lazarovits *et al*. 2001; Oka and Pivonia, 2002).

Many sources of organic matter, such as liquid or solid wastes, are effective for controlling plant-parasitic nematodes and promoting plant growth in different plant pathosystems, including those of animal origins, such as poultry litter, bovine manure, fish waste, and sewage sludge (Saeed *et al*., 2018; Brito *et al*., 2020). In general, there is a scarcity of information on the efficiency of fish wastes in controlling plant-parasitic nematodes. The objective of this study was to evaluate the effect of effluents of semi-intensive tilapia pond (STP) and intensive tilapia biofloc (ITB) systems on *M. incognita* reproductivity and eggplant growth with relation to two different soil type, i.e., sandy soil and sandy loam soil.

MATERIALS AND METHODS

Nematodes source

A pure culture of root-knot nematode, *M. incognita* was obtained from an isolate propagated on sunflowers at the Nematology Division Experimental Area, Zoology and Agricultural Nematology Department, Faculty of Agriculture, Cairo University.

Tested plant

Two-week-old eggplant seedlings (cv. Classic) with uniform size were transplanted and divided into two groups according to soil type (Table I). The first group was cultivated (one seedling/pot) in clay pots (15 cm. diameter) filled with steam-sterilized sandy loam soil (1:1, v/v) and irrigated daily with 150 mL. The second group was cultivated in clay pots (15 cm. diameter) filled with sandy soil and irrigated with the same method.

Table I. Experimental soil texture.

Soil type	Sand %	Silt %	Clay %	pH	E.C.
Sandy loam	73.8	15.1	11.1	7.9	0.29
Sandy	90.3	3.5	6.2	8.5	0.89

E.C., Electrical conductivity; Sandy, mix of coarse and fine sand.

Irrigation sources

The following water sources were used to irrigate plants: (1) Effluents from a semi-intensive tilapia (STP) pond. Nile tilapia with an average of 50±1.20 g were stocked in six replicates 1 m^{-3} tank at the rate of 12 fish per tank. Daily, the tilapia tanks received 4 and 10 g/ m^{-3} dry chicken manure and supplementary diet (18% crude protein).

(2) Effluents from an intensive tilapia biofloc (ITB) tank. Biofloc is an organic aquaculture system based on activation of heterotrophic bacterial growth to assimilate toxic ammonia in the fish production system and this microbial protein can be grazed by fish (Avnimelech, 1999). Microbial flocs were generated from three 1 m^{-3} fiberglass tanks (Mabroke *et al*., 2019). The tanks were stocked with 300 fish each with an average of 2.5±0.10. The tanks were maintained without water exchange for 45 days. Three porous stones (cylindrical shape of 4 cm in length) were placed in each tank to maintain the dissolved oxygen above 4 mg/L. The tanks received a daily supplementary diet (30% crude protein) and molasses as a carbon source at a C/N ratio of 16:1.

(3) Well water (WW).

The water quality parameters and average numbers of phytoplankton and zooplankton are shown in Tables II and III.

Table II. The water quality parameters of irrigation sources before the experiments.

Water quality parameters	WW	STP	ITB
Water temperature (°C)	26.5	27.4	29
Dissolved oxygen (mg/L)	2.8	6.03	5.4
Total alkalinity (mg$CaCO_3$/L)	110	355.5	297
pH	8.8	8.53	7.7
Total ammonia (mg-N/L)	Nd	1.43	1.93
Total phosphorus (mg p/L)	Nd	0.513	33.5
Orthophosphate (mg p/L)	Nd	0.256	16.4
Secchi disc visibility* (cm)	100	28.95	40.01

WW, well water; STP, semi-intensive tilapia pond; ITB, intensive tilapia biofloc; Secchi disc visibility, a popular limnological instrument for determining the clarity of the water.

Experimental management protocol

The experiments were laid out in a 2×3×3 (soil type, inoculation time, and irrigation source) factorial completely randomized design with six replications. For sandy loam soil, the seedlings for each of the three irrigation sources (STB, ITB, and WW) were divided into three subgroups: the first subgroup was inoculated with 3000 individuals of second-stage juvenile (J_2) of *M. incognita* one-week after planting, the second subgroup was inoculated with 3000 J_2 of *M. incognita* 45 days after planting, and the third subgroup was kept without inoculation. The second group of eggplant seedlings was cultivated in sandy soil and treated with the three subgroups as previously described. All groups were arranged on a clean bench in the greenhouse. The environmental conditions during the experiment period (April to June, 2020) inside the greenhouse were 27±4°C, 55±7% humidity, and 13.6:10.4 L:D photoperiods. At the end of experiment, the plants were harvested and data on the plant growth (length and fresh and dry weights) were recorded, and the percentages of change over the control (WW un-inoculated plant) were calculated with the following formula: Change (%) = [(Treatment – Control)/Control] x100. The nematode populations were extracted from the soil using the sieving technique (Hallmann and Subbotin, 2018) and counted with the aid of a stereoscopic microscope and a Hawksley counting slide. The stages embedded in the roots (developmental stages, females, egg masses, and eggs/egg mass) and the number of galls were counted. All treatments were carried out with six replicates.

Table III. The phytoplankton and zooplankton contents in different irrigation water sources.

Water microorganisms	STP	ITB
Phytoplankton		
Total blue-green algae (org/L)	$1.8x10^7$	$2.2x10^7$
Total green algae (org/L)	$6.0x10^6$	$6.7x10^6$
Total diatoms (org/L)	$1.3x10^5$	$6.2x10^4$
Total *Euglena* (org/L)	0	$6.2x10^4$
Total algae (org/L)	$2.4x10^7$	$2.9x10^7$
Chlorophyll a conc. (µg/L)	741	22
Zooplankton		
Total zooplankton (org/L)	$7.3x10^3$	$1.9x10^5$

For abbreviation see Table II.

Biochemical changes

For biochemical changes, sub-samples of the dry plant (shoot+root) of each treatment in each replication were analyzed for estimation of protein according to Lowry *et al.* (1951), total amino acids according to Hamilton *et al.* (1943) and total carbohydrate according to Malik and Srivastava (1985) at the Central Chemistry Lab, Faculty of Agriculture Research Park (FARP), Faculty of Agriculture, Cairo University.

Statistical analysis

To determine the effect of all independent variables (soil types, irrigation water sources, and time of inoculation) on the dependent variables (length and fresh and dry weight of eggplant), a two-way multivariate analysis of variance (MANOVA) was conducted. Then, the data for all attributes were statistically analyzed by analysis-ANOVA with SPSS version 23 to find the significant difference in the parameters studied between various treatments where the means were compared using Duncan's test (p = 5%).

RESULTS

Eggplant parameters

Multivariate ANOVA revealed that each of the soil types, irrigation water sources, and time of inoculation significantly affected the length and fresh and dry weight of the eggplant. No significant interactions between the soil type and the inoculation time and irrigation source were observed for all three tested parameters. In contrast, there were significant interactions between the inoculation time and irrigation source for both the plant length and fresh weight; however, this interaction was insignificant for the plant dry weight. The interaction of all three factors was insignificant for all tested parameters (Table IV).

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Significant suppressions were observed in the numbers of formed galls, egg-masses, nematode final population, nematode reproduction factor, and Rf (Pf/Pi), as well as the eggs/egg-mass and egg production (%) with the ITB and STB irrigation sources, compared to those with the WW irrigation source (Table V). Significant differences in nematode suppression, i.e., formed galls and final population were noticeable among treatments relating to the inoculation time. Irrigation with ITB had a significant effect at 45 days after inoculation but not 7 days after inoculation. In contrast, STP had significantly decreased nematode performance for both inoculation time points. STP and ITB had significantly decreased egg production (%) for both inoculation time points. The applications of WW inoculated with nematodes 45 days after planting achieved the highest value of Rf and number of eggs/egg-mass.

The plant growth parameters were slightly elevated in the STP and ITB compared to the WW treatment (Table VI). The plant length of eggplant was significantly increased in the STB and ITB treatments compared to the

Table IV. Multivariate analysis of variance (ANOVA) on soil type, irrigation water sources, and time of inoculation on eggplant growth infected with 3000 J_2 of *Meloidogyne incognita*/pot.

Source	Df	Length (cm)			Fresh weight (g)			Dry weight (g)		
		Mean square	F	P	Mean square	F	P	Mean square	F	P
Soil_type	1	1321.156	174.679	<.001	560.667	74.130	<.001	85.378	20.168	<.001
Irrigation source	2	1483.523	196.147	<.001	732.015	96.785	<.001	109.739	25.922	<.001
Inoculation time	2	1701.030	224.905	<.001	898.027	118.73	<.001	134.292	31.723	<.001
Soil type × Irrigation source	2	18.205	2.407	.104	1.532	.203	.818	.223	.053	.949
Soil type × Inoculation time	2	21.272	2.813	.073	8.229	1.088	.348	1.272	.301	.742
Irrigation source × Inoculation time	4	80.306	10.618	<.001	41.660	5.508	<.001	6.181	1.460	.235
Soil type × Irrigation source × Inoculation Time	4	.992	.131	.970	.899	.119	.975	.137	.032	.998
Error	36									

Table V. Effect of different irrigation water sources on the reproduction of *Meloidogyne incognita* on eggplant in sandy loam soil, and sandy soil.

Treatment	Inoculation time after	Reproduction parameters					
		Galls	Egg-masses/ Root	Final population (on root + in soil)	Rf*	Eggs/ Egg-mass	Egg production (%)**
Sandy loam soil							
WW	7 days	2314±145.5 b	1851±61.4 b	14721±229 b	4.9±0.39 b	337±57.1 b	45±1.4 b
	45 days	3492±195.0 a	2739±36.8 a	22218±695 a	7.4±0.42 a	509±60.7 a	100±0.0 a
STP	7 days	1577±149.8 c	1262±59.2 d	10036±812 d	3.3±0.32 c	230±42.0 cd	21±1.1 e
	45 days	922±193.4 d	737±39.0 e	5864±155 e	2.0±0.29 d	134±40.1 d	7±0.7 f
ITB	7 days	2145±190.9 b	1716±60.3 bc	13646±503 bc	4.5±0.35 b	313±47.1 bc	39±1.2 c
	45 days	2024±144.5 bc	1619±37.9 c	12787±712 c	4.3±0.32 b	293±50.4 bc	34±1.7 d
	F (df=5,30)	25.164	183.999	88.12	5.289	15.408	791.98
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sandy soil							
WW	7 days	5615±737.22 a	4679±417.11 a	35726±577 a	11.9±1.85 a	820±47.30 a	100±0.0 a
	45 days	2892±494.75 c	2410±214.84 c	18401±1527 c	6.1±1.50 c	422±24.34 c	27±2.3 c
STP	7 days	1152±356.42 e	960±85.58 d	7330±1001 e	2.4±0.95 e	168±9.69 e	4±0.29 e
	45 days	1972±310.11 d	1643±146.47 e	12545±501 d	4.2±1.70 d	288±16.61 d	12±0.76 d
ITB	7 days	3780±669.49 b	3150±280.81 b	24051±2172 b	8.0±1.27 b	552±31.84 b	45±2.65 b
	45 days	2681±429.47 c	2234±199.15 d	17057±418 c	5.7±1.32 c	392±22.61 c	23±1.45 c
	F (df=5,30)	82.945	693.789	87.63	5.74	50.908	477.3
	P	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means (n= 6) followed by the same letter(s) within each column are not significantly different ($p \leq 0.05$) according to Duncan's multiple range test. Inoculum level= 3000 J_2 of *Meloidogyne incognita*/pot. WW, well water; STP, semi-intensive tilapia pond and ITB, intensive tilapia biofloc. ±, Std. Error. * Rf, Pf/Pi (Rf, Reproduction factor; Pf, Final population; Pi, Initial population). ** % Egg production= (Total number of eggs per root of treatment/the highest total number of eggs per root)x100.

WW treatment for both inoculation time points. The same trend was achieved for fresh weight except for ITB7 days after inoculation, which was not significantly different with WW7 days after inoculation. However, the plant dry weight increased significantly in STB and ITB after 45 days of inoculation but not 7 days after inoculation. On the other hand, in uninoculated plants, irrigation with both of STP and ITB caused significant increases in the plant growth criteria (length and fresh and dry weights) compared to the WW irrigation source.

For uninoculated plants, both the ITB and STB irrigation sources executed different effects on the eggplant content of total protein, total amino acids, and total carbohydrates (Table VII). With regard to the inoculated plants, the plant protein significantly increased in both STB and ITB compared with that of WW for both inoculation times.

The total amino acids were significantly lower in inoculated plants after 45 days in plants irrigated with WW or ITB compared with that of STB. Inoculated plants with STP and ITB irrigation sources had significant increases in the total carbohydrates when compared with inoculated plants with a WW irrigation source.

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Both the ITB and STB treatments significantly reduced the RKN parameters, Rf, and the number of eggs/egg-mass and egg production (%) compared with the WW treatment (Table V). The source of STP showed significant effects for both time points for all nematode parameters. The ITB treatment decreased the nematode parameters compared to WW; however, this was less pronounced than for STP (significant differences for 7 days but only tendencies for 45 days.

The irrigation with STP wastes caused significant increases in the plant growth criteria (length and fresh and dry weights) compared to irrigation with WW (Table VI). The plant length and fresh and dry weights were significantly increased in STB and ITB treatments compared to WW treatment for both inoculation time points. For inoculated plants with nematodes, the plant parameters were affected more when nematodes were added after 7 days of planting than when added after 45 days of planting.

Table VI. The effect of different irrigation water sources on eggplant growth infected with *M. incognita* in sandy loam soil and sandy soil.

Treatment	Inoculation time after planting	Plant growth*					
		Length (cm)	Change (%)	Fresh weight (g)	Change (%)	Dry weight (g)	Change (%)
Sandy loam soil							
WW	Uninoculated	42.0±4.19 c	-	32.4±3.58 c	-	12.5±2.42 bc	-
	7 days	31.9±3.05 e	-24.0	25.1±3.86 d	-22.5	9.7±2.41c	-22.4
	45 days	40.9±4.98 cd	-2.6	29.9±3.92 cd	-7.7	11.5±2.07 bc	-8.0
STP	Uninoculated	69.4±6.18 a	65.2	50.9±5.73 a	57.1	19.7±4.94 a	57.6
	7 days	44.6±4.84 c	6.2	33.8±3.95 c	4.3	13.1±3.61 bc	4.8
	45 days	65.6±6.06 a	56.2	48.2±4.61 a	48.8	18.6±4.57 a	48.8
ITB	Uninoculated	57.8±4.79 b	37.6	40.4±5.71 b	24.7	15.6±4.52 ab	24.8
	7 days	36.8±5.03 d	-12.4	27.5±3.91 d	-15.1	10.6±2.75 bc	-15.2
	45 days	54.8±6.09 b	30.5	39.0±3.94 b	20.4	15.1±3.32 ab	20.8
	F (df=8,45)	68.281		31.929		4.789	
	P	<0.001		<0.001		0.003	
Sandy soil							
WW	Uninoculated	23.6±1.56 d	-	25.5±1.70 c	-	9.8±0.36 cd	-
	7 days	15.5±1.70 e	-34.3	19.3±1.05 d	-24.3	7.4±0.27 e	-24.5
	45 days	22.7±1.46 d	-3.8	24.8±1.62 c	-2.6	9.6±0.35 cd	-2.0
STP	Uninoculated	45.5±3.88 a	92.8	42.1±3.45 a	65.1	16.2±0.59 a	65.3
	7 days	35.7±2.78 b	51.3	27.1±1.86 c	6.3	10.4±0.38 c	6.1
	45 days	42.5±3.55 a	80.1	39.8±3.21 a	56.1	15.3±0.56 a	56.1
ITB	Uninoculated	36.2±2.89 b	53.4	35.0±2.71 b	37.3	13.5±0.50 b	37.8
	7 days	29.4±2.12 c	24.6	22.3±1.36 cd	-12.6	8.6±0.31 de	-12.2
	45 days	33.8±2.64 b	43.2	33.2±2.52 b	30.2	12.8±0.47 b	30.6
	F (df=8,45)	43.661		25.087		31.353	
	P	<0.001		<0.001		<0.001	

For abbreviation and Statistical details, see Table V.

Table VII. The effect of different irrigation water sources on the eggplant chemical contents infected with *M. incognita* in sandy loam soil and sandy soil.

Treatment	Inoculation time after planting	Proteins		Amino acids		Carbohydrates	
		Total protein (g%)	Change (%)	Total amino acids (mg/g)	Change (%)	Total carbohydrates (g%)	Change (%)
Sandy loam soil							
WW	Uninoculated	3.98±0.77 c	-	0.23±0.01 e	-	5.20±1.04 f	-
	7 days	4.12±0.79 c	3.5	0.35±0.02 cd	52.2	5.81±1.16 de	11.7
	45 days	4.10±0.79 c	3.0	0.20±0.01 e	-13.0	5.41±1.08 ef	4.0
STP	Uninoculated	5.32±1.02 ab	33.7	0.31±0.01 cde	34.8	6.42±1.28 b	23.5
	7 days	5.43±1.05 a	36.4	0.80±0.04 a	247.8	7.13±1.43 a	37.1
	45 days	5.40±1.04 a	35.7	0.58±0.03 b	152.2	6.98±1.40 a	34.2
ITB	Uninoculated	4.43±0.85 c	11.3	0.28±0.01 de	21.7	5.91±1.18 cd	13.7
	7 days	4.98±0.96 ab	25.1	0.41±0.02 c	78.3	6.31±1.26 bc	21.3
	45 days	4.92±0.95 b	23.6	0.28±0.01 de	21.7	6.11±1.22 bcd	17.5
	F (df=8,45)	16.835		31.037		18.706	
	P	<0.001		<0.001		<0.001	
Sandy soil							
WW	Uninoculated	2.32±0.19 e	-	0.43±0.01 e	-	4.88±1.07 d	-
	7 days	3.64±0.29 bc	56.9	0.55±0.01 d	27.9	5.61±1.23 cd	15.0
	45 days	3.90±0.32 ab	68.1	0.53±0.01 d	23.3	6.49±1.42 abcd	33.0
STP	Uninoculated	2.18±0.18 e	-6.0	0.85±0.01 ab	97.7	8.10±1.78 a	66.0
	7 days	3.84±0.31 ab	65.5	0.77±0.01 b	79.1	7.56±1.66 ab	54.9
	45 days	4.42±0.36 a	90.5	0.86±0.01 a	100.0	7.80±1.71 a	59.8
ITB	Uninoculated	2.44±0.20 de	5.2	0.66±0.01 c	53.5	7.80±1.71 a	59.8
	7 days	3.04±0.25 cd	31.0	0.66±0.01 c	53.5	7.32±1.61 abc	50.0
	45 days	4.44±0.36 a	91.4	0.65±0.01 c	51.2	5.85±1.28 bcd	19.9
	F (df=8,45)	19.326		25.523		4.419	
	P	<0.001		<0.001		0.004	

For abbreviation and statistical details, see Table V.

The chemical components of the eggplants varied in relation to the irrigation sources (Table VII). Eggplant seedlings irrigated with different water sources in all inoculation times gave close or, in some cases, slightly higher determinations when compared with WW uninoculated plants. Protein content was not significantly affected by any of the irrigation treatments when nematodes were inoculated after 45 days. Significant differences were observed in the total amino acids among all treatments and the WW (uninoculated and inoculated after 7 and 45 days). Most irrigation sources significantly increased the total carbohydrate content when compared with WW (uninoculated plants). The increase ranged between 23.3% – 100% in total amino acids and 15%–66% in total carbohydrates. There was no definite correlation between the plant contents of total protein, total amino acids, and total carbohydrates and the treatments, which indicates that these compounds induced tolerance in plants against nematode attack.

Both water sources (STP and ITB) achieved higher nematode reduction in sandy soil compared with sandy loam soil in plants inoculated 7 days after planting. In contrast, inoculation 45 days after planting in sandy loam soil achieved higher efficiency in nematode reduction compared with sandy loam soil (Fig. 1).

DISCUSSION

The utilization of water sources provided with organic and inorganic manure caused a significant decline in the

population of RKN, in both the root and soil, reduced the root damage of STP and ITB irrigated plants as compared with WW, and subsequently improved the plant growth criteria (length and fresh and dry weights). The current results indicate that STP and ITB contained high amounts of algae, diatoms, and zooplankton as well as organic and inorganic components. These organisms produce some secondary metabolites, such as hormones, indoles, cytokinins, gibberellins, and brassinosteroids, which are considered plant growth regulators (Lee *et al*., 2008; El-Eslamboly *et al*., 2019).

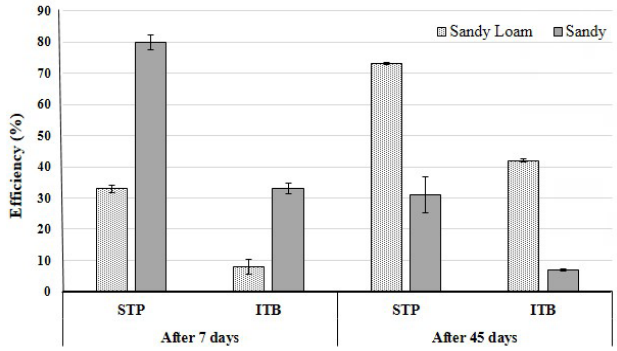

Fig. 1. The efficiency (%) of different irrigation sources on *M. incognita* reproductivity inoculated 7 and 45 days after planting in two soil types (sandy and sandy loam). Semi-intensive tilapia pond (STP) and intensive tilapia biofloc (ITB).

An earlier study showed that algal extracts applied to the soil can reduce gall formation on plants infested with *M. incognita* (Paracer, 1987). The seaweed algae species not only controlled the nematode in the soil but also increased the health of the plants (Khan *et al*., 2009). Diatoms and algae produce high amounts of antioxidants, polyphenols, flavonoids, and certain enzymes that play important roles as biological controls for a wide range of plant-parasitic nematodes (Jiménez *et al*., 2011; Chtourou *et al*., 2015).

The research demonstrated that the addition of organic manure has beneficial effects for nematode control through stimulating the multiplication of microorganisms (fungi and bacteria), soil physical conditions (water retention, cation exchange capacity, and soil aggregation), soil biological activity, and crop performance (Abubakar *et al*., 2004; Kesba *et al*., 2013; Osman *et al*., 2018). The microorganisms cause the suppression of parasitic nematodes in the soil and improve the growth, development, and performance of infected plants with nematodes due to the direct stimulation of predators that compete with RKN for space, water, food, etc. (Jatak, 2002). The toxins produced by the microorganisms have adverse effects on the RKN's activities, survival, and density, hence, increasing the plant yield (Abolusoro *et al*., 2015).

The irrigation source of STB with chicken manure includes organic acids, such as butyric and propionic acids, for which a nematicidal activity against the free-living stage of plant-parasitic nematodes has been demonstrated where these acids may have a direct or indirect role in the biological defense mechanism through increasing the proteins and fatty acids in the root tissues (Browning *et al*., 2004). It is important to understand the mechanism of vacuolization in plant-parasitic nematodes to undoubtedly modify the perceptions of the dynamic behavioral and resistance patterns of these parasites (Rajasekharan and Lee, 2020).

Other acids were found to be more effective on *M. incognita* J2, such as lactic and acetic acids (Seo and Kim, 2014), oxalic acid (Jang *et al*., 2016), indole-3-acetic acid, and 4-hydroxybenzoic acids, due to the formation of vacuoles in the mid and posterior regions of J2, which contained glycerophospholipids and sphingolipids, polyketides, prenol lipids, and glycerolipids, which subsequently fused, as a biological marker of parasite death (Bogner *et al*., 2017). Accumulated toxins of the decomposing products and tannins in nematotoxic polyphenols marked an increase in the numbers of natural enemies that are parasitic on nematodes.

The microbial breakdown of nitrogen-containing substances in the soil via the processes of mineralization might have a part as an operative tool against nematodes by increasing predacious nematodes, nematode-trapping fungi, and their toxins (Zhang *et al*., 2020). $NH_3$and possibly nitrite is among the reduction compounds responsible for the nematodes. The direct or indirect influence of the pH, magnesium, potassium, calcium ions, and moisture could also adversely affect nematode activity, growth, reproduction and improve soil texture (Dubey, 1968; Saeed *et al*., 2018).

Regarding the biochemical changes in plants, our results indicate that both irrigation water sources increased the contents of proteins, amino acids, and carbohydrates in the plants inoculated with RKN 7 and 45 days after planting in the two soil types. Incidentally, an increase in the total protein was found with the increase in amino acids and nucleic acids, and some of these inorganic substances are likely incorporated into various organic compounds (Kesba *et al*., 2012, 2013).

All irrigation water sources in our study achieved an increase in the total protein of plants infected with RKN, which is consistent with other previous findings (Kesba *et al*., 2012). In contrast, the STB and ITB sources increased the total carbohydrates in the plants in the two soil types.

This change in the total carbohydrates in different host plants due to nematode infection was recorded (Kesba *et al*., 2012). However, differing results were recorded by others. This contradiction may be due to many factors e.g., the used doses, the origin of treatment, plant variety, susceptibility, nematode species/races, density, assayed plant part, and time of harvest (Dubey, 1968; Farahat *et al*., 2012).

The results in this study indicated that both STP and ITB achieved higher nematode reduction in sandy soil compared with sandy loam soil in plants inoculated 7 days after planting but inverted findings were observed for inoculation 45 days after planting. Due to the high content of salts and the continuous drip of irrigation in sandy loam soil, we propose that soil moisture had a considerable effect on the nematode population and behavior. Previous results reported that the soil composition and texture affected the phytoparasitic nematode populations where an increase was achieved more rapidly in fine sands compared with sandy loam soils (Feil *et al*., 1997).

In general, organic amendments are essential for maintaining the quality of different soil types, including sandy loam and sand, by improving the biological, physical, and chemical soil conditions (Soumare *et al*., 2003; Rashad *et al*., 2011). With regard to the fertilization effect, the analysis of irrigation sources in this study stated that STP and ITB contain ammonia, phosphorus, and orthophosphate which were missed in the WW. In fact, we could not make sure that STP and ITB have a direct effect against the nematodes or the effect is via the plant. In this context, ammonia plays an important role in nematode control where anhydrous and aqueous ammonia, urea, and other ammonium compounds have been used directly for nematode control (Farahat *et al*., 2012). However, phospho-fertilizer was most effective in reducing root galling and egg mass production, and also reduce both egg hatching and survival of J2 (Rashad *et al*., 2011). Moreover, phosphate fertilizer has an indirect effect on nematode control where it induces systemic acquired resistance in plants against RKN (Habash and Al-Banna, 2011).

CONCLUSIONS

The irrigation water source of STP wastes (amended with chicken manure) was found to be the best in decreasing the population of RKN in infected eggplant roots when compared with ITB in the two tested soil types. An integrated aquaculture-agriculture system (IAA) plays a potential role in decreasing the population of plant-parasitic nematodes as well as enhancing plant growth and may be considered an acceptable strategy to achieving sustainable agriculture. Future investigations and large-scale field studies are needed to emphasize and confirm our results with effluents generated from different tilapia production systems on eggplant and other crops. Also, other studies should focus on how these treatments affect the environment, non-target organisms, and soil health which are based on multidisciplinary strategies. Also, future studies could be carried out on an autoclaved version of STP and ITB to see to what extent the effect is due to living organisms in STP and ITB. Further, it should be looked at which components in the STP and ITB have the biocontrol effect, e.g. the acids.

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Statement of conflict of interest

The authors have declared no conflict of interest.

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