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THE ROLE OF SOIL MOISTURE REGIME IN ENHANCING BIOFUMIGATION EFFICACY AGAINST *Meloidogyne Incognita* (KOFOID and WHITE) CHITWOOD ON TOMATO

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ABSTRACT

Anaerobic soil disinfestation (ASD), through decomposition of organic matter in the soil is currently recommended for the control of soil borne pests including nematodes. A greenhouse trial was conducted aimed to assess the efficacy of different soil moisture regimes i.e. field capacity (FC), saturation (SA) and flooding (FL) with and without forage radish (*Raphanus sativus*) biomass addition on suppressing of root knot nematode (*Meloidogyne incognita*) in tomato plant growing soil. In addition to the six treatments of soil moisture regimes with and without fodder radish, Vydate, as synthetic chemical nematicide was used as positive control treatment. However, FC soil moisture regime without fodder radish served as negative control treatment. pH, redox potential (Eh) and oxygen diffusion rate (ODR) were measured at the soil in one-week intervals during 4 weeks of fodder radish decomposition period before tomato seedlings (cv. Elisa) transplanting. Numbers of (*M. incognita*), reproductive factor and galling index were determined 12weeks after transplanting. Tomato crop growth parameters including plant length, fresh and dry plant weights and fruit fresh weights were also recorded. Obtained data results that pH, Eh and ODR in the soil during 4 weeks of fodder radish decomposition dramatically declined under soil flooding with fodder radish green manure treatment. Flooding the soil with fodder radish significantly reduced nematode population density, reproductive factor and galling index values. The treatment was comparable to that obtained with Vydate treatment and was finally reflected on improvement of all studied tomato growth attributes.

INTRODUCTION

Methyl bromide was the major chemical fumigant used as pre-planting soil disinfestation for the last few decades. However, it has been shown to cause some various hazard problems for both environment and mankind health **(Prather *et al.,* 1984)**. The search efforts for alternative to that highly effective soil fumigant has been emphasized **(Ristaino and Thomas, 1997)** with high preference for biological fumigation methods. There has been some forms of pre-planting soil disinfestation with various crops in order to reduce many soil- borne pests including fungi, bacteria, as well as nematodes, weeds and insects **(Spadaro and Gullino, 2005)**. Using various *Brassica* species as green manure proved to be a successful practice for soil disinfestation by many researches **(Kirkegaard and Sarwar, 1998; Goud *et***

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***al*., 2004)** indicated that Biological soil disinfestation (ASD) can be used as a promising alternative for the harmful chemical fumigation methods. The application of ASD,in Japan is conducted as follows: 1- incorporating the plant biomass organic manuring into the soil. 2- flooding the soil with irrigation water, and 3- soil surface covering with a plastic film. The organic manuring decomposition processes last for at least 3 weeks then plastic films are removed followed by field plowing then soil conditions are suitable for cultivation of the main crop **(Devi, 2018)**. There are different plant biomass which can be used under ASD conditions like wheat bran, rice, grasses or other organic materials **(Blok *et al*., 2000; Czyż, 2004; Goud *et al*., 2004; Momma, 2008)**. Many plant pathogens showed significant population reduction under anaerobic soil conditions due to the activity of bacterial communities developed under such anaerobic conditions **(Blok *et al*., 2000)**. The anaerobic bacteria contains *clostridia* class which produce harmful compounds to pathogens like skatole, inole, cresol and some phenolic compounds via the amino acids fermentation such as tryptophan and tyrosine **(Macfarlane and Macfarlane 1995)**. **Momma and Izumi, (2006)** indicated that different fatty acids like acetate or butyrate are produced via the activity of such bacterial groups. **Mowlick *et al*. (2012)** detected such fatty acids under ASD suggested that acetate, butyrate and other substances growth produced by *clostridia* groups are responsible for suppression some soil-borne pathogens. Due to the inherent similarities between biofumigation (BF) which used brassicas green manures under filed capacity soil moisture condition and ASD, the combination of the two practices seems over promising and provides an improved constituent for pest management programs and finally increasing crop yield. The aim of current study was to investigate the effects of soil moisture regime treatments and fodder radish *Raphanus sativus* organic manuring on *Meoidogyne incognita* (Kofoid and White) Chitwood and on tomato crop growth attributes.

MATERIALS AND METHODS

Identification of *Meloidogyne* Species

Tomato plants infected with root-knot nematode were collected from the experimental site, thoroughly washed under a stream current tap water to remove the adhering soil particles and then cut into small pieces. A single egg-mass from the adult females was isolated and reared separately on tomato seedlings (*Solanum lycopersicum* L. cv. Elisa), which were grown in 10 cm plastic pots filled with steamed sterilized sandy clay soil and kept in a greenhouse at 25±5ºc Sixty days after inoculation, infected tomato plants were taken off and their roots were examined for species identification.

Perineal patterns of the root-knot nematode adult females were prepared for each sample according to **Netscher and Taylor (1974)** and identified to species level which based on juvenile measurements and perineal patterns examination of adult females **(Eisenback *et al*., 1981; Jepson, 1987)**.

Experimental Design

The greenhouse trial was laid as 7 treatments in completely randomized design, replicated four times. The studied factors included three soil moisture contents i.e. field capacity, saturation and flooding alone or combined with fodder radish green manure. Soil moisture constants, % *i.e.* wilting point, field capacity and saturation percent were determined according to **Richards (1954)** using the pressure cooker and membrane apparatus. The recorded values were 1.85, 7.73 and 18.20%, respectively. The experiment was conducted in plastic pots contain10 kg soil. The mean initial J2 *M. incognita* population density in the soil was 134/250g soil. Forage radish plant biomass was taken from the field during full blooming stage and fresh plant biomass was chopped to small pieces using a cuter and dried then incorporated to the soil at the rate of 875g/10kg soil. The soil used was loamy sand in texture with pH, electrical conductivity and organic matter content of 7.85, 1.76 dSm^{-1} and 0.08%, respectively **(Jackson, 1973)**. The total experimental pots were 28pots include 7 treatments in 4 replicates. 24 pots received their appropriate irrigation water volumes to reach the soil to its field capacity (FC), saturation (SA) and flooding (FL) treatments while 4 pots served as positive control treatment using chemical nemacide Vydate which were left dry till tomato seedlings transportation, while FC without fodder radish green manure served as negative control treatment. After that, the 24 pots were covered with impermeable polythene white plastic sheets for 4 weeks to enhance the decomposition of added brassica biomass and also to prevent loss of volatile isothiocyantes (ITCs). After 4 weeks of organic matter decomposition period plastic covers were removed and left for 2 weeks then the 4 positive control pots were treated with chemical nemacide at recommended rate then two tomato seedlings (cv. Elysa) which is a nematode sensitive cultivar were transplanted in every pot. General agronomic practices were implemented to raise the seedlings for 12 weeks.

Data Collection and Statistical Analysis

During the period of 4 weeks of biomass decomposition, soil reaction pH, redox potential (Eh) and oxygen diffusion rate (ODR) in the soil at the depth of 5 cm were measured at one week intervals using glass and platinum electrodes while Ag/AgCl (silver/silver chloride half-cell) served as a reference electrode. Three readings of both aforementioned parameters were monitored, and the mean values were regressed. C/N ratio of the forage radish biomass was determined according to **Cottenie *et al*. (1982)**. After 84 days of tomato plants transplanting, the plants were uprooted carefully from the pots and roots were washed under running tab water to remove any soil particles. The nematode parameters in the soil were determined including nematode population in soil samples of 250g which were collected from the root zone of every treatment and extracted by sieving and decanting methods **(Barker, 1985)**. The roots were subjected to galling index (1-10) examination according to **Zeck (1971**). Reproductive factor was calculated as follows RF=PF/PI where PF was the final nematode population and PI was initial population. Tomato plant growth parameters include plant length (shoots and roots) (cm), fresh and dry weight (shoots and roots) (g/plant) and fruit fresh weigh (g/plant) were recorded. Analysis of variance was used to determine the effect of applied treatments on nematode numbers in the soil as well as tomato plant growth attributes.

Analysis of Collected Data

All obtained data were subjected to analysis of variance (ANOVA) using a generalized linear models (GLM) procedure of statistic of SAS (SAS, Institute, Cary, NC.). To detect the difference of applied treatments all obtained means were separated using Student-Newman-Keuls (SNK) method (S-N-K) test at 95% level of confidence.

RESULTS AND DISCUSSION

Identification of Root-Knot Nematodes *Meloidogyne* Species

Examination of the Perineal pattern of the isolated root- knot nematode females revealed the presence of one root-knot nematode species identified as *M. incognita*. About hundred valid species have been described in the genus *Meloidogyne* by **Trinth *et al.* (2019)** and four species are of high economic importance to vegetable production. *M. incognita, M. javanica, M.*

arenaria 8% and *M. hapla*. The most dominant species worldwide was shown to be *M. incognita* in 53% of all field samples followed by *M. Javanica* 30% and *M. arenaria* and *M. hapla* 8% **Taylor and Sasser (1978)**.

Obtained data in Table 1 reveal that fodder radish green manure under flooding soil moisture regime treatment resulted in the lowest nematode population mean value 14.25 larvae/250g soil after 4 weeks of decomposition period. The corresponding values for flooding soil moisture regime without fodder radish treatment resulted in 31.00 larvae/250g soil. On the other hand, the highest mean nematode population density was detected in field capacity soil moisture regime control treatment 51.50 larvae/250g soil. The mean nematode population value under saturation soil moisture regime were 40.75 and 24.75 in both without and with fodder radish treatments, respectively. Such obtained data indicate that fodder radish was more effective under soil moisture regime of flooding conditions in controlling root knot nematode population number compared to other studied treatments. It is worth to note that the high nematode population under Vydate treatment may be due to the fact that Vydate was applied during tomato seedling transportation.

Effect of Soil Moisture Regime with or Without Fodder Radish Green Manure on Soil pH, Eh and ODR

Obtained data in Table 2 illustrate that soil pH decreased with elapsing time during the term of experimental period of four weeks. The higher the soil moisture content, the lower the soil pH values. Such effects were more pronounced under flooding soil moisture regime combined with fodder radish addition. The lower soil pH detected under flooding soil moisture regime + fodder radish application was nearly neutral value of 7.12 after 4 weeks of experimental period. The corresponding value under field capacity soil moisture regime + fodder radish addition was 7.38. It is worth to note that decreasing soil pH under both field capacity and saturation was lesser than that of flooding soil moisture regime with or without fodder radish treatments.

The decreasing effect of soil pH under high soil moisture regime (flooding) with or without fodder radish application (as a source of carbon) followed the expected pattern as described by **Ponnamperuma (1997).** Obtained data in Table 2 illustrate that initial values of Eh and ODR were relatively high (+362 mv) and 94.55 × 10^{-8} cm^{-2} min^{-1}, respectively. After 4 weeks of experimental period, both parameters were decreased and reached (-105.25) and (15.95 × 10^{-8} cm^{-2} min^{-1}) under flooding soil moisture regime combined with fodder radish application, respectively which indicated severe soil reducing conditions.

Such obtained results may be due to the exchange of gases between the soil and atmosphere which is primarily due to diffusion mechanism **(Ponnamperuma, 1997**). Under excessive soil moisture regime content high percentages of soil pores are filled with water. As a result, the diffusion of O_2 into the soil from atmosphere is reduced. The diffusion movement of O_2 in the water is lesser than that in air by about 10.000 times **(Grable, 1966)**. Moreover, there is a high consumption rate of O_2 via fodder radish decomposition which is reflected on both Eh and ODR as a two soil aeration indicator parameters **(Szafranek-Nakonieczna and Stępniewska, 2015)**. Thus, both flooding and saturation soil moisture regime + fodder radish treatments after 4 weeks recorded Eh values -120.75 and -105.25 mv which are located in -100.00 to -300.00 mv as a high soil reducing conditions category. **Stepniewski *et al*. (2000)** and **Czyż (2004)** indicated that ODR values of above 35.00 × 10^{-8} cm^{-2} min^{-1} represent good soil aeration conditions

Table 1. Numbers of *M. incognita*, juveniles per 250g soil after 4 weeks of fodder radish decomposition under different soil moisture regimes

Treatment	Nematode population density mean value
Filed Capacity	51.50
Saturation	40.75
Flooding	31.00
FC + Fodder	31.00
SA + Fodder	24.75
FL + Fodder	14.25
Vydate	134 (initial nematode population)

Table 2. Soil pH, redox potential (Eh) and soil oxygen diffusion rate (ODR) during four weeks of fodder radish decomposition period

		Soil pH			
Treatments	**Times (weeks)**				**Mean**
	1 week	**2 weeks**	**3 weeks**	**4 weeks**	
Field capacity (FC)	7.62	7.66	7.53	7.51	**7.58[a]**
Saturation (SA)	7.54	7.51	7.49	7.49	**7.51[b]**
Flooding (FL)	7.51	7.46	7.42	7.40	**7.45[c]**
F.C fodder + radish	7.44	7.45	7.41	7.38	**7.42[d]**
Saturation + fodder radish	7.41	7.34	7.31	7.29	**7.33[e]**
Flooding + fodder radish	7.31	7.26	7.21	7.12	**7.22[f]**
Mean	**7.47 [a]**	**7.45[b]**	**7.39[c]**	**7.36[d]**	
L.S.D ≤0.05	**T= 0.02 W=0.02 T×W=0.01**				
Soil Redox potential (Eh)					
Treatments	**Times (weeks)**				**Mean**
	1 week	**2 weeks**	**3 weeks**	**4 weeks**	
Field capacity (FC)	362.00	331.00	296.25	278.75	**317.00[a]**
Saturation (SA)	200.00	184.25	178.00	174.50	**184.19[b]**
Flooding (FL)	120.00	93.25	71.75	41.50	**81.63[c]**
F.C fodder + radish	213.25	79.00	27.50	10.75	**82.63[c]**
Saturation + fodder radish	-86.50	-62.50	-101.75	-120.75	**-92.88[d]**
Flooding + fodder radish	-193.25	-170.75	-193.75	-105.25	**-165.75[e]**
Mean	**102.58[a]**	**75.71[b]**	**46.33[c]**	**46.58[c]**	
L.S.D ≤0.05	**T=30.3 W=24.7 T×W=12.5**				
Soil oxygen diffusion rat (ODR)					
Treatments	**Times (weeks)**				**Mean**
	1 week	**2 weeks**	**3 weeks**	**4 weeks**	
Field capacity (FC)	94.55	75.63	70.65	70.65	**77.87[a]**
Saturation (SA)	73.25	54.55	47.85	48.35	**56.00[b]**
Flooding (FL)	33.70	29.60	25.78	25.80	**28.72[e]**
F.C fodder + radish	65.33	54.43	48.83	48.83	**54.35[c]**
Saturation + fodder radish	44.53	40.73	36.15	33.90	**38.83[d]**
Flooding + fodder radish	28.60	21.38	15.95	15.95	**20.47[f]**
Mean	**56.66[a]**	**46.05[b]**	**40.87[c]**	**40.58[c]**	
L.S.D ≤0.05	**T= 0.95 W= 0.77 T×W= 0.81**				

[A,b,c]; Different letters means significant difference between treatments at levels 0.05 of probability.

while below that aeration becomes limited. **Inglett *et al*. (2005**) indicated that Eh values above + 300.00 mv is regarded as aerobic while below + 300.00 mv is regarded as anaerobic. Obtained data revealed that both Eh and ODR values under all three studied soil moisture regimes without fodder radish application were lower than that under corresponding treatments with fodder radish application although all studied treatment reached anaerobic conditions with different magnitudes. Such effects may be due to the low content of native organic matter as a source of organic carbon in the studied soil.

Effect of Soil Moisture Regime and Fodder Radish Application on Studied Nematode Parameters

The effect of soil moisture regime and fodder radish application on studied nematode parameters is illustrate in Tables 3 and 4. After termination of experiment (12 weeks), obtained data cleared that the least mean number of nematodes population (23.7 juveniles/250g soil) was recorded in flooding soil moisture regime + fodder radish application treatment. The percentage reduction was 67.80% lower than filed capacity control treatment. On the other hand, field capacity + fodder radish treatment recorded percentage nematode population reduction of 35.59% compare to field capacity control treatment. The overall effective reduction in nematode population density was recorded in Vydate treatment (18.75/250g soil) with percentage of 74.57% lower than that of field capacity control treatment. Among all studied treatments, flooding soil moisture regime + fodder radish application was comparable to Vydate treatment.

Obtained data clear that mean galling index as a measure of root damage, was 1.84 under flooding soil moisture regime + fodder radish treatment compares to 9.23 under field capacity in control treatment. The percentage reduction under the previous studied treatment was 80.07% lower than field capacity in control treatment. It is worth to note that, galling index mean value under field capacity + fodder radish application treatment was 3.29 with reduction percentage of 64.36% lower than field capacity control treatment.

The overall mean decreasing value of galling index was recorded under Vydate treatment, 1.76 which is 80.93%lower than that of field capacity control treatment. Obtained data also clear that the reproductive factor mean value under ASD as flooding soil moisture + fodder radish application treatment recorded 0.18 with reduction percentage of 66.67% lower than that of field capacity treatment. FC+ FR treatment recorded mean reproductive factor of 0.35 with percentage reduction of 35.19% lower than filed capacity control treatment. The overall significant reduction ($P \leq 0.05$) on mean reproductive factor values 0.14 was recorded as a result of Vydate treatment which represent 74.07% lower than field capacity control treatment. With the three studied nematode parameters, BSD with flooding soil moisture regime + fodder radish treatment resulted in mostly comparable reducing effects with that recorded with for Vydate application treatment.

Effect of Soil Moisture Regime and Fodder Radish Application on Tomato Growth Attributes

Obtained data in Tables 5 and 6 show that the ASD with flooding soil moisture regime + fodder radish treatment resulted in increasing mean values of length of shoots and roots of tomato plants at termination of the experiment (84 days). Both two studied parameters recorded mean values of 47.83 and 20.53 cm with percentage increasing of 40.68 and 79.21% over filed capacity control treatment, respectively. Under filed capacity + fodder radish treatment, the recorded mean values of shoot and root length 42.38 and 17.30 cm with percentages

Table 3. Effect of soil moisture regime with and without fodder radish green manure on numbers of *M. incognita* population (in 250 g soil), galling index and reproduction factors of nematode at the end of experimental period (12 weeks)

Treatments	Means nematode parameters		
	Nematode of J2 Population 250g soil	Galling index	Reproduction factor
Field capacity	73.75[a]	9.23 a	0.54[a]
Saturation	60.50[b]	6.19 b	0.45[b]
Flooding	51.00[c]	3.26 c	0.38[c]
F.C fodder + radish	47.50[d]	3.29 c	0.35[d]
Saturation + fodder radish	41.50[e]	2.81d	0.31[e]
Flooding + fodder radish	23.75[f]	1.84 e	0.18[f]
Vydde	18.75[g]	1.76 f	0.14[g]
L.S.D ≤ 0.05	**1.58**	**0.07**	**0.01**

Different letters in the same column mean significant difference between treatments at 0.05 level.

Table 4. Effect of soil moisture regime with and without fodder radish green manuring and Vydate on percent reduction of *M. incognita* population density, galling index and reproduction factor at the end of experimental period (12 weeks)

Treatment	Population	Galling index	Reproductive factor
Filed Capacity (FC)	-----	-----	------
Saturation (SA)	17.97	33.94	18.52
Flooding (FL)	30.85	64.68	35.19
Filed Capacity (FC) + Fodder radish (FC+FR)	35.59	64.36	35.19
Saturation + Fodder radish (SA+FR)	43.73	69.56	42.59
Flooding + Fodder radish (FL+FR)	67.80	80.07	66.67
Vydate	74.57	80.93	74.07

Table 5. Effect of soil moisture regime with and without fodder radish green manuring and Vydate on tomato crop growth combines parameters after 12 weeks of transplanting

Treatments	Shoot length (cm)	Root length (cm)	Shoot fresh weight (g)	Root fresh weight (g)	Shoot dry weight (g)	Root dry weight (g)	Fruit fresh weight(g)
Field capacity	34.00[f]	11.40[g]	161.4 [g]	85.93[f]	52.83[g]	25.38[g]	424.50[g]
Saturation	38.23[e]	12.60[f]	240.57[f]	86.73[f]	81.05[f]	27.45[f]	429.30[f]
Flooding	39.25[e]	15.53[e]	251.80[e]	88.30[e]	85.40[e]	29.30[e]	445.38[e]
F.C+fodder radish	42.38[d]	17.30[d]	263.00[d]	96.25[d]	92.33[d]	33.68[d]	459.30[d]
Saturation + fodder radish	45.25[c]	18.70[c]	275.38 [c]	99.15[c]	95.30[c]	39.05[c]	469.53[c]
Flooding + fodder radish	47.83[b]	20.53[b]	291.65 [b]	104.23[b]	99.08[b]	42.75[b]	495.98[b]
Vydde	49.10[a]	22.13[a]	296.08 [a]	114.18[a]	102.80[a]	45.30[a]	505.83[a]
L.S.D ≤0.05	1.12	0.59	1.38	1.39	0.87	0.81	2.34

Different letters in the same column mean significant difference between treatments at 0.05 in level.

Table 6. Effect of soil moisture regime with and without fodder radish green manuring and Vydate on percent increase on tomato crop parameters comparing to filed capacity as control treatment at the end of experimental period (84 days)

Treatment	Shoot length (cm)	Root length(cm)	Shoot fresh weight g/plant	Root Fresh weight g/plant	Shoot dry weight	Root dry weight
FC	------	-------	------	------	-------	-------
SA	12.44	10.53	51.16	85.93	53.42	8.16
FL	15.44	36.22	55.98	86.73	61.65	15.45
FC + FR	24.65	51.75	62.92	88.30	74.75	32.70
SA + FR	33.09	64.03	70.59	96.25	80.39	53.86
FL + FR	40.68	79.21	80.67	98.85	87.54	68.44
Vydate	44.62	94.12	83.41	104.00	94.59	78.49

FC= soil field capacity SA= saturation FL=flooding FR= fodder radish increasing of 24.65 and 51.75% over filed capacity control treatment. The mean value for Vydate treatment were 49.10 and 22.13cm with an increase of 44.62 and 94.12% in shoot and root length of tomato, respectively over filed capacity control treatment. Also, BSD with flooding soil moisture regime + fodder radish application treatment resulted in significantly increasing the mean values of both shoot and root of fresh and dry weights of tomato weights over filed capacity control treatment.

Tomato plants subjected to flooding + fodder radish treatment resulted in increase in fresh and dry weight of both shoots and roots (291.65 and 99.08 g/plant) and (104.23 and 42.75 g/plant), respectively. The percentages increase over filed capacity control treatment under such conditions were (80.67 and 87.54%) and (98.85 and 68.44%), respectively. Such increases were comparable with over all increases using Vydate application treatment which recorded (296.08, 102.80 g/plant) and (114.18, 45.30 g/plant) with a percentage increases of (83.41, 94.59%) and (104.00, 78.49%) over filed capacity control treatment, respectively. It is worth to note that the significantly lowest fresh and dry weights of both shoots and roots were recorded under filed capacity control treatment (161.40, 52.83 g/plant) and (85.93, 25.38 g/plant), respectively.

Tomato plants treated with flooding soil moisture regime combined with fodder radish application treatment performed better in soil infested with *M. incognita*. When both studied nematode and crop growth attributes were evaluated under such conditions there were a significantly decrease in studied nematode parameters accompanied with significant increase in tomato growth attributes. Nematode number, galling index and reproductive factor were significantly reduced while all studied tomato growth parameters were increased. The obtained improvement effect under such BSD treatment could be due to that both soil pH as well as aeration statues parameters (Eh and ODR) since they were lowered after 4 weeks of fodder radish decomposition period. On the hand, Flooding + fodder radish treatment resulted lowering soil mean pH value to nearly neutral (7.22) as shown in Table 2. Under such neutral conditions, glucosinolates in fodder radish brassica green manure are enzymatically hydrolyzed to the main products resulting in the production of nematicidal isothiocynates, while under acidic pH soil conditions non biocidal compound are produced **(Pattison *et al*., 2006)**.

Under high soil reducing conditions as a result of lowering both Eh and ODR values, the anaerobically fermentation products due to *clostridia* bacteria may also include produce nematicial compounds. **Stoner (1953)** reported effective root-knot nematode control on two vegetable crops planted after flooding previous rice fields for three months. Less severe root – knot nematode damage was found in Philippine vegetable cropping systems which is based on paddy rice-vegetable rotations as flooding was maintained at least for 4 months.

Brown and Morra (1997) found that increased soil water content has increased ITCs longevity in the soil and could cause increase in pest inhibition.

The concentration of ITCs produced is influenced by soil texture moisture, temperature, microbial community and pH **(Morra and Kirkegaard, 2002; Price, 1999)**.

Pattison *et al.* (2006) indicated that fodder radish (*Raphanus sativus*) has a good biofumigant activity against *Meloidogyne* spp. The GSLs present in fodder radish were 4-methylpentyl GSL ,5-hexenyl GSL, 4-Methylthiobutyl GSL, 5-Methylthiopentyl GSL and 4-methylthio-3-butenyl GSL **(Daxenbichler *et al.*, 1991; Visentin *et al.*, 1992)**.

Adding fodder radish green manure to the soil under soil moisture regime of flooding conditions decreased all studied root knot nematode (*Meloidogyne incognita*) parameters. Most likely this can be attributed to the release of isothiocynates via breakdown of glucosinolates **(Angus *et al.*, 1994; Kirkegaard and Sarwar, 1998)**.

The successful control of root knot nematode by amending soil with *Brassica* crops has been well documented. For instance, **Ibrahim *et al*. (2018)** found that soil amendment with certain Egyptian plants resulted in the control of *M. incognita* on tomato. Also, **Anita (2012)** reported the success of controlling *M. hapla* in celery, using crucifer vegetable leaf wastes.

The creation of anaerobic soil conditions via increasing soil moisture content along with covering the soil with plastic sheets during decomposition of organic matter has also been found to be an important practice for control of soil borne pathogens **(Blok *et al.*, 2000).**

Tomato plants treated with fodder radish green manure under flooding soil conditions performed well and comparable with that treated with Vydate when both nematode population and tomato plant growth parameters were evaluated. Tomato plants under flooding + fodder radish (ASD) application showed higher increase in plant length, fresh and dry shoots and roots weight compared with the field capacity + fodder radish green manure treatment which represent the ordinary bio fumigation (BF) method. Moreover, fodder radish addition under flooding soil moisture regime conditions treatment was comparable to Vydate treatment in terms of improvement of all studied tomato crop growth parameters. This increase in growth parameters may be attributed to biological, physical and chemical improvement in soil parameters in addition to the control of juvenile populations in the soil, resulting in greater root penetration in the soil which enhance good utilization of both water and nutrients by tomato plants. Also, host-parasite relationship might have been altered under such conditions in favor of the host plant thereby minimizing the nematode damage on growing plant. The efficacy of fodder radish green manure under flooding soil conditions may either be due to stimulation of some specific micro-organisms which are capable of parasitizing eggs or other developmental stages of root-knot nematodes or due to the production of substances via decomposition of fodder radish which are toxic to such pests **Pattison *et al.*, (2006**). Tomato plants treated with fodder radish green manure under flooding soil moisture regime conditions showed the best growth parameter with 40.68and 79.21% increase in shoot and root lengths, respectively Table (6) Similar increase was also detected in 80.67, 98.85 and 87.54 and 68.44 % increase for fresh and dry weights of both shoots and roots. Also, saturation soil moisture regime + fodder radish green manure treatment showed better tomato growth when compared to filed capacity with fodder radish green manure treatment (ordinary biofumigation).

The high efficacy of the fodder radish treatment under soil flooding regime in reducing nematode population parameters in tomato crop may be attributed to several factors. The first factor could be the glucosinolates content of fodder radish which are hydrolyzed in the presence of water in the soil to produce isothiocynates which are known to have nematicidal effects. Second factor could be due to increase in growth of anaerobic microorganisms stimulated by fodder radish green manure addition cause a rapid decline in oxygen concentration in the soil and consequently, redox potential (Eh) and oxygen diffusion rate (ODR) decline and development of anaerobic conditions, promote the growth of facultative and obligate anaerobic microorganisms over the aerobic microbial community **(Mowlick *et al.*, 2012)**.

Also, under such reducing conditions short-chain fatty acids (acetic, butyric and propionic acids), aldehydes, alcohols and volatile organic compounds are produced via fermentation of added organic matter. Such produced compounds are toxic and / or suppressive for several soil-borne pathogens, plant parasitic nematodes as well as weeds (**Momma and Izumi, 2006; Momma, 2008). Mowlick *et al.*, (2012)** detected such fatty acids in the ASD soil and strongly suggested that acetate, butyrate or other substance could be the products of the clostridial groups which responsible for the suppression of some soil-borne pathogens.

ASD method like most cultural control techniques will not be a "silver bullet" and will need to be integrated with different approaches such as resistant verities, crop rotation, solarization, bio control agents or augment chemical applications.

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الملخص العربي

دور النظام الرطوبى للتربة في زيادة فعالية عملية التدخين الحيوي على نيماتودا تعقد الجذور على الطماطم

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استهدفت هذه التجربة دراسة تأثير كل من النظام الرطوبى للتربة وإضافة المادة العضوية من فجل العلف على مؤشرات نيماتودا تعقد الجذور وكذلك مؤشرات نمو محصول الطماطم صنف Elisa الحساس للنيماتودا. أُجريت التجربة فى أصص بالصوبة الزراعية لدراسة تأثير النظام الرطوبى للتربة (السعة الحقلية، التشبع، الغمر) بدون إضافة المادة العضوية من فجل العلف أو مع الإضافة مقارنة بالمبيد النيماتودى Vydate. وقد أُعتبرت معاملة السعة الحقلية بدون إضافة فجل العلف (معاملة كنترول) فى أوعية بلاستيكية (أصص) حيث تم إضافة 10 كجم تربة وأُضيف المادة العضوية (فجل العلف) ثم خلطت بالتربة ثم طبقت معاملات النظام الرطوبى للتربة ثم غطيت الأوعية بالبلاستيك الشفاف 50 ميكرون واستمر ذلك لمدة 4 أسابيع خلال تلك الفترة تم قياس كل من الـ pH والـ Redox potential (Eh) ومعدل انتشار الأكسجين Oxygen diffusion rate (ODR) للتربة أسبوعياً لمدة 4 أسابيع بعدها تم إزالة الغطاء البلاستيكي وتُركت الأصص لمدة 15 يوم ثم زرعت شتلات الطماطم صنف (Elisa) بمعدل 2 شتلة لكل أصيص ثم تم إضافة المبيد الكيماوى لمعاملة الـ (Vydate). استمرت التجربة لمدة 84 يوم (12 أسبوعاً) وعند نهاية التجربة اخذت القياسات التالية: تم تقدير كل من تعداد النيماتودا ومعامل التكاثر ودليل التعقد وتم تقدير مؤشرات نمو الطماطم وهى طول النبات (مجموع خضرى ومجموع جذرى) (سم) الوزن الغض والوزن الجاف للنبات (مجموع خضرى، مجموع جذرى) (جم/نبات) الوزن الغض لمحصول الطماطم جم/نبات وكانت أهم النتائج ما يلى: 1- أوضحت النتائج أن خلال فترة تحلل المادة العضوية من فجل العلف (4 أسابيع) أن قيم كل من الجهد الأكسدة والاختزال ومعدل انتشار الأكسجين، قد انخفضت وكان أكبر معدل للانخفاض فى حالة المعاملة (لغمر + اضافة فجل العلف) مما يشير إلى أن التربة قد تحولت إلى الظروف اللاهوائية anaerobic مما يؤدى إلى سيادة المجموعات البكترية اللاهوائية القائمة بعملية تحلل تلك المادة العضوية وإنتاج الأحماض العضوية مثل حمض الخليك والبيوتريك ذات التأثير على نيماتودا تعقد الجذور. 2- أوضحت النتائج بعد 12 أسبوع من شتل نباتات الطماطم أن المعاملة (الغمر + فجل العلف) قد حققت أكبر تأثير على انخفاض أعداد النيماتودا ومعامل التكاثر ودليل التعقد مقارنة بالمعاملة (سعة حقلية فقط). 3- أوضحت النتائج أن جميع مؤشرات نمو نبات الطماطم (طول النبات) الوزن الغض والجاف للنبات وطول المجموع الخضري والجذرى والوزن الغض للثمار قد زادت زيادة معنوية مقارنة بمعاملة الكنترول مما يشير إلى إمكانية استخدام تلك الطريقة المعدلة بالتكامل مع الطرق الأخرى لمكافحة النيماتودا وذلك لتحقيق أفضل النتائج.

الكلمات الاسترشادية: النظام الرطوبى للتربة، نيماتودا تعقد الجذور، التعقيم اللاهوائى للتربة، التسميد العضوي باستخدام فجل العلف، الطماطم.

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