Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
JEZS 2019; 7(6): 993-1001

Received: xx-09-2019
Accepted: xx-10-2019

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Integrated management of *Meloidogyne graminicola* Golden & Birchfield in transplanted rice (*Oryza sativa* Linn.)

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Abstract

An experiment was carried out to find out the integrated management practice against *Meloidogyne graminicola* on transplanted rice cv. IET- 4094 (Khitish) at the Central Research Farm, Gayeshpur, BCKV, Nadia, West Bengal, India during *kharif* season of 2013 and 2014. The study revealed that soil solarization combined with main field application of carbofuran 3G (T_3), nursery + main field application of carbofuran 3G (T_6) and nursery + main field application of cartap hydrochloride 4G (T_7) recorded better growth and yield attributes of rice in comparison to the other treatments. The heading process of rice in T_3 and T_6 was enhanced by 2.7 days and 2.8 days, respectively in comparison to the untreated one. Number of galls per rice seedlings (raised in the nursery0 at transplanting was found considerably low in all the adopted nursery treatments (soil solarization with 25µm thick transparent plastic, carbofuran 3G @ 0.3g *a.i.*/m^2, *Pseudomonas fluorescens* @ 20g/m^2 along with FYM @ 50g/m^2 and cartap hydrochloride 4G @ 0.1g *a.i.*/m^2). The reduction of galls in rice seedling was varied from 74.2% to 78.7%; the maximum being 78.7% in soil solarized plot. The severity of root-knot disease measured in terms of per cent weighted nematode rating (WNR) at harvest was significantly low in T_3, T_6 and T_7. Final WNR was varied from 19.43% to 22.55% among the mentioned treatments with the least from T_3. Adoption of nursery treatment alone failed to keep the *M. graminicola* population low. Nursery treatment coupled with main field nematicide application after 45 days of transplanting succeeded to manage the nematode population. Final soil and root population of *M. graminicola* J2 was found the lowest inT_3 and was nearly followed by T_6 and T_7. Reduction of final *M. graminicola* population over control varied from 41.3% to 71.8% among the mentioned treatments with the maximum being, 71.8% from T_3. The maximum grain (2.315 t/ha) and straw yield (2.147t/ha) were noted in T_3. The net return was found maximum of Rs. 11426.00/ha in T_6. Incremental benefit cost ratio was found maximum (8.31) with nursery application of carbofuran 3G @ 0.3g *a.i.*/m^2 (T4). The return per rupee investment in treatment was estimated as Rs. 5.35 and Rs. 4.42 in T_7 and T_6, respectively. Root-knot nematode population went on increasing where the treatments did not receive any nematicidal application in the main field. Due to short life cycle, *M. graminicola* populations build up rapidly. It is recommended that, to ensure higher rice yield, *M. graminicola* populations should be maintained at low density by adopting suitable management tactics in the main field. The study suggests to adopt the nursery application of carbofuran 3G @ 0.3g *a.i.*/m^2 + main field application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT to bring down the population of *M. graminicola* for ensuring the increased productivity of rice.

Keywords: Carbofuran, cartap hydrochloride, integrated nematode management, *Meloidogyne graminicola, Pseudomans fluorescens,* soil solarization

Introduction

Rice (*Oryza sativa* L.) is a staple food for half of the world's population and contributes 43 per cent of total food grain production and 46 per cent of total cereal production in the world [1]. It ranks third after wheat and maize in terms of worldwide production. India is the world's second largest producer of rice [2]. According to the final estimate for the year 2012-13 by ministry of agriculture, Govt. of India, the production of rice was 105 million tonnes. India is not only the largest producer of cereal but largest exporter of cereal products in the world. Rice (including Basmati and non Basmati) occupies the major share in India's total cereals export with 64.40% during 2011-12 [3]. It occupies about 24 per cent of gross cropped area of the country. West Bengal ranked first among all the states of India in respect of acreage (5.44 million ha), production (15.02 million ton) and productivity (276 kg/ha) of rice in 2012-2013 [4]. Rice is vulnerable to attack by the various pests and diseases. In monetary value, annual crop loss due to plant feeding nematodes in the world is about $157 billion [5].

Paddy grown under different cultivation system is infested by various nematodes. The paddy root-gall nematode, *Meloidogyne graminicola* Golden and Birchfield, 1965, is a pest of global concern and cause havoc irrespective of the system of rice cultivation [6].

Root-knot nematode induced above ground symptoms are not readily apparent, infested plants exhibit various degrees of stunting, lack of vigour, chlorosis and incipient wilting. Formation of terminal root gall is the most characteristic symptom of root-knot nematode infestation in rice.

An avoidable yield loss of rice in India to the tune of 16-32% due to *M. graminicola* was reported [7, 8]. The population level that caused a 10% reduction in yield was estimated at 120 nematodes per 10-day old plant [9]. Losses were as high as 50% in case of severe infestations. Jain *et al*., 2007 [10] reported 10.54% annual yield loss of rice due to root knot nematodes in India. *M. graminicola* caused yield losses of 11-73% in simulations of intermittently flooded rice, whereas under simulated upland conditions, yield loss from *M. graminicola* were between 20-98% [11]. Yield losses in rice caused by *M. graminicola* ranged from 20-80% and 11-73% in upland and in intermittently flooded conditions, respectively [12].

M. graminicola is making its importance felt in almost all the rice growing areas of the world. It is also a serious problem across the rice growing areas of West Bengal [13, 14]. In view of its increasing importance in the rice based cropping sequences in the changing agricultural scenario; an investigation was undertaken to develop an integrated management practice of *M. graminicola* in transplanted rice.

2. Materials and Methods

2.1. Experimental site

The experiments were conducted in an established sick plot highly infested with *M. graminicola* at the Central Research Farm of BCKV, Gayeshpur, Nadia, West Bengal, India. The farm was geographically located at 22º58′15.08″N latitude and 88º29′49.18"E longitude with an elevation of 9.75m above mean sea level. The land was topographically referred as a medium land.

2.2. Experiment details

The experiment was carried out during *kharif* seasons of two consecutive years, 2013 and 2014 to develop an integrated management practice of *M. graminicola* on rice cv.IET-4094 (Khitish). Total seven treatments including an untreated control were replicated thrice adopting Randomized Complete Block Design. Treatments include, T1: Untreated control; T2: Soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June; T3: T_2 + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT; T4: Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.*/m^2 at sowing; T5: Soil application of *Pseudomonas fluorescens* (2×10^6 cfu/g) @ 20g/m^2along with FYM @ 50g / m^2in the nursery bed at sowing; T6: Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.*/m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DATand T7: Nursery bed treatment with cartap hydrochloride 4G @ 0.1g *a.i.*/m^2 at sowing + soil application of cartap hydrochloride 4G @ 1 kg *a.i.*/ha at 45 DAT. For soil solarisation, nursery (measuring 4m^2) soil was ploughed to a fine tilth, watered with rose-can to make the soil moist and then covered with 25µm thick transparent polythene sheet. Polythene sheet at all four sides was secured with bricks. Nursery beds were lightly watered after application of granular nematicides. Main plot was measured 5.1m × 2.5m. The rice seedlings at 30 days crop age were transplanted in conventional method at a spacing of 15cm × 10cm. The crop was fertilized with $N:P_2O_5:K_2O$ @ 80: 40 : 40 kg /ha. Nitrogenous fertilizer was applied in three equal splits. One third of the recommended dose of nitrogenous fertilizer and full dose of phosphorus and potassium were applied as basal dose; remaining amount of nitrogenous fertilizer was top dressed in two equal splits once at 20 DAT (days after transplanting) and another at 40 DAT. Crop was raised following standard recommended package of practices.

2.3. Observation

Initial population of second stage juveniles of *M. graminicola* per 200cc of soil was recorded after final layout of the experimental plots. Ten plants from each plot leaving border rows were selected randomly for recording observation. Observations were recorded on number of galls per seedling at transplanting, plant height (cm) at 15, 30, 45 and 60 DAT, number of tillers/plant at 100% heading, root length (cm) at 40 DAT and at harvest, fresh and dry weight of root (g/hill) at harvest, days to 100% heading, length of panicle (cm), thousand grain weight (g), grain and straw yield (q/ha) and root galls/hill at 40 DAT and at harvest. Root galls were worked out in 0-10 scale using pictorial chart as given by Bridge *et al.*, 2005 [15] where, 0: no galls, 1:10% root galls, 2: 20% root galls, 3: 30% root galls, 4: 40% root galls, 5: 50% root galls, 6: 60% root galls, 7: 70% root galls, 8: 80% root galls, 9: 90% root galls, 10: 100% root gall. Percent weighted nematode rating (WNR) was calculated using following formula [15].

$$\text{WNR}= \frac{\text{(Rating scale 0} \times \text{No. of roots in the rating category)} + \text{(Rating scale 1} \times \text{No. of roots in the rating category)} + \ldots\ldots + \text{(Rating scale 10} \times \text{No. of roots in the rating category)}}{\text{Total number of roots indexed} \times \text{Maximum scale used}} \times 100$$

Nematode population at maximum tillering stage and at harvest from 200cc of soil sample and 5g of root sample of each plot was recorded.

2.4. Study of nematode population

2.4.1. Sampling technique

For initial soil nematode population study, 200cc soil samples were collected from each experimental plot after making layout, while at 40 DAT and at harvest soil samples (200cc) and root sample (5g) from each plot were collected from the rhizosphere of the plant. Each composite soil sample was a representative of 3 subsamples (*i.e.* 3 cores) from each plot. Soils of the subsamples were mixed thoroughly to prepare a composite sample of 200cc.

2.4.2. Storage of samples

Collected soil and root samples were kept in the polythene bag secured with rubber band and labelled properly. Root samples were processed immediately in the laboratory for extraction of nematodes while soil samples were kept in refrigeration at 10-12 ^{0}C temperature till soil nematode extraction process was completed.

2.4.3. Processing of soil and root samples

Nematodes were extracted from 200cc of composite soil samples by Cobb's decanting sieving technique [16] followed by modified Baermann's funnel method [17]. The root samples weighing 5g were washed free of soil and dirt particles under gentle flow of tap water and cut into small pieces of 0.5-1cm by scissors. Thereafter, the roots especially galled ones were crushed gently by forceps and placed on double layer facial tissue paper resting on the aluminium wire-gauge and follow the modified Baermann's technique [17]. The tissue paper wire-gauge assembly was kept undisturbed overnight. The motile stages of vermiform plant nematodes came out from the root tissue, wriggled through the tissue paper and are stored in the water of the petriplates. Nematode suspension was then collected in a plastic container from petriplates and labelled properly.

2.4.4. Killing and fixing

The nematodes were heat killedat a temperature of 60-65 ^{0}C. Later killed nematodes were fixed at 3% formaldehyde and kept separately in the labelled container for further study.

2.4.5. Counting of nematode population:

An aliquot of 2ml thoroughly stirred suspension containing nematodes was taken for counting the nematode population. That was repeated thrice to reduce the error in counting and mean of three observations was used to find out average number of nematodes per ml of suspension. Number of nematodes per ml of suspension was then multiplied by total volume of suspension to get total number of nematodes per 200cc of soil.

2.5. Statistical analysis

Data obtained during experimentation were analysed statistically to get the analysis of variance at 5% level of probability according to Gomez and Gomez, 1984 [18]. Duncan's Multiple Range Test (DMRT) was worked out for comparison of means between treatments at 5% level of probability. Pooled analysis of two years' data was also done. Software MSTATC was used for the analysis.

3. Results and Discussion

3.1 Effect of treatments on shoot length of rice

Two years' experimentation on the management of *M. graminicola* in transplanted rice revealed significant variation in shoot length among treatments (Table 1). Shoot length of the rice crop in all the treatments were found superior over untreated check. Pooled analysis of two years data showed non-significant differences in shoot length among treatments at 15 DAT, but they were significantly better over untreated check (Table 1). Discernible differences in shoot length between treatments were observed commencing from 30 DAT till 60 DAT. Maximum shoot length of 85.48cm was observed in the treatment comprised of soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT (T_3). That was followed by the nursery bed treatment with carbofuran 3G @ 0.3g *a.i.*/m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT (T_6) where, shoot length of rice at 60 DAT was documented as 83.72cm. Final shoot length of rice in the treatment T_7 (nursery bed application with cartap hydrochloride 4G @ 0.1g *a.i.*/m^2 at sowing + soil application of cartap hydrochloride 4G @ 1 kg *a.i.*/ha at 45 DAT) was found next to T_6. Treatment, T_3 was found at par with T_6 but superior over others.

3.2 Effect of treatments on fresh and dry root weight of rice

Fresh and dry root weight of rice plants were taken at harvest. It appeared from thepooled data that fresh and dry root biomass yield of rice was maximum with nursery + main field application of carbofuran 3G i.e. T_6 and was closely followed by T_3(soil solarization + carbofuran 3G) and T_7 (nursery and main field application of cartap hydrochloride 4G); though they were statistically on par with each other but significantly superior over others including untreated check (Table 2).

3.3 Effect of treatments on root length of rice

Pooled data of two years' observation exhibited significant differences in root length of rice among treatments (Table 2). Root length of rice showed a general trend in increase from maximum tillering stage to harvest. Maximum final root length of rice (13.68cm) was recorded in soil solarization of nursery accompanied with main field soil application of carbofuran 3G at 45 DAT (T_3). The treatment comprised of nursery and main field application of carbofuran 3G (T_6) was found next to T_3 in achieving maximum root length.

3.4 Effect of treatments on number of tillers/hill and panicle length of rice

Number of tillers per hill was recorded at 100% heading of the crop while, panicle length was recorded at harvest. A notable difference in the number of effective tillers per hill was observed when compared with untreated check only (Table 3). Maximum number of effective tillers was noted with carbofuran 3G nursery application @ 0.3g *a.i.*/m^2 at sowing followed by its main field application @ 1 kg *a.i.*/ha at 45 DAT being, 12.07/ hill (T_6). Performance of T_3 and T_7 were found next to T_6 with reference to the mentioned growth attribute of rice crop. Mean panicle length of rice unveiled a discernible difference among treatments; the maximum length of panicle was recorded in T_3 being, 20.33cm (Table 3).

3.5 Effect of treatments on days to 100% heading of rice

Pooled of two seasons data on days required to reach 100% heading of rice disclosed significant differences among treatments (Table 3). On an average 86 days were required to reach 100% heading of rice as observed with T_3 and T_6. Huge infestation of root-knot nematode might have delayed heading process as noticed with untreated control plot being, 89 days.

3.6 Effect of treatments on number of galls/seedling at transplanting

Number of root galls per seedlings was recorded at the time of transplanting of rice seedlings from the nursery. All the treatments showed considerably less number of galls per seedlings as compared to the untreated check (Table 4). The least number of galls was recorded in soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days being, 0.19/seedling. Nursery application of carbofuran 3G @ 0.3g *a.i.*/m^2, *P. fluorescens* @ 20g/m^2 along with FYM @ 50g/m^2 and cartap hydrochloride 4G @ 0.1g *a.i.*/m^2 recorded 0.22, 0.23 and 0.23 galls/seedling, respectively (Table 4). All the adopted nursery treatments were found on par with regard to the number of root galls/seedling.

3.7 Effect of treatments on per cent weighted nematode rating (WNR) of rice

Per cent weighted nematode rating (WNR) due to infestation of *M. graminicola* was recorded twice during crop growth period of rice. WNR indicates the severity of root knot/gall disease caused by the root-knot nematodes.

Pooled of two years' observation revealed a lowest WNR being, 10.78% at 40 DAT in T_6 i.e. nursery + main field application of carbofuran 3G. The treatment T_7 where, WNR was marked as 10.88% also remained in close proximity with T_6.

The severity of root-knot disease in terms of per cent WNR at harvest exhibited significant statistical difference between treatments adopted for managing *M. graminicola* in transplanted rice crop. Three treatments *viz.*, T_3, T_6 and T_7had significantly low WNR at harvest in comparison to others. The per cent WNR at harvest varied from 19.43 to 22.55 among mentioned treatments. Untreated control plot recorded maximum WNR being, 80.68%. In contrast, least WNR at harvest was enlisted with soil solarization of nursery accompanied with main field soil application of carbofuran 3G at 45 DAT (T_3) being, 19.43% (Table 4).

3.8 Effect of treatments on population of *M. graminicola* in rice

During *kharif* 2013, no significant difference in initial population of *M. graminicola* per 200cc of soil was found in the main field (Table 5). In 2014, the initial nematode population varied among treatments. There had been a general increase in nematode population recorded at 40DAT from that of initial nematode population in all the treatments. Adoption of nursery treatment alone failed to keep the *M. graminicola* population low as evidenced by the pooled result of soil and root population of J2 recorded at 40 DAT; though the treatments advocated in the nursery like soil solarization and use of cartap hydrochloride 4G @ 0.1 g *a.i.*/m^2 kept the nematode population below threshold in the 2nd year of study. Treatments received nematicidal application in the main field after 45 days of transplanting succeeded to manage the root-knot nematode population in the rice field as confirmed by the low final root and soil population. In contrast, root-knot nematode population went on increasing where the treatments did not receive any nematicidal application in the main field. Final population of *M. graminicola* J2/200cc of soil and 5g of root was found lowest insoil solarization of nursery accompanied with main field soil application of carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT (T_3) being, 227.0 (pooled). That was nearly followed by nursery + main field soil application of carbofuran 3G at 45 DAT (T_6) and nursery + main field soil application of cartaphydrocholride 4G at 45 DAT (T_7) where final population of *M. graminicola* was 228.5 and 247.1/ 200cc of soil and 5g of root, respectively (pooled). Reduction in final population of *M. graminicola* over control varied from 41.3% to 71.8% among the mentioned treatments with the maximum being 71.8% from T_3 (Table 5).

3.9 Effect of treatments on 1000 grain weight of rice

None of the treatments had significant difference in thousand grain weight of rice (Table 6). Maximum weight (17.85g) of thousand grains was noted with soil solarization of nursery accompanied with main field soil application of carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT. That was followed by T_6 and T_7wherethousand grain weight was 17.80g and 17.63g, respectively.

3.10 Effect of treatments on grain yield of rice

All the treatments had contribution towards enhancement of grain yield of rice (Table 6). Except T_2 (soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June) all the treatments showed significant variation in grain yield of rice. Pooled data of two years experimentation unveiled significant performance of T_3, T_6 and T_7 to have better grain production as compared to the others. Though the mentioned treatments were statistically at par but the maximum grain yield (2.315 t/ha) was noted in T_3 (soil solarization of nursery accompanied with main field soil application of carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT). The per cent increase in grain yield among treatments varied from 2.3 to 87.0.

3.11 Effect of treatments on straw yield of rice

Data of two years experimentation revealed better straw production in T_3, T_6 and T_7 (Table 6). The mentioned treatments were statistically at par with each other. Maximum straw yield of 2.147 t/ha were recorded in T_3. The increase in straw yield among treatments varied from 2.1% to 69.7%, the maximum was estimated in T_3.

3.12 Economics of treatments used to manage *M. graminicola* in transplanted rice

All the treatments except soil solarization of nursery (T_2) were found economic to manage *M. graminicola* infestation in rice cv. IET-4094 (Khitish) under transplanted condition. The net return was found maximum of Rs. 11426.00/ha in T_6 i.e. nursery application carbofuran 3G @ 0.3g *a.i.* /m^2 + main field application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT (Table 7). Incremental benefit cost ratio was found maximum (8.31) in nursery application of carbofuran 3G @ 0.3g *a.i.* /m^2 (T4). That was followed by T_7 (nursery application cartap hydrochloride 4G @ 0.1g *a.i.* /m^2 + main field application of cartap hydrochloride 4G @ 1 kg *a.i.*/ha at 45 DAT) and T_6 where, return per rupee investment in treatment was estimated as Rs. 5.35 and Rs. 4.42, respectively.

Two years' experimentation on the management of *M. graminicola* in transplanted rice revealed that soil solarization combined with main field application of carbofuran 3G (T_3), nursery + main field application of carbofuran 3G (T_6) and nursery + main field application of cartap hydrochloride 4G (T_7) recorded better growth and yield attributes of rice in comparison to rest of the treatments. Carbofuran was found most effective in controlling root-knot nematode population and improving growth and yield attributes of sunflower and tomato [19, 20].

Considerably, less number of galls per rice seedlings (raised in the nursery) was recorded at the time of transplanting in all the adopted nursery treatments (soil solarization with transparent polythene sheet for 21 days, carbofuran 3G @ 0.3g *a.i.*/m^2, *P. fluorescens* @ 20g/m^{2}along with FYM @ 50g/m^2 and cartap hydrochloride 4G @ 0.1g *a.i.*/m^2). There was no notable variation among treatments in the number of root galls/seedling at transplanting but the least number of galls was recorded with soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days.

Solarization traps solar radiation with transparent plastic films placed on the soil to maximize conversion and conservation of heat [21]. Solarization generally holds promise for controlling root-knot nematodes [22, 23]. Soil solarization by wrapping the beds with LDPE clear plastic film of 400 gauge for two months alone or in combinations with carbofuran @ 1.5 kg/ha were found economical and effective for the management of *M. incognita, M. javanica, Tylenchorhynchus vulgaris* and *R. reniformis*. These treatments gave healthy transplants with drastic reduction (26 to 99%) in root-knot disease and nematode population over control [24]. In the present experiment, rice seedlings raised in the plots received soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days were not entirely free from root knot nematode infestation. Chellemi, 2002 [25] reported that some of the eggs of root-knot nematode may resist heat. Further, there is a dependence of soil temperatures on both the state of the soil and the climatic conditions during the solarization period. The soil can be re-infested after solarization as nematodes may migrate from deeper layers due to adoption deep tillage practices in rice nursery. These are possibly the reason of not getting 100% gall free seedlings from solarized plots. Jain and Gupta, 1992 [26] recorded 73.3% reduction in the *M. javanica* population in the summer ploughing treatment and 78.5% reduction in the ploughing, followed by covering with transparent polythene sheet for 2 weeks treatment. In a report in 1997, they have stated that maximum reduction of the nematode population was in nursery beds covered with clear polyethylene mulching. This was followed by mulching with black polyethylene sheets which was on par with carbofuran treatment. The reduction of galls in rice seedling at transplanting varied from 74.2% to 78.7% among treatments when compared with control; the maximum being, 78.7% in soil solarized plot (Table 4). This observation remains in parity with the findings made by the earlier workers [27-29].

The severity of root-knot disease measured in terms of per cent WNR at harvest exhibited significant statistical differences between treatments adopted for managing *M. graminicola* in transplanted rice crop. Based on pooled data, three treatments *viz*., soil solarization combined with main field application of carbofuran 3G, nursery + main field application of carbofuran 3G and nursery + main field application of cartap hydrochloride 4G secured significantly low WNR recorded at harvest. Final WNR varied from 19.43% to 22.55% among mentioned treatments with the least from soil solarization combined with main field application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT. Hussain *et al*., 2005 [19] found carbofuran, the most effective in controlling the root-knot nematodes with simultaneous reductions in root-gall formation and egg masses of sunflower. Sharma and Khan, 2009 [27] showed carbofuran @ 33 kg/ha provided 34.6% reduction of root-gall in tomato caused by *M. incognita.* Nanjegowda *et al.*, 2010 [20] observed that carbofuran significantly reduced the nematode population and increased the plant growth compared to control.

There had been a general increase in *M. graminicola* population recorded at 40DAT from that of initial nematode population in all the treatments. Adoption of nursery treatment alone failed to keep the *M. graminicola* population low as evidenced by the pooled result of soil and root population of J2 recorded at 40DAT. Treatments received nursery treatment coupled with nematicidal application in the main field after 45 days of transplanting succeeded to manage the root-knot nematode population in the rice field as confirmed by the low final root and soil population. In contrast, root-knot nematode population went on increasing where the treatments did not receive any nematicidal application in the main field. Soriano and Reversat, 2000[34] stated that carbofuran improved yield of the first rice crop but did not affect the second rice crop. Due to short life cycle, *M. graminicola* populations build up rapidly. It is recommended that, to ensure higher rice yields, *M. graminicola* populations should be maintained at low density by adopting suitable management strategy. Final population of *M. graminicola* J2/200cc of soil and 5g of root was found lowest against soil solarization of nursery accompanied with main field soil application of carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT. That was nearly followed by nursery + main field soil application of carbofuran 3G at 45 DAT and nursery + main field soil application of cartap hydrocholride 4G at 45 DAT Reduction in final population of *M. graminicola* over control varied from 41.3% to 71.8% among treatments with the maximum being 71.8% from soil solarization of nursery + carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT. Khan *et al*., 2012 [29] conducted a study on rice cv. Sugandh-5 and reported that carbofuran and phorate through root-dip plus single soil application provided greatest suppression in galling (16-20%), egg mass production (18-22%) and soil population (27.5−58.2%) of *M. graminicola*, and subsequently increased all the plant growth variables by 9-19%. Present observations affirm the findings of researchers [19, 20, 27, 29, 30, 31]. Soil application of *P. fluorescens* (2×10^6cfu/g) @ 20g/m^2along with FYM @ 50g/m^2 in the nursery bed at sowing did not give any satisfactory result with regards to the reduction of nematode population and enhancement of growth and yield attributing features of rice crop. *P. fluorescens* as seed dressing and soil incorporation significantly lowered the root penetration and rhizospheric populations of *M. graminicola* with simultaneous increase in rice yield by 20.6–26.9% [32]. In papaya, application of *P. fluorescens* or *T. harzianum* in the nursery could not effectively manage the root-knot nematode infestation. Root-gall formation was low when the two bio-agents were applied together in the nursery bed. Root colonization by either of the bio-agent was not affected when used together [33].

Pooled data of two years experimentation unveiled significant performance of T_3, T_6 and T_7 to have better grain and straw production as compared to the others. Though the mentioned treatments were statistically at par but the maximum grain and straw yield (2.315 t/ha and 2.147t/ha) was noted against T_3 (soil solarization of nursery accompanied with main field soil application of carbofuran 3G @ 1kg *a.i.*/ha at 45 DAT). The increase in grain and straw yield in T_3 was 87.0% and 69.7%, respectively. An improvement of rice yield by 30-80% due to management of *M. graminicola* in carbofuran with one or two consecutive crops of cowpea or seasons of fallow has been reported by Soriano and Reversat, 2003 [34].

All the treatments except soil solarization of nursery (T_2) were found economic to manage *M. graminicola* infestation in rice cv. IET-4094 (Khitish) under transplanted condition. The net return was found maximum of Rs. 11426.00/ha in nursery application carbofuran 3G @ 0.3g *a.i.* /m^2 + main field application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT. Incremental benefit cost ratio was found maximum (8.31) with nursery application of carbofuran 3G @ 0.3g *a.i.* /m^2 (T4). That was followed by T_7 and T_6 where, return per rupee investment in treatment was estimated as Rs. 5.35 and Rs.

4.42, respectively. The reason behind high monetary return from nursery application carbofuran 3G was low application cost and low price of chemical besides increased yield obtained as a result of reduction of nematode infestation.

Table 1: Effect of treatments on shoot length of rice (pooled)

Treatments	Shoot length (cm)			
	15 DAT	30 DAT	45 DAT	60 DAT
T_1 (Control)	26.43 b	44.75 c	61.70 c	74.18 d
T_2	30.17 a	48.80 bc	69.37 b	78.52 cd
T_3	31.85 a	63.67 a	79.83 a	85.48 a
T_4	30.10 a	52.92 b	71.77 b	80.50 bc
T_5	30.60 a	53.72 b	72.45 b	80.82 bc
T_6	31.37 a	54.98 b	74.45 ab	83.72 ab
T_7	29.33 a	52.72 b	70.95 b	80.70 bc
S. Em. (±)	0.84	1.93	2.06	1.50
LSD (0.05)	NS	5.64	6.03	4.39

Note: Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability.

Table 2: Effect of treatments on fresh and dry root weight and root length of rice (pooled)

Treatments		Fresh root weight (g/hill)	Dry root weight (g/hill)	Root length (cm)	
				At 40 DAT	At harvest
T_1	Untreated control	4.30 c	0.78 b	10.46 c	11.73 b
T_2	Soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June	4.48 bc	0.86 b	10.76 bc	12.36 ab
T_3	T_2 + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	5.86 a	1.20 a	12.40 a	13.68 a
T_4	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing	4.62 bc	0.88 b	11.66 abc	12.94 ab
T_5	Soil application of *P. fluorescens* (2×10^6cfu/g) @ 20g/m^{2}along with FYM @ 50g/m^2 in the nursery bed at sowing	4.86 bc	0.89 b	11.58 abc	12.72 ab
T_6	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	5.94 a	1.28 a	12.54 a	13.40 a
T_7	Nursery bed treatment with cartap hydrochloride 4G @ 0.1g *a.i.* /m^2 at sowing + soil application of cartap hydrochloride 4G@ 1 kg *a.i.*/ha at 45 DAT	5.39 ab	1.13 a	11.98 ab	13.10 ab
S. Em. (±)		0.30	0.06	0.41	0.49
LSD (0.05)		0.88	0.19	1.20	1.45

Note: Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability.

Table 3: Effect of treatments on number of tillers/hill, panicle length and days to 100% heading of rice (pooled)

Treatments		Number of tillers / hill at 100% heading	Panicle length (cm)	Days to 100% heading
T_1	Untreated control	9.87 b	18.29 b	89.00 a
T_2	Soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June	11.20 a	18.93 ab	87.50 ab
T_3	T_2 + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	11.98 a	20.33 a	86.33 b
T_4	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing	11.50 a	19.65 ab	87.67 ab
T_5	Soil application of *P. fluorescens* (2×10^6cfu/g) @ 20g/m^{2}along with FYM @ 50g/m^2 in the nursery bed at sowing	11.25 a	19.00 ab	88.33 ab
T_6	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	12.07 a	20.27 a	86.17 b
T_7	Nursery bed treatment with cartap hydrochloride 4G @ 0.1g *a.i.* /m^2 at sowing + soil application of cartap hydrochloride 4G@ 1 kg *a.i.*/ha at 45 DAT	11.52 a	19.75 ab	88.50 ab
S. Em. (±)		0.27	0.51	0.80
LSD (0.05)		0.80	1.51	2.34

Note: * Based on pooled data, Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability. Nursery population of M. graminicola was 228 J2/200cc of soil

Table 4: Effect of treatments on number of galls/seedling at transplanting and% WNR of rice (pooled)

Treatments		Number of galls/seedling at transplanting	% reduction in gall over control*	WNR at 40 DAT (%)	WNR at harvest (%)
T_1	Untreated control	0.89 ^{a}	--	19.40 ^{a}	80.68 ^{a}
T_2	Soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June	0.19 ^{b}	78.7	11.55 ^{b}	63.33 ^{b}
T_3	T_2 + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	0.19 ^{b}	78.7	12.45 ^{b}	19.43 ^{d}
T_4	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing	0.22 ^{b}	75.3	12.23 ^{b}	59.77 ^{b}
T_5	Soil application of *P. fluorescens* (2×10^{6}cfu/g) @ 20g/m^{2}along with FYM @ 50g/m^2 in the nursery bed at sowing	0.23 ^{b}	74.2	12.88 ^{b}	48.93 ^{c}
T_6	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	0.22 ^{b}	75.3	10.78 ^{b}	19.73 ^{d}
T_7	Nursery bed treatment with cartap hydrochloride 4G @ 0.1g *a.i.* /m^2 at sowing + soil application of cartap hydrochloride 4G@ 1 kg *a.i.*/ha at 45 DAT	0.23 ^{b}	74.2	10.88 ^{b}	22.55 ^{d}
SEm(±)		0.04	--	0.98	2.96
LSD (0.05)		0.13	--	2.86	8.66

Note: * Based on pooled data, Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability. Nursery population of M. graminicola was 228 J2/200cc of soil

Table 5: Effect of treatments on population of *M. graminicola* in rice during *kharif*, 2013 and 2014

Treatments	INP (J2/ 200cc of soil) *			Population of *M. graminicola*J2/200cc soil + 5g of root*						% reduction of final population *M. graminicola* over control**
				At 40DAT			At harvest			
	2013	2014	Pooled	2013	2014	Pooled	2013	2014	Pooled	
T_1 (Control)	14.60 ^{a} (212.7)	16.53 ^{a} (272.7)	15.57 ^{a} (242.7)	19.33 ^{a} (398.2)	17.53 ^{a} (307.50)	18.73 ^{a} (352.8)	31.44 ^{a} (990.3)	24.93 ^{a} (622.3)	28.18 ^{a} (806.3)	-
T_2	13.93 ^{a} (194.7)	12.80 ^{d} (163.0)	13.37 ^{c} (178.8)	16.47 ^{b} (270.8)	13.73 ^{c} (189.17)	15.10 ^{bc} (230.0)	22.87 ^{b} (522.3)	20.60 ^{b} (424.7)	21.73 ^{b} (473.5)	41.3
T_3	14.40 ^{a} (201.0)	13.23 ^{cd} (174.7)	13.82 ^{bc} (187.8)	15.23 ^{b} (231.3)	13.73 ^{c} (189.00)	14.48 ^{c} (210.2)	14.30 ^{c} (205.3)	15.80 ^{d} (248.7)	15.05 ^{c} (227.0)	71.8
T_4	14.47 ^{a} (209.2)	13.67 ^{cd} (187.0)	14.07 ^{bc} (198.1)	15.83 ^{b} (254.7)	14.60 ^{c} (212.67)	15.22 ^{bc} (233.7)	22.00 ^{b} (483.0)	19.07 ^{c} (361.7)	20.53 ^{b} (422.3)	47.6
T_5	14.20 ^{a} (202.0)	15.13 ^{b} (229.3)	14.67 ^{ab} (215.7)	16.40 ^{b} (268.7)	15.80 ^{b} (248.67)	16.70 ^{b} (258.7)	22.53 ^{b} (510.3)	19.60 ^{bc} (382.7)	21.07 ^{b} (446.5)	44.6
T_6	14.47 ^{a} (209.2)	14.33 ^{bc} (205.5)	14.40 ^{bc} (207.3)	14.97 ^{b} (223.3)	14.77 ^{bc} (217.33)	14.87 ^{c} (220.3)	14.60 ^{c} (213.0)	15.63 ^{d} (244.0)	15.12 ^{c} (228.5)	71.7
T_7	13.80 ^{a} (191.0)	13.53 ^{cd} (282.3)	13.67 ^{bc} (186.7)	15.77 ^{b} (249.0)	13.83 ^{c} (190.33)	14.80 ^{c} (219.7)	15.73 ^{c} (250.7)	15.60 ^{d} (243.0)	15.67 ^{c} (247.1)	69.4
S. Em. (±)	0.57	0.33	0.33	0.68	0.34	0.38	0.83	0.38	0.45	-
LSD (0.05)	NS	1.03	0.97	2.12	1.05	1.12	2.57	1.16	1.34	-

Note:* $\sqrt{(x+0.5)}$ transformed values, Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability, Figures in parentheses indicate original values, **based on pooled nematode population data

Table 6: Effect of treatments on 1000 grain weight, grain and straw yield of rice (pooled)

Treatments		1000 grain weight (g)	Grain yield (t/ha)	% increase in grain yield over control*	Straw yield (t/ha)	% increase in straw yield over control*
T_1	Untreated control	17.00 ^{a}	1.238 ^{c}	--	1.265e	--
T_2	Soil solarization of nursery bed with 25µm thick transparent polythene sheet for 21 days during May-June	17.20 ^{a}	1.266 ^{c}	2.3	1.291e	2.1
T_3	T_2 + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	17.85 ^{a}	2.315 ^{a}	87.0	2.147a	69.7
T_4	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing	17.40 ^{a}	1.852 ^{b}	49.6	1.782cd	40.9
T_5	Soil application of *P.fluorescens* (2×10^{6}cfu/g) @ 20g/m^{2}along with FYM @ 50g/m^2 in the nursery bed at sowing	17.35 ^{a}	1.780 ^{b}	43.8	1.603d	26.7
T_6	Nursery bed treatment with carbofuran 3G @ 0.3g *a.i.* /m^2 at sowing + soil application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT	17.80 ^{a}	2.293 ^{a}	85.2	2.107ab	66.6
T_7	Nursery bed treatment with cartap hydrochloride 4G @ 0.1g *a.i.* /m^2 at sowing + soil application of cartap hydrochloride 4G@ 1 kg *a.i.*/ha at 45 DAT	17.63 ^{a}	2.123 ^{a}	71.5	1.905bc	50.6
SEm(±)		0.74	0.07	--	0.07	--
LSD (0.05)		NS	0.22	--	0.22	--

Note: * Based on pooled grain or straw yield data, Data marked by common letters in a column are not statistically significant according to DMRT at 5% level of probability.

Table 7: Economics of treatments used to manage *M. graminicola* in rice

Treatments	*Gain in grain yield over control (q/ha)	Value of additional yield (Rs. /ha)	Total inputs /ha	Cost of treatment (Rs. /ha)			Net gain (Rs./ha)	Benefit: Cost
				Chemical /Inputs	Labour	Total		
T_2	0.28	392.00	1000 m^2	4300.00	167.00	4467.00	-4075.00	0.09
T_3	10.77	15078.00	1000 m^2+ 33kg	6610.00	417.50	7027.50	8050.50	2.15
T_4	6.14	8596.00	10kg	700.00	334.00	1034.00	7562.00	8.31
T_5	5.42	7588.00	20kg + 50kg	3800.00	83.50	3883.50	3704.50	1.95
T_6	10.55	14770.00	43kg	3010.00	334.00	3344.00	11426.00	4.42
T_7	8.85	12390.00	27.5kg	1980	334.00	2314.00	10076.00	5.35

Note: * Based on mean grain yield of two years, cost of labour Rs. 167/- per man-day, price of rice grain Rs. 1400/- per q

4. Conclusion

Root-knot nematode population went on increasing where the treatments did not receive any nematicidal application in the main field. Due to short life cycle, *M. graminicola* populations build up rapidly. It is recommended that, to ensure higher rice yields, *M. graminicola* populations should be maintained at low density by adopting suitable management tactics in the main field. The study suggests to adopt the nursery application of carbofuran 3G @ 0.3g *a.i.*/m^2 + main field application of carbofuran 3G @ 1 kg *a.i.*/ha at 45 DAT to bring down the population of *M. graminicola* for ensuring the increased productivity of rice.

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