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RESIDUAL EFFECTS OF NEMATODE CONTROL IN RICE FIELDS INFESTED WITH *Hirschmanniella mucronata* AND *H. oryzae*

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Residual effects of carbofuran treatments and cropping of *Sesbania rostrata* on rice root nematode population and rice yield were studied in two paddy fields infested with *Hirschmanniella mucronata* or *H. oryzae*. In both fields, a crop of *S. rostrata* reduced the nematode population for two successive rice crops and increased yields. In the *H. oryzae* infested field, a carbofuran treatment reduced the nematode population for two successive rice crops and increased the yield of three rice crops. The yield of the second rice crop grown after a cropping of *S. rostrata* in both fields and the yield of the third rice crop grown after a carbofuran treatment were correlated with the nematode population observed after the previous rice crop. The increase in rice yield, therefore, could be attributed not only to the fertilizer effect brought about by growing of *S. rostrata* or green manure application but also to the control of the rice root nematode.

INTRODUCTION

The rice root nematodes, *Hirschmanniella* spp., infest most of the flooded rice fields in subtropical and tropical areas, especially in Southeast Asia (Bridge et al., 1990; Cuc and Prot, 1992; Prot et al., 1994). Because flooded rice agrosystems contribute 95% of the total rice production in Southeast Asia, rice root nematodes are the nematodes having the greatest potential economic impact in rice (Prot, 1993). They are pathogenic to irrigated rice (Mathur and Prasad, 1972; Fortuner, 1974, 1977; Babatola and Bridge, 1979) and usually their control by soil nematicide treatments or crop rotations results in significant yield increase (Taylor, 1969; Ichinohe, 1972; Ahmad et al., 1984; Prasad et al., 1986; Aung and Prot, 1990; Prot et al., 1992). However, nematode control may have side effects on other pests, soil microfauna, soil microflora, and mineral nutrient availability. Moreover, because the yield is not always correlated with the nematode population density after control of the nematodes, there are suggestions that the increase in yield observed does not reflect a yield reduction caused by these parasites (Cadet and Quénéhervé, 1982; Ichinohe, 1988).

Because of the potential economic impact of rice root nematodes, it is important to determine if they can reduce the yield of flooded rice under field conditions. The experiments reported here were designed to avoid a direct effect of nematode control on the test crop. The effect of nematode control measures on rice yield and rice root nematode populations and their relationships were studied on the second and third crops following nematode control.

MATERIALS AND METHODS

Two experiments were conducted on two different sites. The first experiment was conducted on the experimental farm of the International Rice Research Institute (IRRI) in a field infested with a pure population of *Hirschmanniella mucronata.* The second experiment was conducted in a field infested with *Hirschmanniella oryzae* alone on the experimental farm of the University of Southern Mindanao (USM), Philippines. In both experiments, nematodes were extracted from 200 cm^3 soil samples with a combination of sieving and modified Baermann funnel methods (Hooper, 1986) and from 3 g subsamples of roots by chopping roots into pieces 5-10 mm long and then placing them in a mistifier for 5 days (Seinhorst, 1950).

Residual Effect in *Hirschmanniella mucronata* Infested Field

The experiment was a continuation of a previously reported study (Prot et al., 1992). In the previous study, the population of *H. mucronata* had been controlled by growing *Sesbania rostrata* and different nitrogen applications and incorporations of *S. rostrata* were combined with the nematode control. The different treatments previously applied were as follows: two continuous rice crops (T1); nitrogen (60 kg/ha) in the form of ammonium sulfate broadcasted at transplanting of the second rice crop (T2); nitrogen (60 kg/ha) applied twice, at transplanting and maximum tillering of the second rice crop (T3); shoots of *S. rostrata* (10 t/ha) incorporated as green manure between the first and the second rice crop (T4); removal of shoots and roots of *S. rostrata* following its growth as first crop (T5); removal of shoots but not roots of *S. rostrata* following its growth as first crop (T6); *S. rostrata* plants uprooted and then shoots but not roots incorporated into the soil (T7); and roots and shoots of *S. rostrata* incorporated into the soil after its cultivation as first crop (T8).

Individual plot area was 20 m^2 and treatments were arranged in a randomized complete block design with five replications. After this experiment, the field was left fallow for five months and then soil samples (four per plot) were collected to estimate the population density of nematodes present in each plot. An irrigated rice crop (cv IR58) was then grown in the field. Fertilizer was not applied to the crop. At maturity of the crop, the yield was determined in each plot on 4 m^2 which did not present any damage caused by pests or diseases. Soil and root samples (four per plot) were also collected to estimate the final nematode population. Data were analyzed by ANOVA, means were separated by Duncan's multiple range test and the correlation between the yield of the rice crop and the initial soil nematode population density was tested.

Residual Effect in *Hirschmanniella oryzae* Infested Field

Eight treatments were applied: four successive rice crops (T1); four successive rice crops with incorporation into the soil of 10 t/ha of *S. rostrata* shoots between the first and the second rice crops (T2); a crop of *S. rostrata* followed by the removal of its shoots and roots and three successive rice crops (T3); a crop of *S. rostrata* followed by the removal of its roots, incorporation of its shoots (10 t/ha) and three successive rice crops (T4); a carbofuran treatment (4.5 kg ai/ha) followed by a sequence identical to T1 to T4, respectively (T5 to T8). Individual plot area was 20 m^2 (4m x 5m). Treatments were arranged in randomized complete block design with six replications. IR58 was grown for the first two cropping seasons and IR72 for the last two. Nitrogen was applied to each crop at a rate of 90 kg/ha in three equal splits at transplanting, maximum tillering and panicle initiation stages. The initial nematode population was estimated by collecting soil samples (four samples per plot) 2 days after the application of carbofuran. Thereafter, nematode population was estimated at harvest of each successive crop by collecting four soil and root samples per plot. Yields of the successive rice crops were estimated on 4 m^2 with no pest or disease damage. Data were analyzed by ANOVA, means were separated by Duncan's multiple range test and the correlation between the yield of the third rice crop and the root nematode population density observed at harvest of the second rice crop was tested.

RESULTS AND DISCUSSION

Five months after the completion of the previous experiment in *H. mucronata* infested field, the soil population density of the nematode was still less in plots where *S. rostrata* had been grown before a rice crop than in plots continuously planted to rice (Table 1). Moreover, the final soil and root population densities of *H. mucronata* observed on the rice crops grown later remained lower in plots where *S. rostrata* had been grown or incorporated as green manure into the soil than in plots planted continuously to rice without green manure incorporation.

The yield of the new crop was higher ($p < 0.05$) in the plots where *S. rostrata* had been grown or incorporated into the soil than in control plots where no treatment had been previously applied. The yield was also correlated ($p < 0.001$) with the initial soil population density of *H. mucronata* and 57% of the variation of the yield could be explained by the variation of the nematode population (Fig. 1). The incorporation of *S. rostrata* had a residual effect during the second rice crop on both nematode population and yield when the nematode had not been previously controlled.

At maturity of the successive crops grown in *H. oryzae* infested field, the nematode was mostly observed in the roots. Only a few nematodes were observed in the soil, hence, the soil

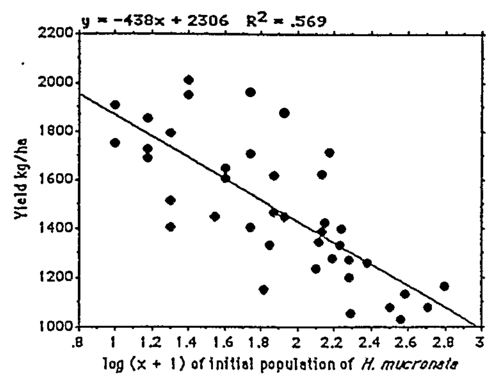

Fig. 1. Linear regression observed between rice yield and the number of *Hirschmanniella mucronata* present in the soil at planting time.

populations observed at maturity stage of the different crops are not reported. After the carbofuran treatment the number of *H. oryzae* detected in the soil was lower in treated than in untreated plots (Table 2). At maturity of the first crop, the number of nematodes observed in the roots was lesser in *S. rostrata* and in rice plants

Table 1. Initial soil (Pi-s), final soil (Pf-s) and root (Pf-r) population densities of Hirschmanniella mucronata *and yield observed on a rice crop grown in field plots which have previously received different treatments.*

Treatments Previously Applied[a]			Population Density of *Hirschmanniella mucronata*			
1st crop	2nd crop	Fertilizer or crop residue	Pi-s /dm³ of soil	Pf-s /dm³ of soil	Pf-r /3g of roots	Rice yield kg/ha
T1 R	R	-	390 a[b]	352 a	40 a	1140 c
T2 R	R	F	155 bc	331 a	28 b	1342 bc
T3 R	R	2F	212 b	235 a	33 ab	1258 bc
T4 R	R	+S	123 b-d	108 b	18 c	1470 ab
T5 S	R	-S(total)	64 cd	42 b	12 cd	1531 ab
T6 S	R	+Sr	25 d	33 b	9 d	1728 a
T7 S	R	+Ss	37 d	23 d	13 cd	1660 a
T8 S	R	+S(total)	26 d	57 b	12 cd	1730 a

[a] R = rice; S = *S. rostrata*; F = one application of fertilizer; 2F = two application of fertilizer; +S = incorporation of shoots of *S. rostrata*; -S(total) = removal of roots and shoots of *S. rostrata* after first crop; +Sr = incorporation of *S. rostrata* roots after removal of shoots; +Ss = incorporation of *S. rostrata* shoots after roots were removed; +S(total) = incorporation of roots and shoots of *S. rostrata* after first crop.

[b] Values are means of five replicates. Means in each column followed by the same letter do not differ at $\underline{P} < 0.05$ according to Duncan's multiple range test.

grown in carbofuran-treated soil than in roots of rice plants grown in untreated soil. At maturity of the second crop, the nematode counts from rice grown following the cropping of *S. rostrata* or in plots previously treated with carbofuran remained less than those observed in rice grown in plots continuously planted to rice without preliminary nematode control. Moreover, the root population density of *H. oryzae* was lower in plots where *S. rostrata* was incorporated into the soil between the first two rice crops than in plots where rice was grown successively without green manure application. At maturity of the third crop, the number of nematodes observed in the rice roots from plots where nematode control had been previously applied were not significantly different from those observed in the untreated plots. At maturity of the fourth crop of the different cropping sequence, no significant difference was observed in root populations of *H. oryzae* for all plots.

The yield of the first rice crop was significantly higher in carbofuran-treated plots than in untreated plots (Table 3). During the second cropping, the rice yield was higher in plots where *S. rostrata* had been incorporated as green manure, in plots where *S. rostrata* had been grown, and in plots which were previously treated with carbofuran than in untreated plots. During the third cropping, rice yields were higher in plots that had been previously treated with carbofuran and where *S. rostrata* had been grown than in plots where nematode had not been controlled. During the fourth cropping no significant difference in yield was observed among treatments. The rice yield obtained during the third cropping was negatively correlated ($p > 0.001$) with the root population of *H. oryzae* observed at maturity of the second crop (Fig. 2). However, the variation of the nematode population accounted for only 21% of the yield variation. The incorporation of *S. rostrata* as green manure resulted in yield increase only for the first rice crop that followed its incorporation and when *H. oryzae* had not been previously controlled. This incorporation also resulted in a decrease of the nematode population density as in the other field and as previously observed (Prot et al., 1992). The cropping of *S. rostrata* was more efficient in controlling the nematode than its incorporation alone and resulted in a yield increase for the two rice crops which followed. These observations suggest that the yield increase observed on rice crops following the cropping of *S. rostrata* results not only from an increase in nitrogen availability but also from the decrease of the nematode population density.

The increase in yield observed after a nematode control measure has been applied may result from the decrease in nematode population density and/or from side effects of the control method. Two nematode control methods were used in this study: a cropping of *S. rostrata* which is a trap plant (Germani et al., 1983; Pariselle 1987; Hendro et al., 1992), and a carbofuran treatment of the soil. The cropping and the incorporation of *S. rostrata* can modify the mineral nutrient availability by increasing the nitro-

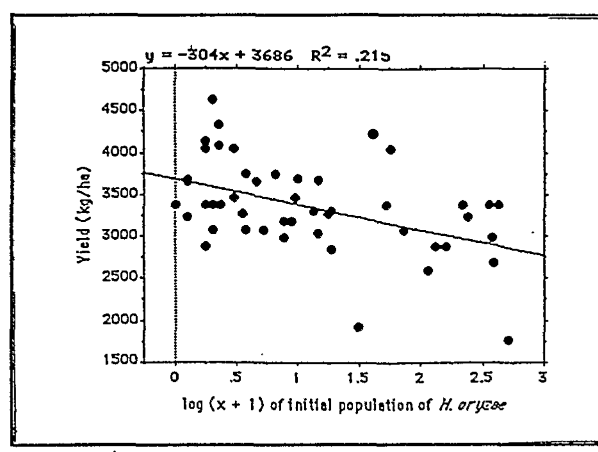

Fig. 2. Linear regression observed between rice yield and the number of *Hirschmanniella oryzae* observed in the roots at maturity of the preceding rice crop.

Table 2. Initial soil population (Pi), and final root population (Pf) of Hirschmanniella oryzae *yield observed in different cropping sequences in an experiment conducted at the University of Southern Mindanao, Philippines.*

Cropping Sequence	Pi, Number of Nematodes/200 cm³ of soil	*Pf, Number of Nematodes /3g of roots*			
		1st crop	2nd crop	3rd crop	4th crop
T1: R-R-R-R[a]	155 a[b]	215 a	341 a	105 b	258 a
T2: R-Si-R-R-R	142 a	266 a	162 b	163 a	256 a
T3: S-R-R-R	129 a	1 b	17 c	105 b	252 a
T4: S-Si-R-R-R	136 a	0 b	13 c	58 b-d	184 a
T5: C-R-R-R-R	25 b	1 b	8 c	94 bc	297 a
T6: C-R-Si-R-R-R	25 b	0 b	9 c	37 cd	113 a
T7: C-S-R-R-R	31 b	1 b	4 c	29 d	167 a
T8: C-S-Si-R-R-R	20 b	0 b	2 c	57 b-d	175 a

[a] C = carbofuran treatment (4.5 kg ai/ha); R = rice crop; S = *Sesbania rostrata* crop;
Si = incorporation of 10 t/ha of shoots of *S. rostrata* as green manure.

[b] Values are means of six replications. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple-range test.

Table 3. Rice yield obtained in different cropping sequences during an experiment conducted in a field infested with Hirschmanniella oryzae *at the University of Southern Mindanao, Philippines.*

Cropping sequence	**Yield (t/ha)**			
	1st crop	**2nd crop**	**3rd crop**	**4th crop**
T1: R-R-R-R[a]	2.59 b[b]	1.34 b	2.96 cd	4.92 a
T2: R-Si-R-R-R	2.67 b	1.92 a	2.73 d	4.98 a
T3: S-R-R-R	-	2.07 a	3.23 b-d	4.87 a
T4: S-Si-R-R-R	-	2.03 a	3.19 b-d	4.78 a
T5: C-R-R-R-R	3.49 a	1.85 a	3.56 ab	4.95 a
T6: C-R-Si-R-R-R	3.42 a	1.92 a	3.48 a-c	4.72 a
T7: C-S-R-R-R	-	1.99 a	3.79 a	4.85 a
T8: C-S-Si-R-R-R	-	2.4 a	3.88 a	4.98 a

[a] C = carbofuran treatment (4.5 kg ai/ha); R = rice crop; S = *Sesbania rostrata* crop; Si = incorporation of 10 t/ha of shoots of *S. rostrata* as green manure.

[b] Values are means of six replications. Means in each column followed by the same letter do not differ at $P < 0.05$ according to Duncan's multiple-range test.

gen content of the soil (Rinaudo and Moudiongui, 1985). Nematicides may stimulate plant growth and yield (Garbedian and Van Gundy, 1982; Venugopal and Litsinger, 1984; Barker et al., 1988).

If the yield increase observed after growing or incorporating *S. rostrata* was only due to an increase in nitrogen, the nitrogen effect would most certainly be greater and last longer when the green manure was incorporated than when it was grown and removed.

The carbofuran treatment resulted in a yield increase for the three crops which followed the treatment. Carbofuran can stimulate rice growth in absence of nematode (Venugopal and Litsinger, 1984) and therefore may have a direct effect on the increase in yield observed on the first crop following the treatment. However, carbofuran is quickly degraded in soil, especially in tropical paddy fields where it is also lost to the atmosphere through transpiration (Getzin, 1973; Siddaramappa and Watanabe, 1978; Siddaramappa et al., 1978). Therefore, it is unlikely that the carbofuran treatment had a direct effect on the second and third crops following the treatment.

The possible effect of treatments on pests and diseases was avoided by estimating the yield in each individual plot in an area free of damage caused by pests or diseases. Unknown residual effects of the treatments on soil microfauna and(or) microflora and(or) on nutrient availability could have also been responsible for the residual effect on the yield. However, the yield of the second rice crop was correlated to the nematode population observed after the first rice crop and the residual effect on the yield vanished when the effect of the treatments on the nematode population disappeared. If changes of an unknown factor following the treatments was responsible for the increase in yield, this factor would have to be affected simultaneously with the nematode population by the different treatments applied.

Results observed in these experiments suggest that the increase in rice yield that occurred was at least partially due to the control of the nematode population and not only to side effects of the treatment. Therefore, these observations support the hypothesis that rice root nematodes can reduce rice yield under field conditions.

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