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# EFFECTS OF WATER REGIME ON THE DISTRIBUTION OF *MELOIDOGYNE GRAMINICOLA* AND OTHER ROOT-PARASITIC NEMATODES IN A RICE FIELD TOPOSEQUENCE AND PATHOGENICITY OF *M. GRAMINICOLA* ON RICE CULTIVAR UPL R15


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In a rice field toposequence including upland, rainfed lowland and irrigated rice, *Meloidogyne graminicola* was present in all three rice production systems, whereas *Pratylenchus zeae* was present only in upland rice, and *Hirschmanniella oryzae* in flooded fields. The prevalence and mean intensity of *M. graminicola* were greater in flooded fields than in upland fields. In a greenhouse experiment, *M. graminicola* reduced the growth and yield of rice cv. UPL R15 when this cultivar was grown under upland conditions but not under irrigated conditions. *M. graminicola* is well adapted to irrigated conditions and shallow flooding does not affect its reproduction. However, shallow flooding reduced the percentage of roots damaged by the nematode, resulting in an absence of yield-reducing effect by the nematode under irrigated conditions.



*Keywords:* ecology, *Hirschmanniella oryzae, Meloidogyne graminicola*, pathogenicity, *Pratylenchus zeae,* rice, toposequence, water regime


The rice root-knot nematode, *Meloidogyne graminicola*, Golden & Birchfield, has been observed mainly in upland rice, rainfed lowland rice and nurseries (Manser, 1968, 1971; Rao & Israel, 1971, 1972) where it can limit plant growth and cause yield losses (Rao *et al.*, 1986; Jairajpuri & Baqri, 1991; Prot *et al.*, 1994b). However, *M. graminicola* is well adapted to survive under flooded conditions and has been observed in deep water rice in Bangladesh and Vietnam (Page *et al.*, 1979; Cuc & Prot, 1992) where it can reduce plant growth before flooding and cause yield loss by reducing stem elongation resulting in a drowning out of the plants during the deep flooding (Bridge & Page, 1982). Recently it has been observed in more than 50% of the irrigated rice fields in two of the major rice-producing areas of the Philippines (Prot *et al.*, 1994a) but Kinh *et al.* (1982) have reported that permanent flooding reduced the damage to rice due to *M. graminicola*. Therefore, it appears important to study the effects of shallow flooding on the distribution of *M. graminicola* and on its pathogenicity.

The objectives of the experiments reported here were to study: i) the effect of the water regime on the distribution of *M. graminicola* under field conditions;

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and ii) the effect of the water regime on the pathogenicity of the nematode on rice cv. UPL Ri5.

## MATERIALS AND METHODS

### *Distribution of root parasitic nematodes in a rice field toposequence*

The distribution of *M. graminicola* and other root-parasitic nematodes associated with rice was studied along a 400 m long toposequence on the slope of Lake Taal shore in Laurel, Batangas, Philippines. In this location, rice is grown under upland rice conditions in the upper part of the toposequence (15-10 m above lake level), under rainfed lowland conditions in the middle part (10-5 m above lake level), and under irrigated conditions in the lower part along the shore of the lake (5-0.5 m above lake level). Under upland conditions, rice is grown from May to October, followed by maize or occasionally stringbean or sesame. Two rice crops are grown annually under rainfed lowland and irrigated conditions, the first crop from May to October and the second between December and March. Upland fields are ploughed while rainfed and irrigated fields are ploughed and puddled. Nurseries are prepared in the fields and 14-day-old seedlings are transplanted. Upland rice fields are never flooded. Rainfed lowland fields are intermittently flooded depending on the rainfall. Irrigated rice fields are flooded 3-5 days following transplanting and kept flooded until maturity of the rice crop. Soils are of sandy loam type in upland and rainfed lowland fields, and of silt loam type in the irrigated area.

The study was conducted in September, 1993 when the rice crop was between flowering and maturity stages. The rice cultivars C4 and UPL Ri5 were grown in the three rice production systems. Dumali, IR60, IR64, and PSBRC2 were grown under rainfed lowland and irrigated conditions. IR10, IR42, IR54, and IR65 were grown only under irrigated conditions. A total of 470 samples were collected (10 samples/ha), 130 in upland fields and 170 in each of the two other rice production ecosystems. Each soil (2 kg) and root (one root system) sample was collected by uprooting a rice hill. Nematodes were extracted from 200 $cm^3$ subsamples of soil 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).

Prevalence (percent of samples where the genus was present) and mean intensities per 200 $cm^3$ of soil and 3 g of roots were calculated (Boag, 1993) for each genus in each production system.

### *Pathogenicity of* Meloidogyne graminicola *on cultivar UPL Ri5*

The pathogenicity of *M. graminicola* on UPL Ri5 was studied under two water regimes in two different soils: a clay loam and a sandy loam soil. The clay loam soil contained 44% clay, 37% silt, 19% sand, and 0.12% nitrogen. The sandy loam soil contained 9% clay, 20% silt, 71% sand, and 0.05% nitrogen. Five-day-old seedlings (three per pot) of UPL Ri5 were transplanted in 20-cm-diam × 35-cm-high polyvinyl pots containing 8.5 kg of dry soil saturated to its maximum capacity with a thin layer of water standing on the surface of the soil. The *M. graminicola* population used in this experiment was originally collected from Laurel, Batangas, on irrigated rice. It was cultured in a greenhouse on cv. IR58 under upland conditions. Second stage juveniles (J2) were obtained by placing infected roots in a mistifier (Seinhorst, 1950). Only J2 collected during 24-h periods were used as inoculum and were introduced in the soil around the seedling in five equal splits at transplanting and thereafter at 3 day intervals. Five initial inoculum levels (Pi) were used: 0, 10, 100, 1,000, and 10,000/kg of dry soil. In all pots, the soil was maintained saturated until the last inoculation.

In pots where irrigated conditions were simulated, the soil was flooded with 5 cm of standing water just after the last inoculation. Thereafter, pots were watered three times per week to maintain them permanently flooded until maturity. After the last inoculation, the soil of pots simulating upland conditions was maintained between saturation and field capacity by watering the pots three times per week. Nitrogen was applied in all treatments at a rate of 80 kg/ha (1.8 g/pot) in three equal splits at transplanting, maximum tillering and panicle initiation stages.

All combinations of nematode inoculum levels, water regimes and soil types were arranged in a split split plot design with six replications. Water regime was considered as main plot, soil type as subplot, and inoculum level as sub-subplot.

At maturity, stems and leaves dry weight, plant height, flag leaf area, root dry weight, number of panicles, percentage of unfilled spikelets, and grain yield were recorded for each plant. Root systems were chopped into 0.5-1 cm pieces and J2 were extracted from 3 g subsamples by placing them for 5 days in a mistifier (Seinhorst, 1950). The degree of root galling was estimated using the following rating scale: 1 = no gall; 2 = 1-25% roots with galls; 3 = 26-50% roots with galls; 4 = 51-75% roots with galls; and 5 >76% roots with galls. Data were analyzed using ANOVA and means were separated by Duncan's multipe range test (DMRT).

## RESULTS

### *Distribution of root-parasitic nematodes in a rice field toposequence*

Nine genera of root-parasitic nematodes were present in the toposequence (Table I). *Hirschmanniella oryzae*, *M. graminicola*, and *Pratylenchus zeae* were the prevalent species and observed in rice roots as well as in the soil. *M. graminicola* was present in the three rice production systems but its prevalence and mean intensity were greater in rainfed lowland and irrigated fields than in upland fields. *H. oryzae* was observed under rainfed lowland and irrigated conditions but not in upland fields. High mean intensities of *P. zeae* were observed in upland fields but this nematode was not detected in rainfed lowland and irrigated fields. *Helicotylenchus* sp. and *Tylenchorhynchus* sp. were observed with high mean intensities under upland conditions and with low mean intensities under rainfed lowland and irrigated conditions. *Criconemella* sp. *Hoplolaimus* sp., *Rotylenchulus* sp., and *Xiphinema* sp. were present only in upland soils.

TABLE I

*Prevalence (P: % of samples where the species or genus is present) and mean intensity (MI) in 200 cm³ of soil and 3 g of roots of nematode species and genera observed in a toposequence of upland (UR), rainfed lowland (RFL) and irrigated (IR) rice fields in the Philippines*

| | Rice production system | | | | | |
|---|---|---|---|---|---|---|
| | UR | | RFL | | IR | |
| P and MI | Soil | Roots | Soil | Roots | Soil | Roots |
| | | | *Meloidogyne graminicola* | | | |
| P | 16 | 21 | 55 | 100 | 38 | 89 |
| MI | 23 | 263 | 889 | 16183 | 519 | 4063 |
| | | | *Hirschmanniella oryzae* | | | |
| P | 0 | 0 | 9 | 16 | 25 | 43 |
| MI | 0 | 0 | 7 | 36 | 44 | 95 |
| | | | *Pratylenchus zeae* | | | |
| P | 90 | 100 | 0 | 0 | 0 | 0 |
| MI | 403 | 7255 | 0 | 0 | 0 | 0 |
| | | | *Criconemella* | | | |
| P | 54 | 0 | 0 | 0 | 0 | 0 |
| MI | 14 | 0 | 0 | 0 | 0 | 0 |
| | | | *Helicotylenchus* | | | |
| P | 48 | 0 | 12 | 0 | 6 | 0 |
| MI | 158 | 0 | 10 | 0 | 3 | 0 |
| | | | *Hoplolaimus* | | | |
| P | 8 | 0 | 0 | 0 | 0 | 0 |
| MI | 5 | 0 | 0 | 0 | 0 | 0 |
| | | | *Tylenchorhynchus* | | | |
| P | 14 | 0 | 4 | 0 | 2 | 0 |
| MI | 240 | 0 | 9 | 0 | 17 | 0 |
| | | | *Rotylenchulus* | | | |
| P | 2 | 0 | 0 | 0 | 0 | 0 |
| MI | 4 | 0 | 0 | 0 | 0 | 0 |
| | | | *Xiphinema* | | | |
| P | 5 | 0 | 0 | 0 | 0 | 0 |
| MI | 5 | 0 | 0 | 0 | 0 | 0 |

*Pathogenicity of* Meloidogyne graminicola *on cultivar UPL Ri5*

Root gall indices were greater ($p < 0.01$), but the total number of J2 recovered was less ($p < 0.05$) under upland than irrigated conditions (Table II). Soil type, Pi and interactions between water regime and soil type, water regime and Pi, and soil type and Pi influenced the root gall index ($p < 0.05$) but not the number of J2 recovered per 3 g of roots.

Plant growth parameters were diversely influenced by water regime, soil type and Pi (Table III). Stems and leaves dry weight, plant height, flag leaf area and dry root weight were less ($p < 0.01$) under upland than irrigated conditions. Stems and leaves dry weight, plant height and flag leaf area were less ($p < 0.01$) in sandy loam than in clay loam soil but dry root weight was not influenced by the soil type. Stems and leaves dry weight and dry root weight were decreased ($p < 0.01$) by increasing Pi. Pi significantly affected the flag leaf area in sandy loam soil under upland conditions and did not influence the plant height. Significant interactions were observed between water regime and soil and water regime and Pi on stems and leaves dry weight ($p < 0.01$) and on plant height ($p < 0.05$).

TABLE II

*Effect of different inoculum levels of* Meloidogyne graminicola *(Pi) on the root galling index and the number of J2 recovered per 3 g of roots at maturity of rice cultivar UPL Ri5 grown under two water regimes and in two different soils*

| | Irrigated | | | | | Upland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Pi | Clay loam | | Sandy loam | | Mean | Clay loam | | Sandy loam | | Mean |
| | | | | | Root galling index | | | | | |
| 0 | 1.0[a] | A[b] c[c] | 1.0 | A b | 1.0 α[d] | 1.0 | A c | 1.0 | A b | 1.0 α |
| 10 | 2.0 | A ab | 2.2 | A a | 2.1 β | 3.8 | B b | 4.7 | A a | 4.2 α |
| 100 | 2.3 | A a | 2.0 | A a | 2.2 β | 4.5 | A a | 4.8 | A a | 4.7 α |
| 1,000 | 1.8 | B b | 2.3 | A a | 2.1 β | 4.3 | B a | 5.0 | A a | 4.7 α |
| 10,000 | 2.3 | A a | 2.3 | A a | 2.3 β | 4.3 | B a | 5.0 | A a | 4.7 α |
| | | | | | Number of J2 per 3 g of roots (x 1,000) | | | | | |
| 0 | 0 | - | 0 | - | 0 α | 0 | - | 0 | - | 0 α |
| 10 | 25 | B c | 138 | A a | 81 α | 31 | A a | 24 | A a | 27 α |
| 100 | 114 | A ab | 124 | A a | 119 α | 31 | A a | 43 | A a | 37 β |
| 1,000 | 179 | A a | 83 | B ab | 131 α | 41 | A a | 34 | A a | 38 β |
| 10,000 | 91 | A bc | 23 | A b | 57 α | 26 | A a | 22 | A a | 24 α |

[a] Mean of six replications.
[b] In a row under each water regime, means followed by a common upper case letter are not significantly different at the 5% level by DMRT.
[c] In a column, means followed by a common lower case letter are not significantly different at the 5% level by DMRT.
[d] In a row, means of averaged over all subplots followed by the same symbol are not significantly different at the 5% level by DMRT.

TABLE III

*Effect of different inoculum levels of* Meloidogyne graminicola *(Pi) on the stems and leaves dry weight, the plant height, the flag leaf area and the dry root weight at maturity of rice cultivar UPL Ri5 grown under two water regimes and in two different soils*

| Pi | Irrigated | | | Upland | | |
|---|---|---|---|---|---|---|
| | Clay loam | Sandy loam | Mean | Clay loam | Sandy loam | Mean |
| | | | Stems and leaves dry weight (g) | | | |
| 0 | 58[a] A[b] a[c] | 38 B a | 48 α[d] | 51 A a | 43 B a | 47 α |
| 10 | 47 A b | 39 B a | 43 α | 44 A b | 31 B b | 38 β |
| 100 | 54 A a | 35 B ab | 44 α | 34 A c | 24 B c | 29 β |
| 1,000 | 45 A b | 30 B bc | 38 α | 25 A d | 15 B d | 20 β |
| 10,000 | 44 A b | 29 B c | 37 α | 24 A d | 10 B d | 17 β |
| | | | Plant height (cm) | | | |
| 0 | 157 A a | 151 A ab | 154 α | 142 A a | 144 A a | 143 β |
| 10 | 155 A a | 149 A b | 152 α | 140 A a | 126 B a | 133 β |
| 100 | 160 A a | 149 B b | 154 α | 132 A a | 121 B a | 126 β |
| 1,000 | 161 A a | 159 A a | 160 α | 145 A a | 115 B a | 130 β |
| 10,000 | 160 A a | 158 A ab | 159 α | 139 A a | 125 B a | 131 β |
| | | | Flag leaf area ($cm^2$) | | | |
| 0 | 576 A a | 388 B a | 482 α | 398 A a | 355 A a | 377 β |
| 10 | 524 A a | 409 B a | 466 α | 379 A a | 226 B b | 302 β |
| 100 | 598 A a | 361 B a | 479 α | 277 A b | 203 A b | 240 β |
| 1,000 | 520 A a | 372 B a | 446 α | 354 A ab | 213 B b | 284 β |
| 10,000 | 533 A a | 411 B a | 472 α | 334 A ab | 170 B b | 252 β |
| | | | Dry root weight (g) | | | |
| 0 | 5.4 A a | 4.7 A a | 5.1 α | 2.2 A a | 2.1 A a | 2.1 β |
| 10 | 4.5 A bc | 4.9 A a | 4.7 α | 1.7 A ab | 1.8 A a | 1.8 β |
| 100 | 4.9 A ab | 4.2 A a | 4.6 α | 1.4 A bc | 1.5 A ab | 1.5 β |
| 1,000 | 3.8 A c | 3.3 A b | 3.5 α | 0.9 A c | 0.9 A bc | 0.9 β |
| 10,000 | 3.9 A c | 2.4 B c | 3.2 α | 0.9 A c | 0.4 A c | 0.6 β |

[a] Mean of six replications.
[b] In a row under each water regime, means followed by a common upper case letter are not significantly different at the 5% level by DMRT.
[c] In a column, means followed by a common lower case letter are not significantly different at the 5% level by DMRT.
[d] In a row, means of averaged over all subplots followed by the same symbol are not significantly different at the 5% level by DMRT.

Number of panicles ($p < 0.01$) and grain yield ($p < 0.01$) were less under upland than under irrigated conditions and in sandy loam than in clay loam soil (Table IV). Number of panicles and grain yield were reduced by the nematode under upland but not under irrigated conditions. There were significant interactions between water regime and Pi on the number of panicles ($p < 0.01$) and the grain yield ($p < 0.05$). The percentage of unfilled spikelets was greater under

TABLE IV

*Effect of different inoculum levels of* Meloidogyne graminicola *(Pi) on the number of panicles, the percentage of unfilled spikelets and the grain yield at maturity of rice cultivar UPL Ri5 grown under two water regimes and in two different soils*

| Pi | Irrigated | | | Upland | | |
|---|---|---|---|---|---|---|
| | Clay loam | Sandy loam | Mean | Clay loam | Sandy loam | Mean |
| | | | Number of panicles | | | |
| 0 | 10.3 A[b] ab[c] | 8.5 B a | 9.4 α[d] | 10.0 A a | 8.8 A a | 9.4 α |
| 10 | 10.8 A a | 8.5 B a | 9.7 α | 8.8 A b | 8.7 A ab | 8.7 α |
| 100 | 11.0 A a | 8.3 B a | 9.7 α | 9.0 A ab | 7.3 A b | 8.2 β |
| 1,000 | 9.2 A b | 7.5 B a | 8.3 α | 6.8 A c | 4.7 B c | 5.7 β |
| 10,000 | 10.0 A ab | 8.8 B a | 9.4 α | 6.5 A c | 3.0 B c | 4.7 β |
| | | | Percentage of unfilled spikelets | | | |
| 0 | 20 A a | 18 A b | 19 β | 28 B a | 43 A ab | 36 α |
| 10 | 23 A a | 20 A b | 21 β | 30 A a | 39 A b | 34 α |
| 100 | 17 A a | 23 A ab | 20 α | 26 A a | 26 A c | 26 α |
| 1,000 | 23 A a | 31 A a | 27 β | 29 B a | 51 A a | 40 α |
| 10,000 | 20 A a | 27 A ab | 24 β | 36 A a | 42 A ab | 39 α |
| | | | Grain yield per plant (g) | | | |
| 0 | 37.9 A ab | 25.6 B a | 31.8 α | 25.0 A a | 17.4 B a | 21.2 β |
| 10 | 35.9 A b | 24.8 B a | 30.3 α | 23.2 A a | 11.2 B b | 17.2 β |
| 100 | 41.4 A a | 24.2 B a | 32.8 α | 16.2 A b | 12.5 A b | 14.3 β |
| 1,000 | 35.3 A b | 24.2 B a | 29.8 α | 15.5 A b | 5.2 B c | 10.3 β |
| 10,000 | 38.1 A ab | 20.8 B a | 29.4 α | 14.2 A b | 4.7 B c | 9.5 β |

[a] Mean of six replications.
[b] In a row under each water regime, means followed by a common upper case letter are not significantly different at the 5% level by DMRT.
[c] In a column, means followed by a common lower case letter are not significantly different at the 5% level by DMRT.
[d] In a row, means of averaged over all subplots followed by the same symbol are not significantly different at the 5% level by DMRT.

upland than under irrigated conditions. Soil type and Pi did not affect the percentage of unfilled spikelets.

## DISCUSSION

The nematode fauna was more diverse under upland conditions, where eight genera were observed, than in the two rice production systems subjected to flooding. Moreover, the plant parasitic nematodes, which are known to cause yield loss in rice, were not equally distributed among all rice production systems. *M. graminicola* was observed under all water regimes while *P. zeae* was observed only in upland fields and *H. oryzae* was present only in fields that are flooded for at least a period of time. These results confirm that *H. oryzae* is well adapted to aquatic conditions (Norton, 1978) and that *P. zeae* is mostly associated with upland rice (Bridge *et al.*, 1990; Villanueva *et al.*, 1992). The prevalence and mean intensity of *M. graminicola* were greater under rainfed lowland and irrigated conditions than under upland conditions. In these fields, flooding did not limit the reproduction of the rice root-knot nematode. The low prevalence and mean intensity of *M. graminicola* observed in upland fields may result from the crop rotation used by the farmers or from competition (Eisenback, 1993) with *P. zeae*. During this study, large numbers of second stage juveniles were obtained from the roots collected at maturity in permanently flooded irrigated rice fields, whereas Bridge & Page (1982) did not observe nematodes in roots of deep water rice plants after several months of flooding. This is probably because after several months of deep flooding the basal root system deteriorates (Catling, 1992) and the oxygen concentration decreases down the stem at a rate of about 50% for each metre of stem length (Setter *et al.*, 1987).

Water regime and soil type both influenced growth and yield of UPL Ri5. Most of the growth and yield parameters were greater under irrigated conditions than under upland conditions indicating that cv. Upl Ri5 is better adapted to irrigated than to upland conditions. Growth and yield were also better in clay loam soil than in sandy loam soil and this may be related to differences in soil texture, soil water-holding capacity, or nutrient availability between the two soils. The better plant growth under irrigated conditions and consequential greater food supply for the nematodes may explain the greater number of J2 obtained per gram of root under irrigated than under upland conditions. This has already been observed by Bridge & Page (1982). However, permanent flooding that may limit the migration of J2 between roots of the same root system (Bridge & Page, 1982) resulted in a smaller percentage of damaged roots. The greater ability of J2 of *Meloidogyne* to migrate in a sandy soil than in a clay soil (Prot & Van Gundy, 1981) may explain why a greater percentage of roots were galled in sandy loam soil than in clay loam soil under upland conditions.

Under upland conditions, especially in sandy soil, *M. graminicola* was able to infest most of the roots. This resulted in a drastic reduction in root development and consequential reductions in shoot growth and grain yield. Under irrigated conditions, the limitation of the spread of *M. graminicola* infestation within the root system resulted in a greater development of the latter, which allowed a greater development of the above-ground parts of the plant than under upland conditions in the presence of the nematode.

*M. graminicola* is a strong parasite of rice and can cause serious yield loss under upland conditions. It is well adapted to irrigated conditions and shallow flooding does not limit its development. However, flooding appears to favour the development of the root system of the rice plant and to limit the spread of *M. graminicola* within the root system. This results in little effect of increasing inoculum densities of the nematode on the yield of UPL Ri5 under irrigated conditions.

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RÉSUMÉ

*Effet du régime hydrique sur la répartition des nématodes parasites des racines dans une toposéquence de rizières et sur la nocuité de* Meloidogyne graminicola *envers le cultivar de riz UPL Ri5*

Dans une toposéquence incluant des champs de riz pluvial, de riz de nappe et de riz irrigué, *Meloidogyne graminicola* était présent dans les trois systèmes de production rizicole alors que *Pratylenchus zeae* n'était présent que dans les champs de riz pluvial et *Hirschmanniella oryzae* que dans les champs inondés. La prévalence et l'intensité moyenne de *M. graminicola* étaient plus grandes dans les champs inondés que dans les champs exondés en permanence. Au cours d'une étude réalisée en serre, *M. graminicola* réduisait la croissance et le rendement en grains du cv. UPL Ri5 lorsque celui-ci était cultivé en conditions pluviales mais non s'il cultivé en conditions irriguées. *M. graminicola* est bien adapté à une submersion, peu profonde qui ne diminue pas sa reproduction. Cependant, l'irrigation réduit le pourcentage de racine infestées par le nématode ce qui annule l'effet de ce dernier sur le rendement en grains.

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