The effect of *Pratylenchus zeae* on the growth and yield of upland rice

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SUMMARY

The root lesion nematode *Pratylenchus zeae* is widely distributed on upland rice but its economic importance has not been assessed. In a field trial, following a five month clean fallow, the control of *P. zeae* using carbofuran, increased the yield of cv. Upl Ri-5 whilst the yield of cv. Kinandang Patong was unaffected. Pre-sowing soil population densities (P_i) of *P. zeae* were low (0-111 nematodes/100 ml soil) and there were no obvious symptoms of infection during early vegetative growth although the plant height of Upl Ri-5 was slightly reduced. At harvest the yield of treated plants was increased by 13-29 % of that of untreated plants having a mean infection of 1 350 nematodes/g root ($P < 0.05$). In the glasshouse the rate of growth and tillering of cv. IR36 was significantly reduced with a high P_i (630-3 000 nematodes/100 cm^3 soil). Infected root systems were stunted and mean root fresh weight was reduced by 40-60 %. Although infection reduced the no. of spikelets/plant, these plants had a higher harvest index and consequently grain yield was unaffected. The relationship between yield and the population density of *P. zeae* at different crop growth stages, in the field indicates low tolerance and a high relative minimum yield of 65 %.

RÉSUMÉ

Influence de Pratylenchus zeae *sur la croissance et la récolte du riz de plateau*

Pratylenchus zeae est très répandu sur le riz de plateau mais son importance n'a jamais été évaluée. Aux Philippines, un essai au champ mis en place après cinq mois de jachère nue indique que les traitements nématicides contre *P. zeae* provoquent une augmentation de la récolte du cv. Upl Ri-5 mais n'affecte pas celle du cv. Kinandang Patong, tout aussi sensible à ce nématode. La population initiale (P_i), avant semis, de *P. zeae* était faible (0-111 nématodes/100 cm^3 de sol) et aucun symptôme de maladie n'était visible en début de végétation bien que la hauteur des plants du cv. Upl Ri-5 fut légèrement réduite. A la récolte, le rendement des plants traités était de 23 à 29 % plus élevé que celui des témoins, avec une infestation moyenne de 1 350 nématodes/g de racines ($P < 0.05$). En serre, le taux de croissance et la production de tiges par le cv. IR 36 étaient significativement réduits par des P_i fortes (630-3 000 nématodes/g de racines). Les systèmes radiculaires infestés étaient rabougris et le poids de racines fraîches réduit de 40 à 60 %. Bien que l'infestation provoque une diminution du nombre de panicules par pied, ces pieds avaient un index de récolte plus élevé si bien que la production de grain n'en était pas affectée. La relation entre la récolte et la densité des populations de *P. zeae* aux différents stades de végétation, au champ, indique une tolérance faible accompagnée d'une récolte minimale élevée (65 %).

The root lesion nematode *Pratylenchus zeae* is widely distributed. It has been reported on upland rice in U.S.A., Brazil, Zimbabwe, Ivory Coast, Cuba, Malawi and Senegal (Atkins, Fielding & Hollis, 1957; Gateva & Penton, 1971; Fortuner, 1975, 1976) and recent surveys have shown that it is a common parasite of upland rice in the Philippines (Plowright, unpubl.). *Pratylenchus zeae* has a wide host range, infecting many of the cereals, grains and cash crops grown by subsistence farmers as well as common weeds such as *Dactylodenium aegyptium*, *Digitaria sanguinalis* and *Echinochloa crusgalli* (Fortuner, 1976). These features make the nematode a potentially important parasite of upland rice, but there is very little information which helps in assessing its pest status. *Pratylenchus* spp. have been associated with poor growth of upland rice in Zimbabwe (Martin, 1972) and in India *Pratylenchus* " *indicus* " Das, 1960 *(sp. inq.)* was reported to cause severe stunting of young plants and yield loss of 12-17 % (Rao & Prasad, 1977). Observations at the International Rice Research Institute (IRRI) in the Philippines, have shown that poor growth in upland rice is commonly associated with infection and root damage by *P. zeae* (J. Bridge, pers. comm.).

The objective of this work was to assess the effect of *P. zeae* on the growth and yield of upland rice. The work was part of a broader assessment of the importance of plant parasitic nematodes on upland rice.

Materials and methods

Crop loss assessment experiments were done in the field and in a heated glasshouse (25-35 °C). The selection of rice cultivars was based on glasshouse screening tests for resistance to *P. zeae* in which the cultivar Upl Ri-5 was categorised as relatively susceptible and Kinandang Patong and IR36 as relatively resistant compared to the mean reproduction of *P. zeae* on 75 cultivars tested.

GLASSHOUSE EXPERIMENT

Pratylenchus zeae infected roots of the glasshouse culture host cv. IR36 were cut into 1 cm lengths, mixed with moist soil and stored in loosely tied plastic bags for 60 days at 15-20 °C. A mixture of uninfected roots and soil was prepared and stored in the same manner. After storage the population density of *P. zeae* was determined using the tray method (Whitehead & Hemming, 1965) and infested soil was diluted with heat sterilised clay-loam to achieve initial soil population densities (P_i) of 0, 630 and 3 000 *P. zeae*/100 cm^3 soil. This soil was placed in 14 cm diameter, 1 dm^3 plastic pots, arranged in a randomised block layout and sown with twelve seeds/pot of rice cv. IR36. Ten days after emergence the seedlings were measured and thinned to 1/pot. Harvested seedlings were dried to constant weight at 80 °C to determine dry matter yield.

Records of plant height (to the tip of the tallest leaf) and number of tillers/plant were made each week until flowering and again at harvest. Mature panicles were removed and stripped of seed and sterile spikelets. These were separated, counted and weighed to determine total and 100 seed weight (14 % moisture); remaining shoot material was dried to constant weight at 80 °C. Nematode population densities in roots at harvest (Pf) were determined from a 25 % sample of the root ball. The sample was washed, weighed and stained in acid fuchsin 0.01 % w/v (Bridge, Page & Jordan, 1981). Stained roots were cut and macerated and nematodes in two or three sub-samples (2 % by volume) were counted.

FIELD EXPERIMENT

An area of land, on the IRRI experimental farm, infested with *P. zeae* was chosen for the field trial. The area had been sown to rice for several years but had been a clean fallow throughout the 1987 dry season.

The layout of the experiment was a randomised block with four replicates of eight plots measuring 2 m × 5 m with 50 cm alleyways. The upland rice cultivars Upl Ri-5 and Kinandang Patong were sown to each of four nematicide treatments (carbofuran) 0, 2, 4 & 8 kg a.i./ha within each block.

Carbofuran was broadcast over the soil surface and incorporated to a depth of approximately 15 cm by two passes of a small powered rotavator. Nine furrows/plot, spaced at 25 cm intervals were made using a small plot, manually dragged harrow and ten seeds were sown every 25 cm along the furrow giving 21 hills/furrow. Two rows of sorghum were sown to provide a wind break around the experiment and were cut to the height of the rice crop. The experiment was weeded during the first two weeks after sowing and the hills were thinned to five plants/hill. Missing hills were transplanted from the border rows and their position recorded. The experiment was irrigated immediately after sowing but no further irrigation was employed.

Pre-treatment, soil population densities of *P. zeae* and other parasitic Tylenchida were estimated from a bulked sample comprising ten systematically located, soil cores/plot (2.5 cm diameter × 15 cm). Nematodes were extracted from a 100 cm^3 sub-sample of each sample on a Baermann funnel at 25 °C. After seven days nematodes were concentrated and counted.

Subsequent soil and root nematode population estimates were made at maximum tillering, flowering and maturity. Sampling at maximum tillering and flowering was done by digging up half of each of four hills in rows 2 and 8, i.e. a sample equivalent to four hills derived from eight sample points. The soil associated with roots was shaken off, bulked and sub-sampled as above. Roots were washed free of remaining soil and cut into < 1 cm lengths. These were mixed and a 3 g sub-sample was macerated and placed on a 90 µm sieve in water at 25 °C. Nematodes were concentrated and counted as above. Nematode population estimates, made immediately after harvest, were done in the same manner as above except that hills were sampled from the harvest rows 4, 5 and 6. Transplanted hills were not used for nematode sampling.

Crop establishment was assessed by counting the number of hills/plot after emergence. From 30-60 days after sowing, the number of tillers/hill and plant height (to the tip of the tallest leaf) were recorded each week. Measurements were taken from four units of four adjacent hills in a square. The positon of each unit, located in rows 3-7 was determined at random and a different randomisation was used for each replicate. Plant height was measured on a single hill in each unit, while tillers were counted on all (Gomez, 1972).

From the onset of flowering, the number of flowering hills in rows 4, 5 and 6, were counted every two days until all had flowered.

At maturity, eight alternate hills from each of rows 4, 5 and 6 (avoiding transplanted hills) were harvested after recording plant height (to the tip of the tallest panicle) and the number of panicles/hill. A sub-sample, comprising the tallest panicle from each hill sampled, was taken in order to determine panicle length, 1000 grain weight and the proportion of filled spikelets. The remaining panicles were threshed and grain weights at 14 % moisture were calculated.

The cv. Kinandang Patong became infected with stem borer but there were no significant differences in the mean number of infected tillers/plot for each treatment, which were 27, 39, 33 and 38 on plots receiving 0, 2, 4 and 8 kg a.i. carbofuran/ha respectively. Upl Ri-5 was not infected by stem borer.

The raw data from both experiments were analysed by analysis of variance and means were compared using Duncan's multiple range test (Duncan, 1955). Relationships between rice yield and the population density of *P. zeae* at different crop growth stages were plotted and the values of terms were determined for each curve, in a crop loss model based on Nicholson's (1933) competition curve :

$$Y = Y_{min} + (1 - Y_{min}) z^P \quad (1)$$

where Y is the relative yield, Y_{min} is the relative minimum yield, z is a constant slightly less than 1 and P is the nematode population density. Graphical plots of field data assumed that carbofuran did not directly influence crop growth and that with a half life of approximately 20 days, nematode multiplication was delayed by 20, 40 and 60 days at the rates of 2, 4 and 8 kg a.i./ha respectively.

Results

Glasshouse experiment

Pratylenchus zeae did not influence seedling emergence but the initial rate of leaf extension was lower for plants in soil infested with a P_i of 3 000 nematodes/100 cm³ soil and at 10 days after emergence these plants were shorter than those in soil with a P_i of 630 nematodes/100 ml soil and uninfected, control plants in soil infested with a P_i of 3000 nemaplants ($P < 0.001$) (Fig. 1).

The rates of shoot extension, from 10 to 45 days after emergence, were approximately the same for infected and uninfected plants. Thereafter a decrease in the rate of shoot extension occurred which was later and less pronounced as P_i increased so that at flowering there were no differences in plant height between infected and uninfected plants (Fig. 1).

The rate of production of tillers was initially slower in infected plants but all plants attained approximately the same maximum rate for a period between 40 and 67 days after emergence. The period of maximum tillering rate shortened with increasing P_i and coincided with the reduction in the rate of shoot extension before flowering (Fig. 1). The final number of tillers at flowering decreased with increasing P_i ($P < 0.001$) (Fig. 1).

The fresh weight of infected roots at harvest was reduced to 45-60 % of that of uninfected roots ($P < 0.01$) but there was no difference in root weight or P_f of *P. zeae* between infested treatments (Tab. 1).

Infection with *P. zeae* reduced the number of panicles ($P < 0.05$) and spikelets/plant ($P < 0.001$), however the number and weight of grain/plant was the same in infected and uninfected treatments (Table 1).

The relationship between the number of spikelets/plant and P_i and P_f of *P. zeae*, was adequately described by the model (equation above) (Fig. 2). The relative minimum yield (0.60-0.62) occurred at a threshold P_i of 1 500 nematodes/100 ml soil and P_f 10 000 nematodes/g root. Grain yield itself was linearly correlated with P_f ($r = -0.645$, $P < 0.01$), but unrelated to P_i.

Harvest index (ratio of grain weight to total plant weight) was linearly correlated with the initial population density of *P. zeae* ($r = 0.644$, $P < 0.01$).

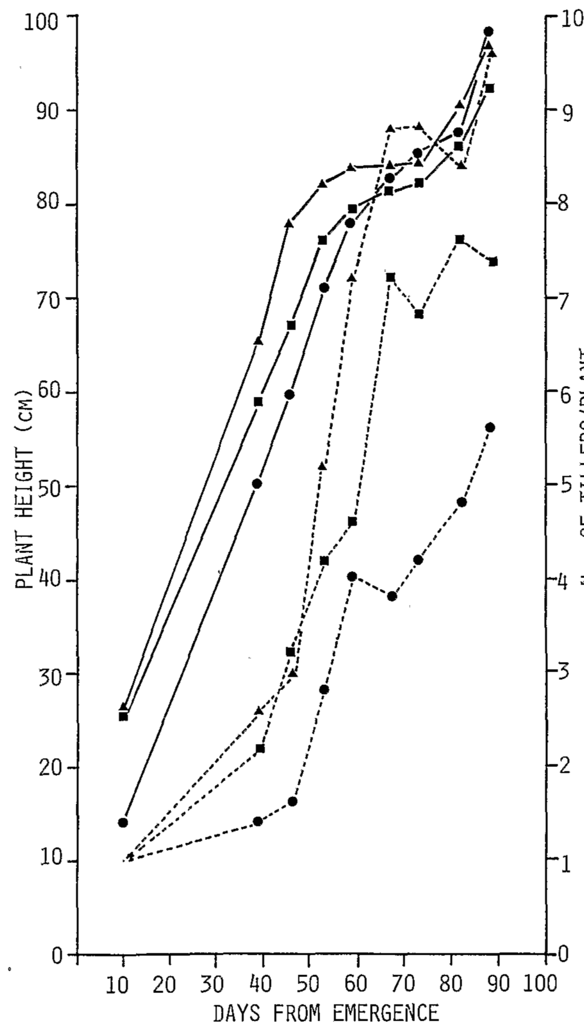

Fig. 1. The influence of initial population density of *Pratylenchus zeae* 0, ▲; 660, ■ and 3 000, ● nematodes/100 ml soil on plant height (solid line) and tillering (broken line) of rice cv. IR36.

Field experiments

The number of established hills/plot for Kinandang Patong and Upl Ri-5 was the same in plots with and without carbofuran.

Table 1

The influence of *Pratylenchus zeae* on root weight and yield components of rice cv. IR36

P_i /100 ml soil	P_f /g root	Root fresh wt. (g)	No. of panicles/plant	No. of spikelets/plant	No. of grain/plant	Wt. of grain (g)
0	0 *a*	7.3 *b*	11.4 *b*	1190 *b*	835	17.34
630	11786 *b*	4.39 *a*	8.8 *a*	890 *a*	717	14.72
3000	13220 *b*	3.31 *a*	7.4 *a*	823 *a*	724	15.24
P	< 0.05	< 0.01	< 0.05	< 0.001	NS	NS

Data are means of 5. Within a column, means not followed by the same letter are different at the level of P indicated. NS indicates no significant differences between means in a column.

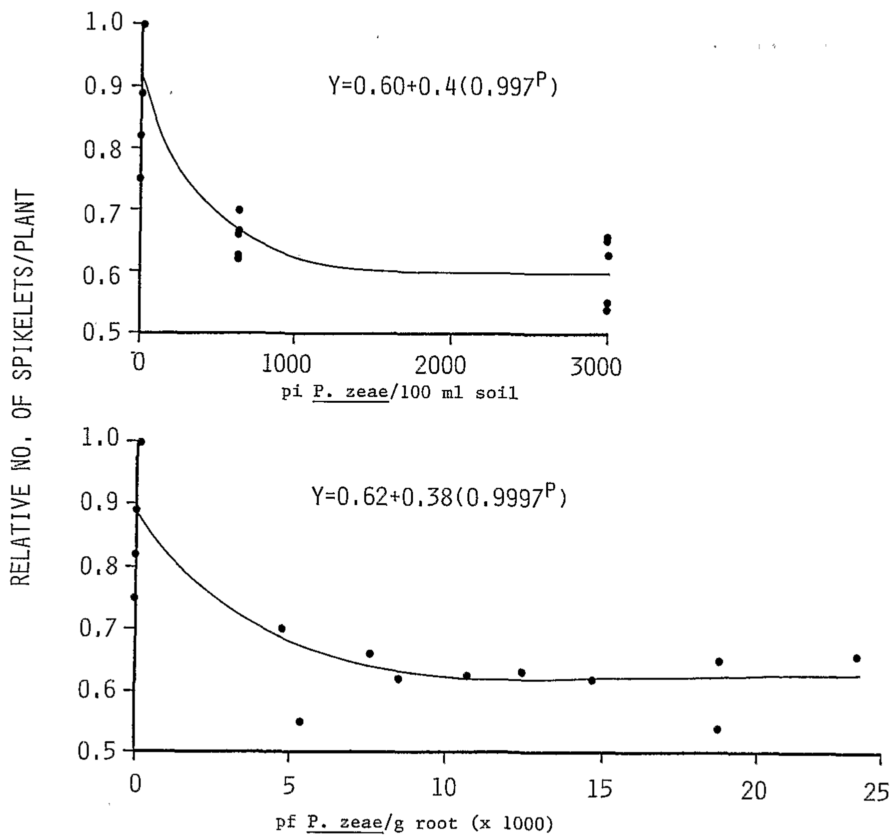

Fig. 2. The relationship between the number of spikelets/plant and population density of *P. zeae* on rice cv. IR36 in pots.

From 30 to 45 days after sowing the plant height of Kinandang Patong in untreated plots was less than that from plots treated with carbofuran (8 kg a.i./ha) ($P < 0.05$) but this difference was not evident at subsequent assessments. The plant height of cv. Upl Ri-5 at 30 days after sowing was less on untreated plots than treated plots and this difference was evident throughout the assessment period and at harvest ($P < 0.05$) (Fig. 3, Table 2).

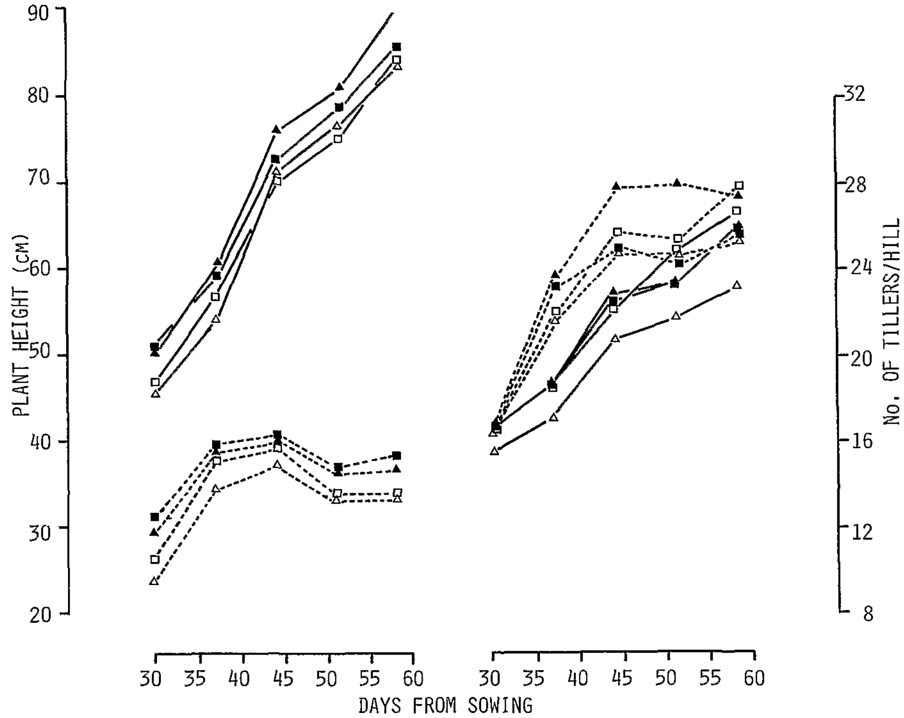

Fig. 3. The influence of carbofuran at 0, △; 2, □; 4, ■ and 8, ▲ kg/a.i./ha on plant height (left) and tillering (right), rice cv. Kinandang Patong (solid line) and rice cv. Upl Ri-5 (broken line) in a field infested with *Pratylenchus zeae*.

Table 2

The effect of carbofuran on plant height and the yield of upland rice cvs Kinandang Patong and Upl Ri-5 in a field infested with *Pratylenchus zeae*

Carbofuran kg a.i./ha	Plant height at harvest (cm)		No. of panicles /hill		No. of grain /panicle		Total grain yield kg/ha	
	Kinandang Patong	Upl Ri-5	Kinandang Patong	Upl Ri-5	Kinandang Patong	Upl Ri-5	Kinandang Patong	Upl Ri-5
0	132	103 *a*	6	10	145	85 *a*	2005	1984 *a*
2	131	107 *b*	7	11	133	103 *b*	2372	2253 *ab*
4	129	107 *b*	7	11	121	104 *b*	2141	2565 *b*
8	131	108 *b*	7	11	131	98 *b*	2012	2426 *b*
P	NS	< 0.05	NS	NS	NS	< 0.05	NS	< 0.05

Within a column, means not accompanied by the same letter are different at the P indicated. (Means of 24 samples of each of four replicates.)

Treatment with carbofuran did not significantly influence the rate of production or the maximum number of tillers/hill of cv. Kinandang Patong or cv. Upl Ri-5 nor did it affect the number of panicles/hill at harvest (Fig. 3, Table 2).

The field trial was infested with *P. zeae*, *Tylenchorhynchus annulatus*, *Helicotylenchus pseudorobustus* and *Criconemella onoensis*. The average initial soil population density of *P. zeae* was 18 (0-82)/100 cm^3 soil and 33 (2-111)/100 cm^3 soil, in plots sown with Kinandang Patong and Upl Ri-5 respectively. There were no significant, coincidental, pre-treatment, differences in nematode population density.

Treatment with carbofuran, significantly reduced the number of *P. zeae*/g root of both cultivars and *P. zeae*/100 cm^3 soil at maximum tillering, flowering and harvest ($P < 0.01$ or $P < 0.05$), however, there were no significant differences between application rates of 2, 4 and 8 kg a.i./ha (Fig. 4, Table 3).

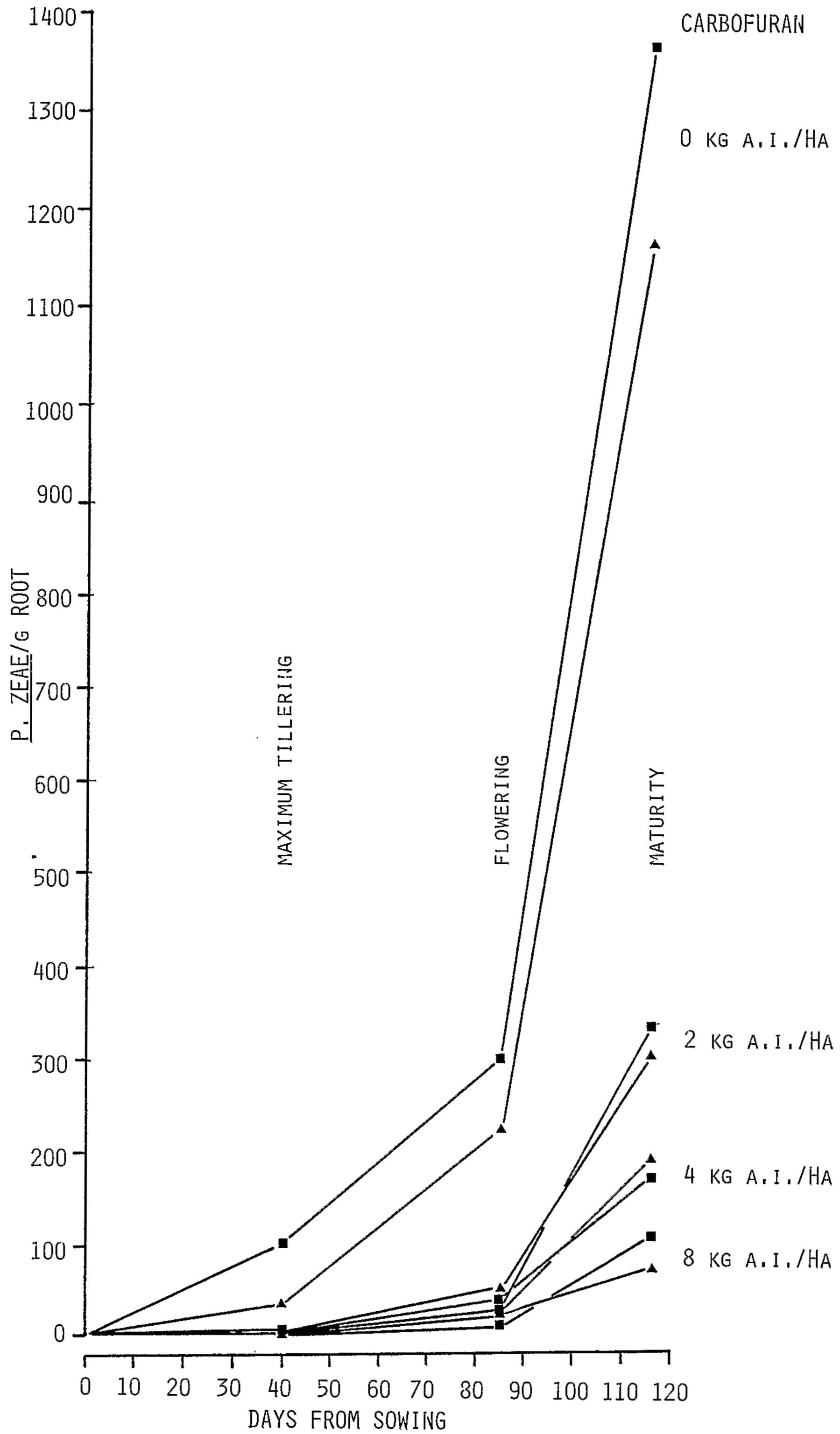

Fig. 4. The effect of carbofuran on the population dynamics of *P. zeae* on rice cv. Upl Ri-5, ■ and cv. Kinandang Patong, ▲.

Table 3

The soil population densities of *Pratylenchus zeae* and *Tylenchorhynchus annulatus* on upland rice cultivars Upl Ri-5 and Kinandang Patong at different crop growth stages

Carbofuran kg a.i./ha	Maximum tillering		Flowering		Harvest	
	Kinandang Patong	Upl Ri-5	Kinandang Patong	Upl Ri-5	Kinandang Patong	Upl Ri-5
P. zeae/100 ml soil (means of 4)						
0	34 *b*	12 *b*	16 *b*	39 *b*	75 *b*	103 *b*
2	1 *a*	3 *a*	4 *a*	4 *a*	27 *a*	17 *a*
4	2 *a*	2 *a*	3 *a*	4 *a*	20 *a*	29 *a*
8	1 *a*	< 1 *a*	2 *a*	3 *a*	24 *a*	19 *a*
P	0.01	0.05	0.01	0.01	0.05	0.05
T. annulatus/100 ml soil (mean of 4)						
0	200 *b*	185 *b*	80	24	515	339
2	59 *a*	33 *a*	65	21	573	493
4	60 *a*	22 *a*	54	30	879	533
8	28 *a*	18 *a*	64	25	488	546
P	0.05	0.01	NS	NS	NS	NS

For each nematode, within a column, means not accompanied by the same letter are different at the P indicated.

The average pre-sowing soil population densities of *H. pseudorobustus* and *C. onoensis* were less than one nematode/100 cm^3 soil and densities of these nematodes remained low (i.e. < 40 nematodes/100 cm^3 soil) throughout the trial period. The population density of *T. annulatus* was also low initially (eight nematodes/100 cm^3 soil) but increased during the trial and at maximum tillering was inversely proportional to the rate of carbofuran. The density on untreated plots at flowering had dropped whilst that on treated plots had remained approximately unchanged. Numbers of *T. annulatus* on Upl Ri-5 at harvest were directly proportional to grain yield (Table 3).

Carbofuran increased the number of grains/panicle of Upl Ri-5 and total grain yield was increased by 13-29 % ($P < 0.05$) of the untreated control (Table 2); 1 000 grain weight, panicle length and number of panicles/hill were not affected. The yield of Kinandang Patong was not affected by carbofuran.

The relationship between grain yield of Upl Ri-5 and population density of *P. zeae* was described by the model (equation 1). Logarithm transformation of population densities gave significant linear correlations ($r = -0.606$, $P < 0.05$) ($r = -0.628$, $P < 0.01$) and ($r = -0.595$, $P < 0.05$) at maximum tillering, flowering and harvest respectively. The relative minimum yield was 64-65 % of maximum yield and occurred at a population density of approximately 75, 150 and 1 000 *P. zeae*/g root at maximum tillering, flowering and harvest respectively (Fig. 5).

The grain yield of Kinandang Patong was not related to the density of *P. zeae*.

Discussion

This work has demonstrated that *P. zeae* can cause yield loss in upland rice. Cultivars appear to differ in their tolerance of nematode infection since the control of *P. zeae* on the cultivar Upl Ri-5 resulted in a yield increase, over infected plants, of 13-29 %, whereas the yield of the equally susceptible cultivar, Kinandang Patong, was not influenced by nematode control.

The control of other plant parasitic nematodes, *T. annulatus*, *C. onoensis* and *H. pseudorobustus* was temporary and the population density of the most numerous of these, *T. annulatus*, tended to fluctuate directly with yield suggesting that they were not causing damage.

The relationship between the yield of rice and the density of *P. zeae* differed in pot and field experiments. In the field, the yield loss curve for rice cv. Upl Ri-5 fitted the exponential model (see above) indicating low tolerance to *P. zeae*, whereas in pots the relationship was linear which suggests some tolerance. The relative minimum yield was the same in both glasshouse and field experiments. These differences in tolerance may be due to cultivar differences but may also be an artefact of pot conditions since the relationship between the potential yield, given by the total number of spikelets, and the population density of *P. zeae* was of the same form as that for grain yield in the field.

The expression of tolerance in pots was probably facilitated by adequate soil moisture which would help to alleviate the effect of the significant reduction of root biomass which occurred. However, the relationship between harvest index and P_i suggests a possible mech-

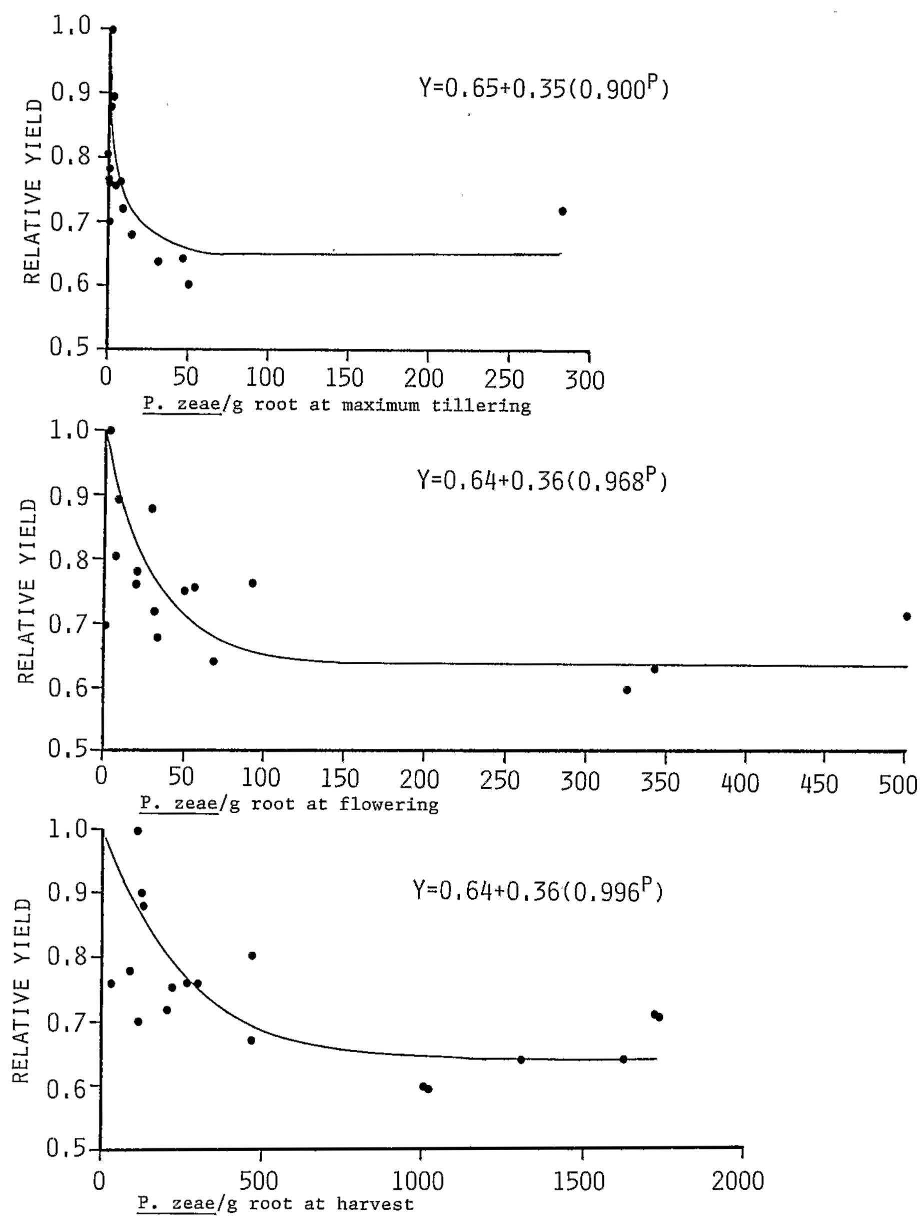

Fig. 5. The relationship between the yield of rice cv. Upl Ri-5 and the population density of *P. zeae* in roots at different growth stages.

anism operating through the partitioning of biomass into grain filling in infected plants. In the field, tolerance to nematodes may depend on soil moisture and therefore damage by *P. zeae* would be more conspicuous in drought or generally unfavourable growing conditions. Drought avoidance strategies in plants, such as deep roots, may also provide nematode tolerance.

The pre-sowing population densities of *P. zeae* in the field experiment were low and probably close to the minimum detectable level without more detailed sampling. The data therefore predict that yield loss can be expected if detectable population densities of *P. zeae* are present. The constant minimum yield over a wide range of population densities suggests that higher yield losses than those observed in this field trial are unlikely. High pre-sowing population densities of *P. zeae* may affect establishment and reduce minimum yield in the field, however there is no evidence that such densities, equivalent to those used in the pot experiment, occur in the field. Prasad and Rao (1978) generally found low pre-sowing population densities of *P. indicus* (3-16 nematodes/100 g soil) and their data suggest that in a range of rice cropping systems, which allowed a fallow period before rice, *P. indicus* population densities rapidly decline to these levels. Unless intercropping of rice and other susceptible crops such as maize is practised then the same is likely to be true for *P. zeae*. Yield loss will then depend on the susceptibility and tolerance of a rice cultivar. In the present work, the population dynamics of *P. zeae* on Upl Ri-5 and Kinandang Patong was the same and the difference in the susceptibility of the two cultivars determined in pot tests was not evident in the field. Nevertheless, consistent differences in susceptibility between rice cultivars have been found (Plowright, unpubl.) and may prove to be useful.

If future tests show that tolerance to *P. zeae* infection is stable and widespread then this is more likely to be useful in alleviating nematode problems particularly if it is linked to drought tolerance or avoidance.

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