The relationship between initial population density of potato cyst nematode *Globodera pallida* and the yield of partially resistant potatoes

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SUMMARY

The relationship between initial population density of *Globodera pallida* and yield was examined in five partially resistant and one non-resistant potato genotypes in a field trial. In the previous year, the experimental area had been manipulated using resistant and non-resistant potato genotypes to give plots with a range of initial population densities. The results showed that there were differences in the yield losses sustained by the different genotypes but that these were not related to their level of resistance. The data were examined using linear (Brown, 1969) and loglinear (Oostenbrink, 1966) regression models, an exponential model (Seinhorst, 1965) and an inverse linear model. The inverse linear model was found to summarise the data as adequately as the exponential model but with one less parameter.

RÉSUMÉ

Relation entre taux de la population initiale du nématode à kyste Globodera pallida *et valeur de la récolte de pommes de terre partiellement résistantes*

Un essai au champ a permis d'étudier la relation entre le taux de la population initiale de *Globodera pallida* et la valeur de la récolte chez cinq génotypes de pomme de terre partiellement résistants et un génotype non résistant. Les années précédant l'essai, le terrain avait été aménagé de façon à disposer d'un éventail de populations initiales. Les résultats ont montré des différences de récolte entre génotypes, mais ces différences ne sont pas liées au niveau de résistance. Les données ont été exploitées grâce à des modèles de régression linaire (Brown, 1969) et loglinéaire (Oostenbrink, 1966), un modèle exponentiel (Seinhorst, 1965) et un modèle linéaire inverse. Ce dernier permet une définition des données aussi bonne que celle fournie par le modèle exponentiel, mais avec un paramètre en moins.

Potato yield is adversely affected by potato cyst nematodes (PCN). However, damage can be reduced by planting cultivars with different levels of tolerance (Trudgill, 1986) and resistance on a rotational basis. Nematicide trials to investigate tolerance differences have been conducted using resistant or partially resistant potato genotypes where yields from treated and untreated plots were compared (Trudgill *et al.*, 1983; Trudgill, Mathias & Tones, 1985; Whitehead *et al.*, 1984, 1987; Dale *et al.*, 1988). These trials identified tolerance differences but were not designed to study the relationship between initial PCN density *(Pi)* eggs/gm soil and yield loss.

Differences in tolerance to nematode damage are of particular importance in cultivars with resistance to PCN as these cultivars are most likely to be grown in infested soils. Strategies for maximising long-term yield can be investigated by modelling the interactions between *Pi* and yield. Equations relating the relationship between *Pi* and tuber or plant yield are an integral part of these models.

Three equations have been used in the literature to describe the effect of *Pi* on yield. Brown (1969) fitted a simple, linear yield loss model

$$E(Y) = a + b\,(Pi) \qquad (1)$$

to field trial data for non-resistant cultivars. Here Y is the observed tuber yield and $E(Y)$ is its expected value for a given value of *Pi*. A variant of this model was suggested by Oostenbrink (1966) who regressed yield on *log (Pi)*, giving the log-linear model

$$E(Y) = a + b\,(\log Pi) \qquad (2)$$

Seinhorst (1965) introduced the exponential model

$$\{E(Y) = Y_{max}\,[m + (1 - m)z^{(Pi-T)}] \text{ if } Pi > T$$
$$E(Y) = Y_{max} \text{ if } Pi \leqslant T\} \qquad (3)$$

This equation has four parameters : Y_{max}, the expected yield in the absence of nematodes; T, the threshold for *Pi* below which no damage occurs; z, the rate at which increasing *Pi* decreases expected yield and m, the ratio of minimum $(Pi = \infty)$ to maximum $(Pi = 0)$ expected yield. Seinhorst justified the additional complexity by providing these biological interpretations for the parameters. Equation *(3)* is difficult to interpret because tolerance depends on the three parameters m, T and z. We introduce a fourth equation, the inverse linear model

$$E(Y) = Y_{max}\,[1 - (1 - m)\,Pi/(c + Pi)] \quad (4)$$

giving fitted curves which are qualitatively like those from equation *(3)*, in that they have sigmoidal shape when plotted against *log (Pi)*. Equation *(4)* can be derived [redacted]

This paper describes an analysis of data from an experiment in which a field population of PCN was manipulated to give a range of *Pi*. The tuber yields were analysed by fitting each of the four equations above to the data. The suitability of these equations for describing the relationship between *Pi* and yield loss is discussed.

Materials and methods

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Two of the genotypes (Maris Piper and an early maturing breeders' clone 11242) were non-resistant and seven were breeders' clones, derived from *Solanum*

extracted from the cysts using the modified Bijloo method (Seinhorst & Den Ouden, 1966).

An analysis of variance was performed on the estisubtracted from all residual sums of squares quoted (Table 2).

Table 2

Goodness of fit tests for each of the four models

Model	*d.f.*	*SS*	*F*
Linear	126	3 266	3.5
Loglinear	126	965	1.1
Exponential (Seinhorst, T = 0)	120	954	1.1
Inverse linear (m = 0)	126	954	1.0
Pure error	60	440	

Fitting the linear model (Equation 1) to the data gave a residual sum of squares of 3266 (126 d.f.), indicating a significant lack of fit ($F_{126,60} = 3.5$). This was confirmed by plots of the residuals against *Pi* showing considerable bias.

The log-linear model (Equation 2) gave a residual sum of squares of 965 (126 d.f.) indicating a good fit to the data which was supported by the lack of fit test ($F_{126,60} = 1.1$). The slope parameter (Table 3) can be held constant across five of the genotypes ($F_{4,60} = 1.7$) but not across clone 12243 as well ($F_{1,60} = 94$). However, there is no guarantee that this model will give positive predicted yields for high values of *Pi*, and the fitted curve is unbounded at $Pi = 0$.

most tolerant clone, 12243, the estimates of m and z were very highly correlated. The values of m and z appeared to be constant across the other five genotypes ($F_{8,60} = 1.0$). Furthermore, either m ($F_{1,60} = 2.5$) or z ($F_{1,60} = 0.0$) can be held constant across all varieties, but not both ($F_{2,60} = 113$). Residual plots and the lack of fit test ($F_{120,60} = 1.1$) indicate a good fit.

Table 4

Estimates of Y_{max} and the transformations of parameters m, z (with S.E.s in brackets) from the exponential equation $(T = 0)$ derived from fitting curves to yield as a function of *Pi* for six genotypes of potatoes

Clone	Y_{max}	$Log_e\,[m/(1 - m)]$	$Log_e\,[z/(1 - z)]$
Maris Piper	27.9 (1.9)	− 2.39 (1.71)	3.57 (0.27)
Fiona	24.3 (1.3)	− 1.79 (0.47)	3.35 (0.21)
12243	21.3 (0.6)	− 1.04 (8.11)	5.76 (2.59)
Morag	27.5 (1.7)	− 1.46 (0.37)	3.18 (0.24)
11233	24.2 (1.19)	− 1.68 (0.32)	3.09 (0.20)
Vantage	24.8 (0.97)	− 1.13 (0.32)	3.14 (0.17)

The inverse linear model (Equation 4) gave a slightly better fit to the data than equation 3 (Tables 2 & 5). Constraining m to be zero did not result in a significant lack of fit ($F_{6,60} = 0.3$), whereas it did result in a

[redacted]

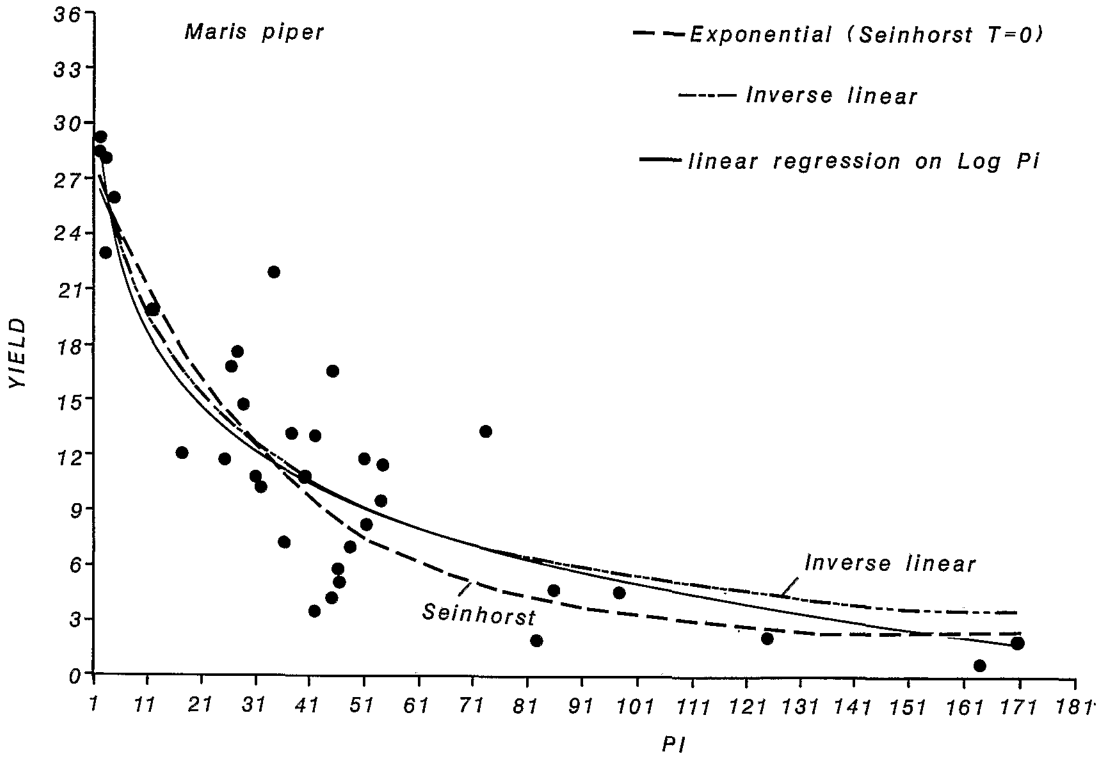

Fig. 2. Unconstrained fits of yields as a function of *Pi* for potato genotype clone 12243 grown in field plots infested with *G. pallida.*

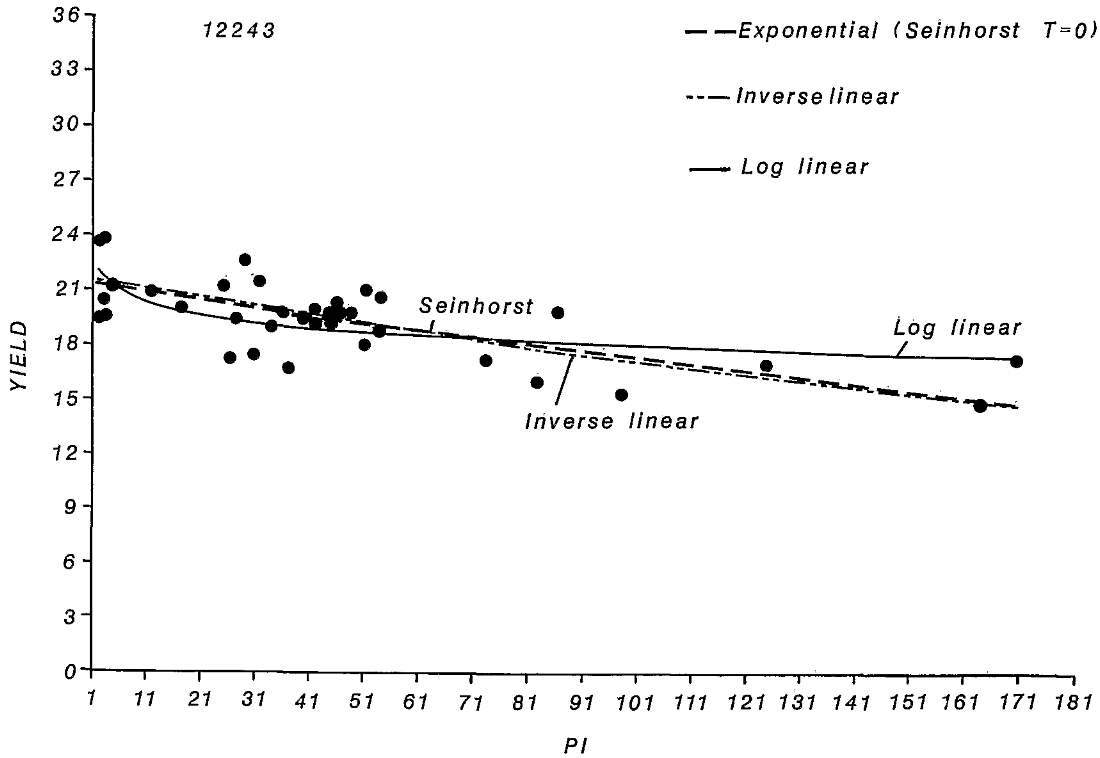

Fig. 3. Unconstrained fits of yield as a function of *Pi* for potato genotype Maris Piper grown in field plots infested with *G. pallida.*

Discussion

There are marked differences between the potato genotypes in the degree of yield loss sustained in heavily infested soil. However, as found by others (Trudgill & Cotes, 1983; Alphey & Phillips, 1988; Dale *et al.*, 1988); there was no obvious relationship between differences in tolerance of damage and the level of resistance to *G. pallida*. Non-resistant Maris Piper was intolerant as was moderately resistant cv. 11233. Vantage, the most resistant cultivar, was moderately tolerant whereas clone

(3) and (4). Of the six genotypes, five appeared to have identical tolerances, whereas the sixth was considerably more tolerant. This latter clone yielded least at low *Pi* but had the greatest yields for *Pi* higher than 11 eggs/g soil.

Whether or not the data support the hypothesis that PCN can reduce tuber yields to nothing is debatable. Fitting Equations (3) and (4) led to different conclusions. This can be accounted for by the different rates of approach to the asymptote assumed by the two

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