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# Determining the Relationship between Population Density of White Tip Nematode and Rice Yield

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## ABSTRACT

**The relationship between initial population density of rice white tip nematode (*Aphelenchoides besseyi*) and yield was examined on *Oryzae sativa* cv. Alikazemi. Experiments were conducted in greenhouse, micro-plot and field conditions. Seinhorst's model was used to describe the relationship between nematode population density and crop yield. The parameters of the model, minimum yield (m), constant coefficient (z) and tolerance limit (T) were obtained from the experimental data. On this basis, the predicted yield was calculated within the initial population (*Pi*) range. To evaluate the difference between the observed yield (Yo) and the predicted yield (Yp), a discrepancy ratio (DR) was calculated. The results revealed that there was a significant correlation between mean yield reduction and nematode populations (P<0.01). At the highest initial population density, grain yield was reduced by 69%. In greenhouse experiments, the discrepancy ratio was larger than 0.03 and the predicted yield was overestimated compared to that predicted in microplot or field experiments. The model had the minimum mean of error when data were incorporated from the field experiments (ME= 0.0149). The indices from microplot and greenhouse experiments were 0.0823 and 0.2036, respectively. The relationship between nematode population density and relative grain yield fitted to the model was under field conditions.** $Y = 0.59 + (1-0.59)0.41^{(P-62.5)}$

**Keywords:** *Aphelenchoides besseyi*, Field, Greenhouse trials, Microplot trials, *Oryzae sativa*, Seinhorst's model,

## INTRODUCTION

Rice white tip nematode (*Aphelenchoides besseyi* Christie, 1942) is one of the most important nematode pests of rice production throughout the world including Iran (Bridge *et al*., 2005, Jamali *et al*., 2006). It is an ectoparasitic nematode of leaves and young tissues. *Aphelenchoides besseyi* is seed borne and can survive in stored seeds for several years, under dry conditioned (Tiwari. and Khare, 2003). The pest is transported in rice seeds, accompanying chaff, and plant material and can also be spread by irrigation in fields (Tiwari and Khare, 2003). White tip disease may occur even in fields where clean seeds are sown. *Aphelenchoides besseyi* reproduces on fungi which colonize post-harvest straw (Sivakumar, 1987). Maximum density of the nematode is reportedly 121 individuals per deformed seed (Gergon and Mew, 1989). The minimum yield loss was reported to be 5% with 30 living nematodes per 100 seeds. Under favorable conditions, only one infested seed is needed to spread the infection (Gergon and Mirsa, 1992; Fukano, 1962). Yield loss is due to the degree of pathogenicity of the nematode, population density, host sensitivity and tolerance as

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well as environmental factors (Trudgill and Phillips, 1998). In infested fields, average loss is 10 to 30% depending primarily on the susceptibility of the planted cultivar and especially on the nematode population density (Prot, 1992). Accordingly, population density can be used to assess damage levels.

Models of nematode populations and crop yields result from the integration of mathematical theories and computer programs that reflect part of presumptive reality. In modeling, past information serves to predict future data and in this instance its main goal is to estimate crop yield based on nematode population and other exiting data. Forecasts of predicted loss, based on estimates of nematode populations, can be used to determine when and if suitable control methods should be applied (Barker *et al*., 1985). Earlier studies were carried out to determine the relationship between nematode-plant interactions and loss threshold or limits of plant tolerance. Results of these studies provide a numbers of experimental models for nematode population and yield loss in crops. Seinhorst was the first nematologist that introduced an effective model of the relationship between yield and nematode number (Seinhorst, 1965).

The Seinhorst's model was based on the Nicholson competition curve (Nicholson, 1933). Using the Seinhorst's model, it was possible to forecast crop yield in an infested fields by collecting data on several densities of nematode populations. The model had two components, tolerance limit (T) and minimum yield (m) which were studied in a nematode-host combination. Seinhorst (1965) believed that each interaction had a distinct level or threshold of nematode population that plant damage depend on it. Furthermore, there was a population density of nematodes below which no crop loss occurred. This was the tolerance limit (T). The model was used as below:

$$Y = m + (1-m)Z^{(P-T)}$$

In this model, Y is the yield (ranging from zero to one), m is the minimum relative yield when nematode population density is maximum, Z is a constant coefficient and less than one; it represents that part of root system which is not invaded when nematode population is at density (P=1). P is the nematode population density and T is the tolerance limit.

The Seinhorst's model has been used for plant parasitic nematodes including root knot nematodes (*Meloidogyne incognita* and *M. graminicola*) and potato cyst nematode (*Globodera pallida*) (Phillips *et al*., 1991; Ehwaeti *et al*., 2000; Poudyal *et al*., 2005). In the present study, the relationship between population densities of *A. besseyi* and rice crop yield was evaluated using this model under comparable greenhouse, microplot and field conditions. The aim of this study was to develop a model to evaluate crop loss through population density of this pathogenic nematode in rice.

## MATERIALS AND METHODS

The soil for nursery, greenhouse pots and microplots was sterilized by sodium metham (145 ml/$m^2$). To ensure the use of healthy seeds, rice seeds of cv. Alikazemi were soaked in water at 55˚C for 15 min and then seeded in a nursery. The grown seedlings were transplanted to pots (25 diameter * 30 depth) and microplots at the three-leaf stage and were inoculated with nematodes.

Nematodes were cultured on *Alternaria alternate* grown on PDA (Potato Dextrose Agar) plates (Jamali *et al*., 2006, 2008). The nematodes were harvested four weeks after inoculation and the populations were recorded. For this purpose, each Petri dish lid was initially removed and the colony surface was thoroughly washed into a container. Then, the medium was sliced and processed by a modified Baermann funnel technique (Hooper, 1990) for 48 hours. Inoculation was carried out using the plastic tube method in leaf pods





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(Jamali *et al*., 2006). Six population levels were used including; 0 (distilled water), 100, 300, 500, 700 and 900 nematodes per plant. The greenhouse experiment was conducted at the temperature of 28-30°C and 85-90% relative humidity. The experimental design was a completely random design with four replicates. After the growth of the plants was completed, crop yield was measured and then nematodes were extracted and counted (Coolen. and D'Herde, 1972).

Microplot experimental conditions were similar to those in the greenhouse. The tests were performed using a randomized complete block design with 4 replicates. Dimensions of the experimental plots were 0.5×1 meter.

To prevent secondary infections and nematode introduction by irrigation, the microplots were isolated using polyethylene sheets and the pots were kept in separate plates. For field experiments, 10 farms were selected in several regions of Gilan province in Iran and the experiments were repeated over a period of two years. In all experiments, rice cv. Alikazemi was used. Nematode population density was measured in early and late stages of the growing season; the crop yield was recorded for two years.

For modeling, all data across the two years were combined. Data analysis and graph drawing were carried out using Stat graphics, SPSS and Excel software. Comparison of means was made using Duncan's multiple range test.

## RESULTS AND DISCUSSION

### Model of Loss Assessment in Greenhouse Tests

Parameters calculated using collected data were compiled and incorporated into the Seinhorst model to compute predicted yields. The predicted yield was then compared with the observed yield (Table 1). The curve of the observed yield against predicted yield shows a high correlation between these two variables based on a polynomial model. The best results were obtained where a quadratic function was used ($R^2$=0.98) (Figure 1). As the P-value is less than 0.01 in the analysis of regression variance (Table 2), there is a significant correlation between them at the 99% level. The calculated $R^2$ showed that using the fitted model, 91.85 of the variation in the observed yield could be accounted for.

**Table1**. Predicted yield compared with observed yield in greenhouse experiment.

| Nematode population | Predicted yield (Yp) | Observed yield (Yo) |
|---|---|---|
| 0 | 1 | 1 |
| 0 | 1 | 1 |
| 100 | 1 | 0.94 |
| 100 | 1 | 0.97 |
| 300 | 0.93 | 0.68 |
| 300 | 0.94 | 0.66 |
| 500 | 0.88 | 0.45 |
| 500 | 0.89 | 0.43 |
| 700 | 0.83 | 0.39 |
| 700 | 0.84 | 0.32 |
| 900 | 0.78 | 0.35 |
| 900 | 0.8 | 0.31 |

Crop loss assessment model in microplots

After inserting the calculated parameters into the Seinhorst's model, the predicted yields at different nematode population densities were estimated under microplot condition (Table 3). The relationship between observed and predicted yields had the best fit when using a quadratic function (Figure 2).

Regression analysis of variance showed that there was a significant correlation between the observed and predicted yields at the 99% confidence level. The calculated $R^2$ was greater under microplot conditions than under greenhouse conditions, and using the fitted model accounted for more variation in the observed yield (Table 4). This indicates a higher degree of variation in the observed yield by using the fitted model (Table 4).





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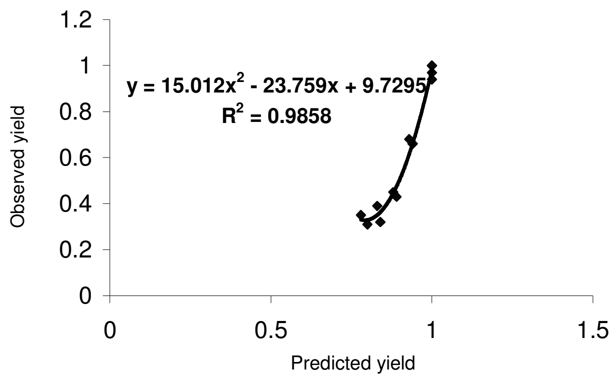


**Figure 1**. Relationship between predicted and observed yields in greenhouse experiments.

**Table 2**. Analysis of regression variance between observed and predicted yields in greenhouse experiment.

| Source | Df | Sum of Squares | Mean Squaires | F-ratio | P-value |
|---|---|---|---|---|---|
| Model | 1 | 0.8225 | 0.8225 | 112.76 | 0.000 |
| Error | 10 | 0.0729 | 0.0072 | | |
| Total | 11 | 0.8955 | | | |

Yo=-2.37587+3.30675 *Yp $R^2$=91.85

**Table 3**. Predicted yield versus observed yield in microplot experiments.

| Nematode population | Predicted yield (Yp) | Observed yield (Yo) |
|---|---|---|
| 0 | 1 | 0.98 |
| 0 | 1 | 1 |
| 100 | 1 | 1 |
| 100 | 1 | 0.99 |
| 300 | 1 | 0.97 |
| 300 | 1 | 0.99 |
| 500 | 0.92 | 0.75 |
| 500 | 0.92 | 0.81 |
| 700 | 0.86 | 0.56 |
| 700 | 0.86 | 0.59 |
| 900 | 0.81 | 0.41 |
| 900 | 0.81 | 0.55 |

## Developing the Crop Loss Assessment Model in Field Experiments

After calculating m, z and T parameters and inserting them into the Seinhorst's model, the predicted yield for each nematode population density was calculated (Table 5). Relationships between observed and predicted yields were linear and the best fitted model is presented in Figure 3.

The regression analysis of variance between observed and predicted yields was significant at the 1% level (Table 6). Since the P-value was less than 0.01, there was a significant relationship between observed and predicted yields at the 99% confidence level based on the linear model. The calculated $R^2$ showed that, by using the fitted model, 78.88% of the variation in the observed yield could be explained. $R^2$ was less in field than in greenhouse and microplot experiments, i.e., accounted for less variability. This reflects the nature of field experiments in which the MSE is usually greater than in greenhouse experiments.

Because the relationship between observed and predicted yields in the fields was linear, decreasing yield in the Seinhorst curve could be adjusted through a linear equation.





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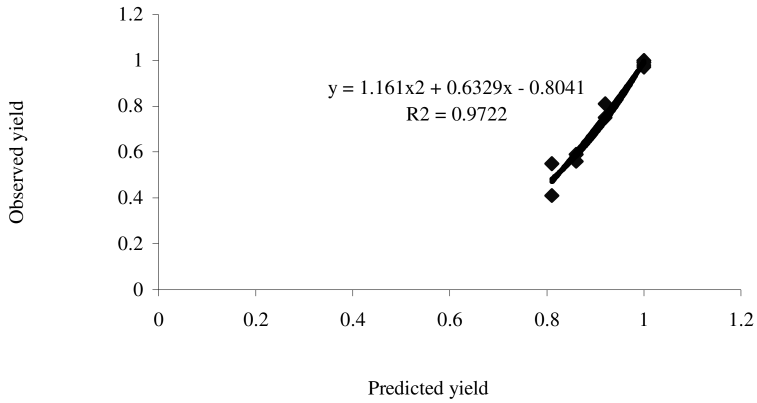


**Figure. 2**. Relationship between observed and predicted yields in microplot experiments.

**Table 4**. Analysis of regression variance between observed and predicted yields in microplot experiments.

| source | df | Sum of Squares | Mean Squares | F-ratio | P-value |
|---|---|---|---|---|---|
| Model | 1 | 0.5173 | 0.5173 | 344.73 | 0.000 |
| error | 10 | 0.015… | 0.0015 | | |
| total | 11 | 0.5324 | | | |

Yo=-1.76675+2.75501 *Yp $R^2$=97.18

To examine the accuracy of the fitted models in greenhouse, microplot and field experiments, the predicted and observed yields were plotted against each other (Figure 4).

The scatter plot of predicted yield (Yp) against observed yield (Yo) as described by the fitted greenhouse, field and microplot models This graph shows that the predicted yield (Yp) from the field model had the best distribution around the 1:1 line. The microplot and greenhouse models ranked second and third, respectively. Consequently, the Seinhorst model made using field data was better than models made using greenhouse and microplot data (Figure4).

Assessing the efficiency of the models

In order to examine the quantitative accuracy of the models, some statistics were used including discrepancy ratio (DR) and the mean of error (ME). Mathematical expression of these statistics are as follows:

**Table 5**. Comparison of predicted and observed yields at different nematode population densities in the field experiments.

| Nematode population | Predicted yield (Yp) | Observed yield (Yo) |
|---|---|---|
| 440 | 0.82 | 0.83 |
| 420 | 0.78 | 0.72 |
| 375 | 0.84 | 0.86 |
| 340 | 0.81 | 0.78 |
| 335 | 0.88 | 0.84 |
| 325 | 0.89 | 0.85 |
| 210 | 1 | 0.88 |
| 170 | 1 | 0.89 |
| 75 | 1 | 0.95 |
| 65 | 1 | 0.91 |
| 0 | 1 | 0.96 |
| 0 | 1 | 0.98 |
| 0 | 1 | 0.99 |
| 0 | 1 | 1 |
| 0 | 1 | 1 |
| 0 | 1 | 0.97 |
| 0 | 1 | 0.98 |
| 0 | 1 | 1 |
| 0 | 1 | 1 |
| 0 | 1 | 1 |

**Table 6**. Analysis of regression variance between observed and predicted yields in the field experiment

| Source | Degree of freedom | Sum of squares | Mean squares | F-ratio | P-value |
|---|---|---|---|---|---|
| Model | 1 | 0.1059 | 0.1059 | 67.25 | 0.0000 |
| Error | 18 | 0.0283 | 0.0015 | | |
| total | 19 | 0.1342 | | | |

Yo= 0.0295784+0.935775 *Yp R=78.88

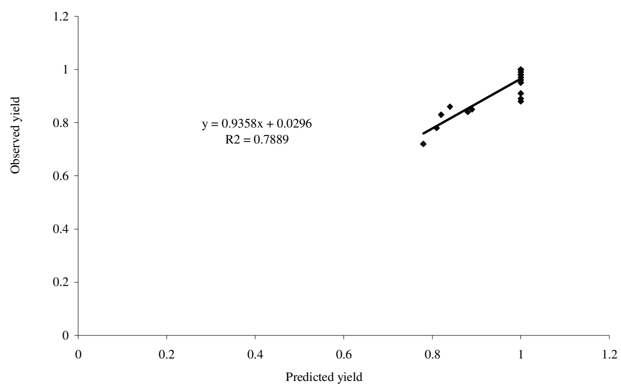


**Figure. 3**. The relationship between observed and predicted yields under field conditions.

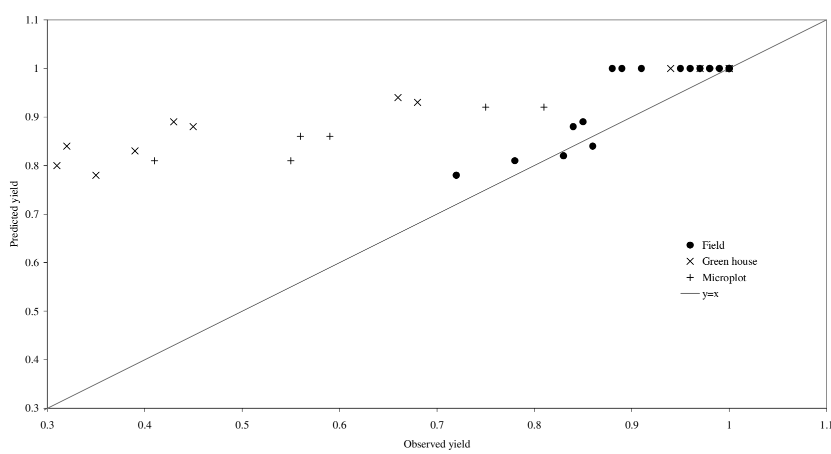


**Figure 4**. The scatter plot of predicted yield and against observed yield as described by the fitted greenhouse, field and microplot models.

Discrepancy Ratio $DR = \log_{(10)} \frac{Y_P}{Y_O}$

The Mean of Error $ME = \frac{1}{N}\sum_{i=1}^{N} DR$

Assessment of differences between predicted and observed yields (Yp and Yo) in the above equation was based on the discrepancy ratio used in the calculation of the mean of error. If the predicted and





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observed yields were equal, Yp/Yo ratio and DR would be 1 and 0, respectively. If the discrepancy ratio was greater than zero, the model would overestimate the predicted yield; and conversely if the discrepancy ratio was less than zero, the predicted yield would be underestimated. Accuracy of models can be approved (affirmed) when discrepancy ratio was between -0.3 and +0.3 (Seo *et al*., 1998). Then, the discrepancy ratio values which were in the above mentioned range could be determined.

By this criterion, if the mean of error was approaching zero, the model would be more accurate. Therefore, the difference between the calculated ME and zero could be used as a benchmark for relative accuracy of the model in predicting yield. Table 7 shows the statistics as described above for several models.

The DR values between -0.3 and +0.3 were greatest from the Seinhorst's model based on field data. The microplot and greenhouse models with means of 16, 12 and 7 were in the second and third places, respectively. Therefore, the predicted yield obtained from the field model was closer to the observed yield than those predicted by microplot and greenhouse models. Consequently, the field model was more efficient and reliable. The predicted yield was overestimated (DR>0.3) using the greenhouse model in comparison with the microplot and field models. However, underestimates of predicted yield (DR<-0.3) were observed only for the field model. Hence, the greenhouse model overestimated and the field model underestimated yields. Finally, the greenhouse model was the best fitted model with the data and all the predicted values were acceptable.

However, the fundamental criterion for acceptability of the model was the mean of error. Error was less from field experiments than from microplot and greenhouse tests. Therefore, quantitative comparisons showed that Seinhorst's model was more suitable for the estimation of decreasing yield due to white tip disease in the field. Greater deviation of observed values and high mean error were observed from microplot and greenhouse data. This deviation was clearest in greenhouse tests (0.2036), as its mean error was greater than that in microplot tests (0.0823) in 2 years. Overestimates of yield loss in the greenhouse tests emphasize this.

Another model that interprets the relationships between population density and plant yield is the Elston *et al*.(1991) model . This model is similar to the Seinhorst equation since it was developed as an altered form of the Seinhorst model. If nematode density is average or the highest, the Elston model over-estimates yield loss. That this model could not interpret biological processes was its greatest limitation (Schomaker and Been, 2006).

Although models similar to the Seinhorst model (Noe *et al*., 1991, Elston *et al*., 1991) and quadratic models have also been used to establish relationships between yield and population density (Nardacci and Barker, 1979; Schmitt and Barker, 1981), the Seinhorst's model has been the one most widely applied (Phillips *et al*., 1991; Ehwaeti *et al*., 2000). It was the first model for assessing plant yield (Schomaker and Been, 2006). Recently, this model was used to assess the relationship between nematode populations and relative yield of rice plants infected by *Meloidogyne graminicola* (Poudyal *et al*., 2005) where the Seinhorst's model was found to be very efficient for explaining this relationship.

**Table 7**. Comparison of field, greenhouse and microplot models in two years using discrepancy ratio (DR) and mean of error (ME).

| Model | DR values | | | |
|---|---|---|---|---|
| | DR<-0.3 | -0.3<DR<+0.3 | DR>0.3 | ME |
| Field | 4 | 16 | 0 | 0.0149 |
| Microplot | 0 | 12 | 0 | 0.0823 |
| Greenhouse | 0 | 7 | 5 | 0.2036 |

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## تعیین ارتباط بین تراکم جمعیت نماتد عامل نوک سفیدی برگ و عملکرد برنج

**س. جمالی، ا. پورجم و ن. صفایی**

## چکیده

ارتباط بین تراکم جمعیت اولیه نماتد نوک سفیدی برگ برنج (*Aphelenchoides besseyi*) و عملکرد رقم علی کاظمی مورد آزمون قرار گرفت. آزمون در سطح گلخانه، میکروپلات و مزرعه انجام شد. بدین منظور از مدل پیشنهادی سین هورست که بیان کننده این همبستگی می‌باشد، استفاده شد. پس از برآورد پارامترهای مدل؛ شامل حداقل عملکرد نسبی (m)، ضریب ثابت (Z) و سطح تحمل (T)، میزان عملکرد قابل انتظار برحسب مقادیر جمعیت اولیه (Pi) محاسبه گردید. جهت مقایسه عملکرد مشاهده شده (Yo) و عملکرد قابل انتظار (Yp)، از شاخص نسبت اختلاف (DR) کمک گرفته شد. نتایج نشان داد که میزان کاهش عملکرد با جمعیت نماتد، همبستگی معنی‌داری در سطح احتمال یک درصد دارد. در بالاترین سطح تراکم جمعیت اولیه نماتد، کاهش عملکرد ۶۹ درصد ارزیابی شد. نسبت اختلاف در شرایط گلخانه بیشتر از ۰/۰۳ بوده و مقادیر عملکرد قابل انتظار در مقایسه با میکروپلات و مزرعه، دست بالا پیش‌بینی شدند. مدل مذکور دارای کمترین مقدار متوسط خطا در شرایط مزرعه بود (ME = ۰/۰۱۴۹) در حالی که این شاخص برای آزمایش‌های میکروپلات و گلخانه به ترتیب ۰/۰۸۲۳ و ۰/۲۰۳۶ محاسبه گردید. ارتباط بین جمعیت نماتد و عملکرد نسبی با این مدل $Y= 0.59 + (1\text{-}0.59)\ 0.41^{(P-62.5)}$، از برازش قابل قبولی در شرایط مزرعه برخوردار بود.