

# Soybean and Maize Cropping Models for the Management of *Meloidogyne incognita* in the Coastal Plain<sup>1</sup>

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**Abstract:** Models are presented to describe the influence of rotations of *Meloidogyne incognita*-susceptible cultivars, resistant cultivars, and maize on postharvest abundance of *M. incognita* juveniles in the soil. Depending on initial densities of juveniles, monocultured regimes reached equilibrium densities after a few years of 287, 40, and 10 juveniles per 10 cm<sup>3</sup> soil for susceptible soybean, resistant soybean, and maize, respectively. Yearly changes in the population density of juveniles due to rotation of these crops were simulated by iterative substitution of the model equations for each crop. A maximum density of 319 per 10 cm<sup>3</sup> soil was reached following a susceptible cultivar in a susceptible-resistant soybean rotation. Soybean yield loss estimates are presented for monocultured regimes and for various rotations with maize.

**Key words:** crop rotation, *Glycine max*, *Meloidogyne incognita*, southern root-knot nematode, population dynamics, resistance, *Zea mays*.

In Florida, the root-knot nematode *Meloidogyne incognita* (Kofoid & White) Chitwood is a serious pathogen of soybean, *Glycine max* (L.) Merr. Until recently the nematode was managed by applications of the fumigant nematicides DBCP and EDB. Environmental and health problems have eliminated these nematicides as management tools in soybean production. A lack of cost-effective alternative nematicides has intensified the development and use of *M. incognita* resistant cultivars (3,8) and the use of less susceptible crops in soybean rotation regimes (7). The loss of effective nematicides has been used, in part, to document the need for nematode-crop management models (2). The feasibility of employing soybean yield response equations based on determined nematode populations has been reported (1). In cropping regimes where the soil was left fallow during the winter months, yield losses of susceptible soybean cultivars were shown to be linearly related to the postharvest abundance of *M. incognita* juveniles in the soil following the previous year's crop (5). Sampling in the postharvest to midwinter period when juvenile populations in Florida soils remain relatively static offers advantages over sampling in the soybean preplanting period when juvenile populations are subject to unpredictable and rapid decline (5). The following studies were conducted to derive equations describing the

influence of cropping strategies of soybean and maize, *Zea mays* (L.), on the postharvest numbers of *M. incognita* juveniles and soybean yield loss estimates.

## MATERIALS AND METHODS

Crop rotation studies were conducted from 1972 to 1980 on a site infested with *M. incognita* at the Agricultural Research and Education Center at Jay, Florida (6). The soil was a loamy sand ultisol-typic paleudult, typical of soils throughout the Coastal Plain region of the southeastern United States. Summer crops consisted of soybean cultivars susceptible and resistant to *M. incognita* grown in monoculture and in rotations with maize. The site was maintained as an undisturbed fallow during the winter months. In November of each year, all plots were sampled to determine postharvest populations of second-stage juveniles. Nematodes were extracted using the sugar centrifugal-floatation technique (4), and their numbers per 10 cm<sup>3</sup> soil were recorded.

On the assumption that the populations of these juveniles (Y) were the result of the effect of the preceding crop on the previous year's residual population (X), pairs of X and Y values from each plot, taken over the 8-year period, were used to determine if a relationship existed between X and Y with each crop. Data were combined for analyses from three cultivars of susceptible soybean, four cultivars of resistant soybean, and three cultivars of maize. Data where Y = X = 0 were not used in the analyses. Data that included 90, 79, and 498 pairs for susceptible soybean, resistant

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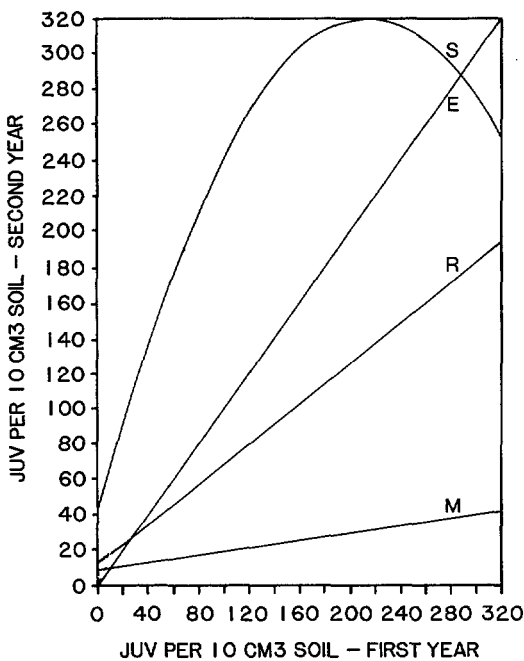


FIG. 1. Relationships between postharvest populations of *Meloidogyne incognita* juveniles in two successive years interposed by planting susceptible soybean (S),  $Y = 44.919 + 2.5667X - 0.006X^2$ ; resistant soybean (R),  $Y = 17.448 + 0.5714X$ ; maize (M),  $Y = 9.424 + 0.1018X$ . E = equilibrium,  $Y = X$ .

soybean, and maize, respectively, were subjected to regression analyses.

#### RESULTS AND DISCUSSION

Highly significant ( $P < 0.001$ ) relationships between  $Y$  and  $X$  were found for all three crops. In association with *M. incognita* susceptible cultivars, residual juvenile densities between 2 years were described:

$$Y = 44.919 + 2.5667X - 0.006X^2$$

corr. coef. = 0.50, df = 88

Where  $X$  was the number of residual juveniles per 10 cm<sup>3</sup> soil after harvest in the first year and  $Y$  was the number after harvest in the second year.

This equation predicted a theoretical postharvest density of 319 juveniles per 10 cm<sup>3</sup> soil in the soybean agro-ecosystem (Fig. 1). This resulted from a previous residual density of  $X = 214$  juveniles per 10 cm<sup>3</sup> soil. Above this value of  $X$ , the estimated residual number of juveniles in the year following the planting of a susceptible cultivar decreased. Planting a susceptible cul-

tivar increased the yearly residual population of juveniles above the restoration level ( $Y = X$ ), provided residual densities were below 287 juveniles per 10 cm<sup>3</sup> soil. At densities higher than this, the planting of susceptible cultivars reduced residual populations below the restoration level. High soil infestation levels could damage a susceptible cultivar so severely that it cannot adequately support existing population levels. Decreased nutritional resources and increased competition within the nematode population resulted in reduced reproduction, hence lower postharvest juvenile populations.

The relationship between residual juvenile populations of two successive years in association with *M. incognita* resistant soybean cultivars was described:

$$Y = 17.448 + 0.5714X$$

corr. coef. = 0.48, df = 77

This equation does not allow for a theoretical maximum population. The slope predicted, however, that residual populations of the nematode were not restored ( $Y < X$ ) when soil containing residual populations of  $X > 40$  juveniles per 10 cm<sup>3</sup> was planted to resistant cultivars the following year (Fig. 1). Thus, when  $X = 100$ , a crop of resistant soybean will produce  $Y = 76$  the following year. Increased populations following  $X < 40$  were indicative of partial (horizontal) resistance of these soybean cultivars to *M. incognita*.

The relationships between residual populations of two successive years in association with maize were described:

$$Y = 9.424 + 0.1018X$$

corr. coef. = 0.27, df = 496

As with resistant soybean cultivars, restoration of the postharvest residual population with maize plantings occurred only at low nematode densities, indicative of the lower status of maize as a host for *M. incognita* as compared with the susceptible soybean cultivars. Postharvest densities of  $X > 10$  juveniles per 10 cm<sup>3</sup> soil were reduced by planting maize in the succeeding year (Fig. 1). Thus, when  $X = 100$ , a crop of maize produced  $Y = 20$  the following year.

*Monoculture models:* Iterative substitutions of  $Y$  for  $X$  in each equation simulated

the population changes following each crop when it was grown in monoculture. This process predicted that postharvest densities would stabilize around equilibrium levels, which were the points where the lines of each equation crossed the restoration line ( $Y = X$ ). This was 287 juveniles per 10 cm<sup>3</sup> soil for the susceptible soybean cultivars, 40 per 10 cm<sup>3</sup> soil for the resistant soybean cultivars, and 10 per 10 cm<sup>3</sup> soil for maize. These equilibrium levels were eventually reached irrespective of the initial soil infestation level preceding the start of the monoculture regime. The equilibrium level for susceptible soybean was close to the theoretical maximum of 319 juveniles per 10 cm<sup>3</sup> soil, and since reproduction of *M. incognita* increased rapidly on this crop, the equilibrium level was reached within 2–3 years whether initial infestation levels were high (Fig. 2A) or low (Fig. 2B). Similarly, monocultured maize, a poor host for *M. incognita* with a low equilibrium level, reached its juvenile equilibrium level within 2–3 years irrespective of the initial soil infestation level. With low initial soil infestations, the equilibrium level for resistant soybean cultivars was reached within 2–3 years. An expanded period of resistant soybean monoculture was needed, however, for high initial populations to be reduced to the equilibrium level (Fig. 2A). This slow decrease was due to the considerable egg production of *M. incognita* females that became established on resistant cultivars (8,9).

*Rotation models:* The influence of crop rotation models on the postharvest abundance of juveniles was simulated by iterative substitution of the crop equations in the desired sequences. The effect of growing susceptible cultivars in increasing rotational sequences with resistant soybean cultivars was schematized (Fig. 3). In the 2-year rotation, simulated equilibrium postharvest populations of juveniles following resistant and susceptible cultivars of 199 and 318 per 10 cm<sup>3</sup> soil, respectively, were reached before 8 years of cropping, depending on the size of the initial infestation (Fig. 3A). It was notable that this rotation produced higher equilibrium densities than either crop when monocultured. The density following resistant cultivars was greatly increased and this rota-

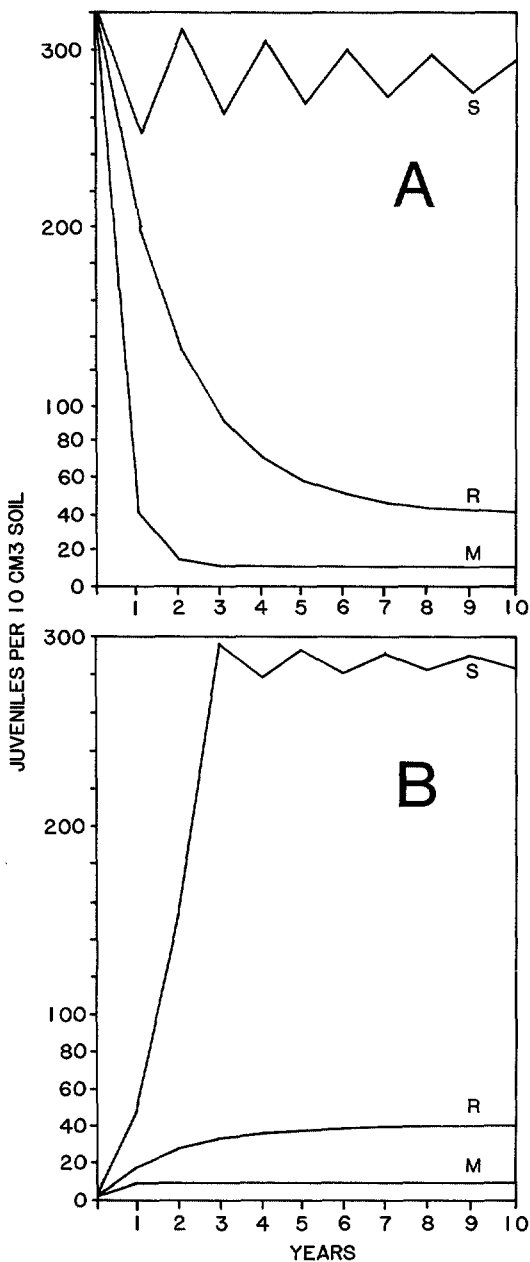


FIG. 2. Predicted postharvest populations of *Meloidogyne incognita* juveniles following initial high population densities (A) and initial low population densities (B) and monocultured to susceptible soybean (S), resistant soybean (R), and maize (M).

tion increased the density following susceptible cultivars to the theoretical maximum soil infestation level. In the longest rotation depicted, when a susceptible cultivar was grown following 4 years of resistant cultivars (Fig. 3D), a maximum

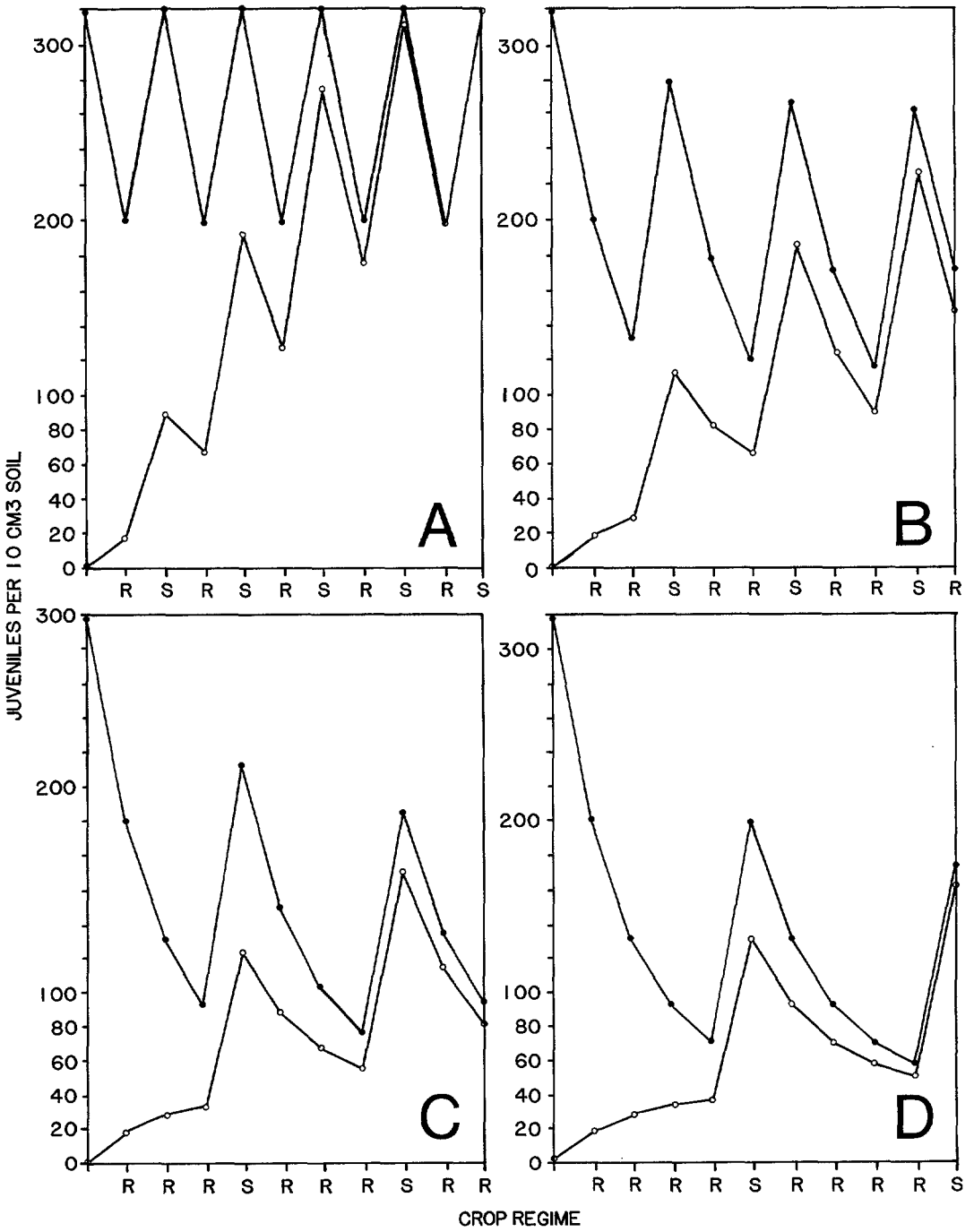


FIG. 3. Predicted postharvest *Meloidogyne incognita* juvenile densities in various rotational sequences of susceptible (S) and resistant (R) soybean cultivars at high (●) and low (○) beginning juvenile densities. A) One-year rotation. B) Two-year rotation. C) Three-year rotation. D) Four-year rotation.

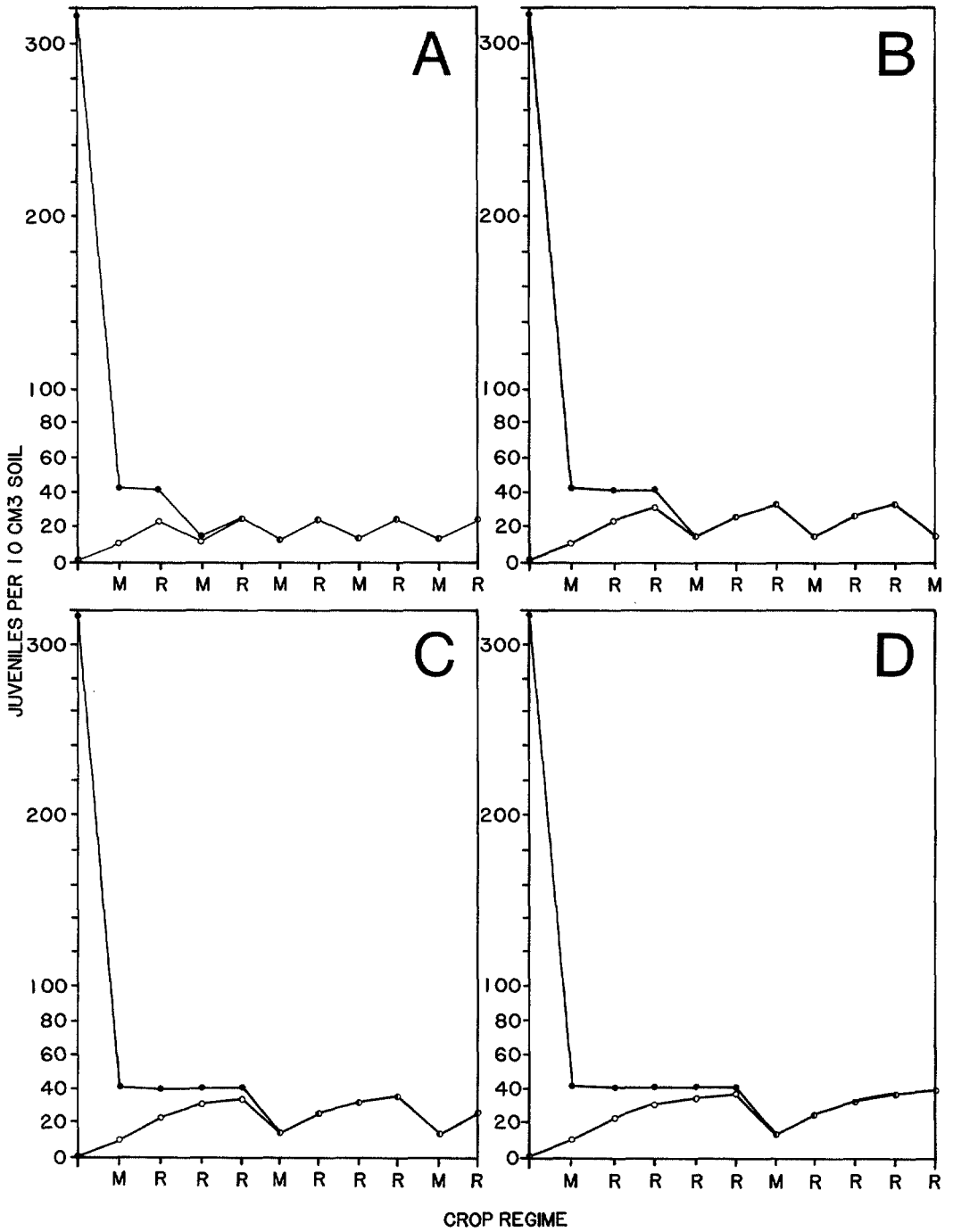


FIG. 4. Predicted postharvest *Meloidogyne incognita* juvenile densities in various rotational sequences of maize (M) and resistant (R) soybean cultivars at high (●) and low (○) beginning juvenile densities. A) One-year rotation. B) Two-year rotation. C) Three-year rotation. D) Four-year rotation.

TABLE 1. Predicted postharvest equilibrium densities of *Meloidogyne incognita* juveniles following maize and resistant and susceptible soybean and estimated soybean yield losses in various cropping regimes.

| Cropping regime* | Postharvest density (juveniles/10 cm <sup>3</sup> soil) | Annual soybean yield loss (kg/ha) | Average annual soybean yield loss for regime (kg/ha) |
|------------------|---|-----------------------------------|--|
| 1. S             | 287   | 1,524                             | 1,524  |
| 2. R             | 40  | 36                                | 36   |
| 3. R             | 199   | 283                               |  |
| S                | 318   | 1,057                             | 670  |
| 4. R             | 164   | 228                               |  |
| R                | 111   | 146                               |  |
| S                | 256   | 589                               | 321  |
| 5. R             | 128   | 172                               |  |
| R                | 91  | 114                               |  |
| R                | 69  | 81                                |  |
| S                | 193   | 366                               | 183  |
| 6. R             | 112   | 148                               |  |
| R                | 81  | 100                               |  |
| R                | 64  | 72                                |  |
| R                | 54  | 57                                |  |
| S                | 166   | 287                               | 133  |
| 7. M             | 12  |                                   |  |
| R                | 24  | 11                                | 11   |
| 8. M             | 13  |                                   |  |
| R                | 25  | 12                                |  |
| R                | 32  | 22                                | 17   |
| 9. M             | 13  |                                   |  |
| R                | 25  | 12                                |  |
| R                | 32  | 22                                |  |
| R                | 36  | 28                                | 21   |
| 10. M            | 13  |                                   |  |
| R                | 25  | 12                                |  |
| R                | 32  | 22                                |  |
| R                | 36  | 28                                |  |
| R                | 38  | 32                                | 24   |
| 11. M            | 19  |                                   |  |
| S                | 90  | 98                                | 98   |
| 12. M            | 38  |                                   |  |
| S                | 134   | 202                               |  |
| S                | 281   | 712                               | 457  |
| 13. M            | 39  |                                   |  |
| S                | 136   | 207                               |  |
| S                | 283   | 722                               |  |
| S                | 291   | 1,503                             | 811  |
| 14. M            | 38  |                                   |  |
| S                | 134   | 202                               |  |
| S                | 281   | 712                               |  |
| S                | 292   | 1,492                             |  |
| S                | 283   | 1,551                             | 989  |

\* S = susceptible soybean; R = resistant soybean; M = maize.

density of 167 juveniles per 10 cm<sup>3</sup> soil was achieved following the susceptible cultivar within a period of 15 years, depending on the initial infestation. Respective cyclical densities following the resistant cultivar will

be 114, 83, 64, and 54 juveniles per 10 cm<sup>3</sup> soil for the first through the fourth crop.

The effect of growing maize in increasing sequences with resistant soybean cultivars was simulated (Fig. 4). The 2-year rotation model indicates that postharvest equilibrium densities of 12 and 24 juveniles per 10 cm<sup>3</sup> soil were achieved following maize and resistant soybean, respectively (Fig. 4A). In the longest rotation, where maize was iterated every 5th year (Fig. 4D), postharvest densities following maize were not substantially increased above those indicated in the 2-year rotation. In the 4-year sequence of resistant soybean cultivars in this rotation, postharvest juvenile densities reached a maximum level of 38 per 10 cm<sup>3</sup> soil following the final year of resistant soybean production. The cropping of maize had a dramatic depressing effect on the postharvest abundance of *M. incognita* juveniles. If maize was introduced at the beginning of the cropping sequence, simulated low postharvest juvenile densities were reached quite rapidly, irrespective of the frequency of maize cropping with resistant cultivars.

*Soybean yield loss estimates:* Yield losses of soybean cultivars susceptible to *M. incognita* in the southern Coastal Plain region of the United States are related to the residual density of juveniles in the postharvest period following the previous summer crop (5). These losses amount to 5.31 kg/ha for each juvenile per 10 cm<sup>3</sup> soil on 'Pickett 71' soybean. Thus, in an established monoculture of susceptible soybean cultivars with postharvest juvenile populations at the equilibrium level, estimated losses of soybean will be  $287 \times 5.31 = 1,524$  kg/ha. Similarly, in a 2-year rotation of susceptible-resistant cultivars after establishment of nematode equilibrium levels, susceptible soybean yield losses will be 199 (equilibrium level following the resistant cultivar)  $\times 5.31 = 1,057$  kg/ha. Resistant cultivars were not so severely damaged by the nematode. Yield losses of resistant cultivars, even in the presence of high nematode infestations, were probably caused by environmental factors other than the nematode. A recent study (8) has shown that soybean yields are inversely related to the amount of root-knot galling. In cultivar testing, where roots were indexed on a scale

of 0 (no galling) to 4 (> 75% root surface galled), susceptible cultivars (gall index greater than 2) had an average galling index of 3.0, whereas resistant cultivars had an average index of 0.5 (8). If we assume that for each value of X in the cropping equations *M. incognita* was six times more damaging to the susceptible cultivar than it was to the resistant cultivar, a yield loss prediction for the latter would be  $5.31 \div 6 = 0.89$  kg/ha for each value of X in the cropping equations. Thus in a stabilized monoculture of resistant soybean in infested soil, a yield loss estimate would be  $40 \times 0.89 = 36$  kg/ha. Similarly, in a 2-year susceptible-resistant rotation, estimated yield losses of the resistant soybean, after stabilization of the nematode, would be  $318$  (equilibrium level following susceptible soybean)  $\times 0.89 = 283$  kg/ha.

Simulated postharvest densities of juveniles and estimated yield losses of soybean in subsequent crops are shown for various cropping regimes in Table 1. These calculations predict the effectiveness of resistant soybean cultivars and maize in moderating the soil infestation levels of *M. incognita* and the need to avoid planting susceptible soybean cultivars in soil infested with the nematode. Once simulated nematode populations became established, there appeared to be negligible differences between monocultured resistant soybean and rotational regimes of resistant soybean and maize in managing the nematode. The choice of the most effective cropping regime involving these crops will be influenced by prevailing economic factors. These may variously favor the planting of soybean or maize. The most effective initial strategy would be to stabilize the nematode population density as quickly as possible. Thus when populations of *M. incognita* were high, planting maize the first year would be the most appropriate decision, even if production of resistant soybean in monoculture was envisioned (Table 2). High population densities following resistant soybean at the initiation of a resistant soybean cropping regime should not be interpreted as a reason for abandoning the practice, since nematode population densities will decline to a lower equilibrium level after a few years of production. Because of the likely enhancement of other

TABLE 2. Influence of planting maize or resistant soybean in the first year of a 4-year rotation on the population density of *Meloidogyne incognita* juveniles, initial nematode density 319 per 10 cm<sup>3</sup> soil.

| Year | Crop* | Juveniles per 10 cm <sup>3</sup> | Crop* | Juveniles per 10 cm <sup>3</sup> |
|------|-------|----------------------------------|-------|----------------------------------|
| 1    | M     | 42                               | R     | 200                              |
| 2    | R     | 41                               | R     | 132                              |
| 3    | R     | 40                               | R     | 93                               |
| 4    | R     | 40                               | R     | 71                               |

\* R = resistant soybean; M = maize.

disease agents, however, monoculturing resistant soybean cultivars may not be a desirable production practice. Consequently, occasional rotation with maize or another poor host for *M. incognita* may be the most advisable course.

The equations for these cropping models were derived from data collected over an 8-year period. They were devised without regard to the influence that seasonal environmental factors may bear on the overwintering mortality of *M. incognita* juveniles. They are, therefore, the result of the influence of the average environmental conditions prevailing during the observation period. More refined models must await studies defining the specific influences that soil factors, such as changes in temperature and moisture, have on the survival of *M. incognita*.

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