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Integrated Management of *Phytophthora* Root Rot of Avocado in Atlixco, Puebla, Mexico

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Abstract. The State of Puebla is a probable center of domestication of avocado. Root rot, caused by the fungus *Phytophthora cinnamomi* Rands is the main parasitic limiting factor in this area. An integrated pest management experiment was established in 1982 in a commercial grove which had several modifications in the general management (irrigation, pruning and chemical fertilization). Additionally, fresh bovine manure (E), alfalfa straw (A), and Metalaxyl (M), alone or mixed were applied in contrasting treatments. Trees have showed a spectacular recovery from 1983 up to 1990. E or A alone or mixed caused a significant reduction in fungus incidence in the roots. M reduced fungus incidence when it was mixed with E or A. The highest frequency of isolations of *P. cinnamomi* resulted from double control trees (without E, A or M and with no management modification). E and EM trees gave a significantly higher accumulated weight of roots (1983-90). Root production and pathogen population decreased parabolically with soil depth. E and M alone or mixed promoted antagonistic fungi and bacteria. All treatments, including control trees (T) (without E, A or M, but whose management was modified as described) improved the canopy appearance as compared with double control trees. There was a significant indirect proportional relation (Spearman rank correlation coefficient rs = -0.83) between the % root infection by *P. cinnamomi* and canopy vigor in a test made in 1987. All treatments were significantly superior to double-control trees in accumulated (1984-90) fruit yields. Control trees produced 367% and E 394% more fruit than double-control trees, and their marginal return rate pointed them as the most profitable. *P. cinnamomi* populations were decreased and root weight was increased in trees that received phosphonate in another experimental plot established in 1989. The project has been carried on with an interdisciplinary team effort, involving so far 38 specialists (11 Ph.D., 16 M.Sc. and 11 B.Sc.). Results have been used in 12 M.Sc. and 5 B.Sc. thesis and in several publications in the Revista Mexicana de Fitopatologia and Agrociencia (official Journal of the Postgraduate College). Important information is being generated that contributes to the objectives of Colegio de Posgraduados, when these experiences are

incorporated in the lectures, research and improved training of postgraduate students.

Mexico is the largest producer of avocado (431,300 ton on 83,000 ha) in the world (Fig. 1). Root rot, caused by the fungus *Phytophthora cinnamomi* Rands, is the main parasitic limiting factor of avocado crop in Mexico and in most of the countries where this tree is cultivated. The fungus rots the roots and causes leaf wilting, defoliation, reduction in fruit production and finally the death of the tree. Isolated control measures have not been consistently effective, including biological control (Broadbent and Baker, 1974; Zentmyer, 1963), resistant rootstocks (Zentmyer, 1980), and chemical control, although recently, the application of phosphonate has been giving good results (Kotzé *et al.,* 1987; Pegg and Whiley, 1987). The State of Puebla is a probable center of domestication of the avocado and in Tochimilco county there are very old orchards of avocado intermixed with other plants in soils with a high content of organic matter. There is a tree with an estimated age of 500 years in that county, perhaps the oldest avocado tree in the world. The tree is healthy and producing fruit, despite the presence of the *P. cinnamomi* in its roots. That tree inspired the present project with the following objectives:

1. To diminish the population of the fungus in the soil, without trying to eradicate it.
2. To promote appropriate conditions: a) to favor the production of roots; b) to favor the development of antagonistic organisms; c) to establish a natural equilibrium between vegetative growth, production of fruit and soil microflora.
3. To understand the physical, chemical and biological action of these strategies in the soil, in the plant and on the pathogen.
4. To apply or validate the results in commercial orchards.
5. To integrate the efforts of different specialists to better focus the work, to better conduct the actions and interpret the results, and to optimize the financial resources.

Materials and Methods

An integrated pest management experiment was established in 1982 in a commercial avocado grove in the State of Puebla, Mexico (Téliz and Garcia, 1982). The grove had the following modifications in its general management: 1) Irrigation from general to individual tree basin flooding. 2) Eight-year-old 'Fuerte' trees, with distinct foliage symptoms and whose root infection was verified, were severely pruned to reestablish the foliage/root equilibrium. 3) All trees were chemically fertilized to invigorate them. Additionally, the following contrasting treatments were applied:

1) Fresh bovine manure (E): (360 kg/tree). (June 82 and 83; Dec 85; April 88)
2) Alfalfa straw (A): (25 kg/tree). (June 82, January 83, June 83, April 88)
3) Metalaxyl (M): (2.5 g.a.i./m2). (Five trimonthly applications from June 82 to June 83; Nov 83; and three biweekly applications in May and June 88)
4) EA

5) EM
6) AM
7) EAM
8) Control (T) (without addition of E, A or M; and with the described general modifications in management)
9) Double-control (DT) (without E, A, or M and without general management modification).

Each treatment was replicated in 7 trees in a completely randomized design. The effect of treatments was evaluated by the percentage of roots infected by *P. cinnamomi,* root weight, canopy appearance and the production of fruit. Fungus incidence in the rhizosphere was obtained from a soil mixture of 10 subsamples; fifty roots per tree were placed in PARPH cultural medium (Jeffers and Martin, 1986). Vigor parameters were: kg fruit/tree, dry *root* weight, canopy appearance assessed with an arbitrary scale from 1 = dead tree to 6 = excellent growth. Soil microorganisms were isolated in specific media from 10 g soil/tree dilutions. Vertical (0-20, 20-50, 50-80, and 80-110 cm) and horizontal (120-160 and 160-200 cm from the trunk) distribution of roots and associated microorganisms was evaluated. Data was analyzed as a complete random block and as a split plot design. Means were compared by Tukey, Duncan and orthogonal contrasts. Canopy appearance was evaluated by Kruscal Wallis and Fredman non parametric methods. Correlation between variables was determined by linear and non-linear regressions.

Results and Discussion

The accumulated effect of the treatments on fungus incidence (% roots infected by *P. cinnamomi* during the eight years is shown in Figs. 2 and 3. Bovine manure (E) or alfalfa straw (A) alone caused a significant reduction in fungus incidence, but their separate effect was enhanced when both treatments were combined. Metalaxyl alone did not reduce total incidence of the fungus as it did when combined with alfalfa or manure. The effect of alfalfa straw on fungus incidence might be explained by the liberation of saponins (Zentmyer, 1980). Double-control trees showed the highest incidence of the fungus in their roots. The dynamics of the four most effective treatments from 1983 to 1990 as compared with double-control trees is shown in Fig. 3. *P. cinnamomi* was isolated with a significantly higher frequency from the roots of double-control trees than from the rest of the treatments. Bovine manure decreased the incidence of *P. cinnamomi* perhaps by promoting the growth of antagonistic fungi and bacteria, as was reported by Juarez, in 1985 (Fig. 4). Metalaxyl and bovine manure alone or mixed were the best treatments in promoting the growth of antagonistic fungi and bacteria. The effect of Metalaxyl on *P. cinnamomi* might be obscured in the accumulation of data, since it was applied in 1982 and 1988. Its effect in these particular years will be published later. Alfalfa straw apparently had a direct negative effect on *P. cinnamomi,* but did not significantly promote the growth of antagonistic fungi and bacteria. The effect of treatments on the production of roots is shown in Fig. 5. The positive effect of bovine manure in promoting root growth is evident, and this was one of the objectives in the management of the disease. Double-control trees apparently produced more roots than control trees, but those roots were coarse and lignified; very few thin roots were found and all of them were rotten. Alfalfa straw apparently did not promote root growth, and this effect was even ex- tended to bovine manure when mixed with alfalfa (EA).

Treatments had a differential effect on the vegetative growth or canopy appearance of each tree. Dynamics of this effect from 1982 to 1990 in three of the best treatments as compared with double-control trees is shown in Fig. 6. The positive effect of treatments on the appearance of the trees is evident. The treatments were applied in 1988; it seems that they might be required again in 1991 to improve their appearance to grade 6 (excellent growth).

The effect of treatments on canopy appearance was statistically superior to DT trees, which have remained in a sustained poor condition. The accumulated effect of all treatments is shown in Fig. 7.

Soil depth parabolically reduced the vertical distribution of avocado roots and the number of *P. cinnamomi* isolations from the roots. The relation between the amount of root and the proportion of *P. cinnamomi* isolations gave an r=0.6194 ($P \leq 0.05$), a very low value that does not show a significant relationship between these two variables. A Spearman coefficient of r_s = -0.83, statistically significant in a test made in 1987, indicated an indirect proportional relation between the % root infection of *P. cinnamomi* and canopy vigor. These type of observations have allowed the development of methods that do not require root inspection. Zentmyer (1980) proposed a visual scale to evaluate avocado root rot. The condition of this evaluation is that canopy appearance must be related only to the presence of *P. cinnamomi* in avocado rhizosphere. This condition is difficult to fulfill under commercial situations, since exclusivity does not usually occur in nature. Other fungi might be involved in avocado, e.g., tristeza (Franco, 1983; Kotzé *et al,* 1987).

The effect of treatments on fruit production is shown in Fig. 8. All treatments resulted in a statistically superior accumulated yield compared with double-control trees (DT). The highest yield obtained in trees treated with EM represents 580% more fruit than DT trees. Control trees (T) and trees treated with E resulted in 367 and 394% respectively more fruit than DT trees, and their marginal return rate indicated that the treatments were the most profitable.

P. cinnamomi populations were decreased, but not eradicated by treatments with E, A, EA, AM or EM. Some treatments favored the production of roots (E and EM) and the development of antagonistic fungi and bacteria (M, E and EM). Canopy appearance was superior in all treatments compared with DT trees, apparently reestablishing a better equilibrium between canopy and root growth, that resulted in better yields. Control trees (T) and those treated with E gave the best marginal return rate.

Another experimental plot was established in 1988 to test the effectiveness of phosphorous acid as a control measure. Four trunk injections (1.4 g.a.i./injection/tree) in

May and July 1989 and 1990 were applied. *P. cinnamomi* populations were decreased and root weight was increased in trees that received phosphite.

Nutrients dynamics in this project (Gutiérrez, 1986; Yepez, 1966) will be published separately. The attempt to understand the results gives us some insight, but also shows us the kind of data required to make our knowledge of this disease more precise. The results have been validated on a commercial basis but not enough to fully understand the disease. Actually we have more questions than answers.

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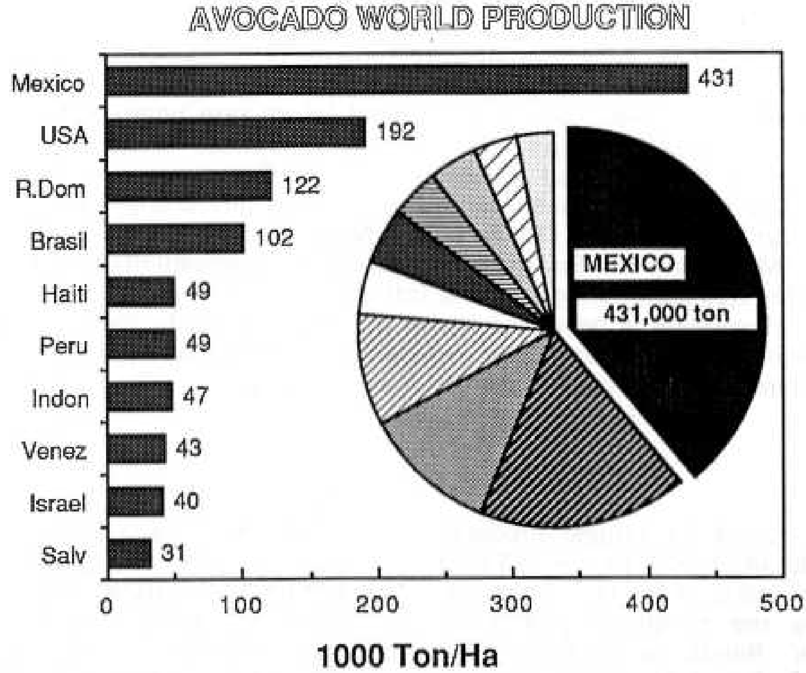

Fig. 1. Production by the 10 largest avocado growing countries in the world.

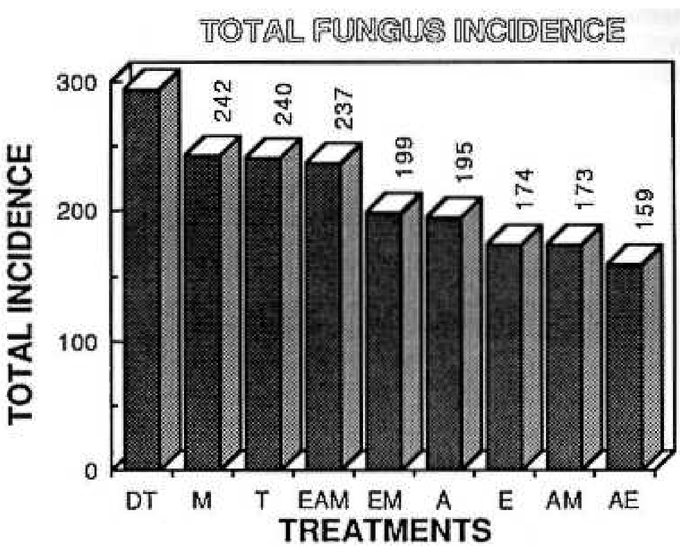

Fig. 2. Accumulated (1983-90) incidence of *Phytophthora cinnamomi* on the roots of 'Fuerte' avocado trees as affected by A= alfalfa; E= bovine manure; M= metalxyl; their combinations; T= control trees that did not receive A, E or M; DT= double-control trees that did not receive A, E or M and with traditional management. Puebla, Mexico.

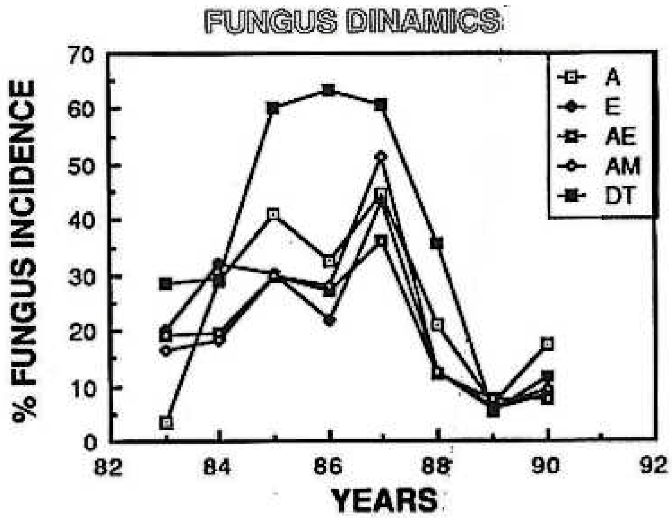

Fig. 3. Dynamics (1983-90) of *Phytophthora cinnamomi* isolated from the roots of 'Fuerte' avocado trees as affected by A= alfalfa; E= bovine manure and M= metalxyl. DT= double-control trees that did not receive A, E or M and with traditional management. Puebla, Mexico.

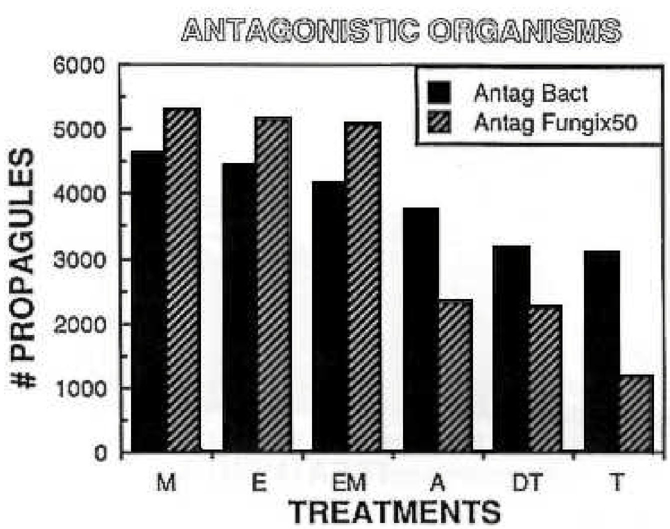

Fig. 4. Accumulated number of isolated fungi (actual number multiplied by 50 for graphing purposes) and colonies of bacteria antagonistic to *Phytophthora cinnamomi* from five trimonthly samplings from soil and roots of 'Fuerte' avocado trees as affected by A= alfalfa; E= bovine manure; M= metalxyl; their combinations; T= control trees that did not receive A, E or M; DT= double-control trees that did not receive A, E or M and with traditional management. Puebla, Mexico.

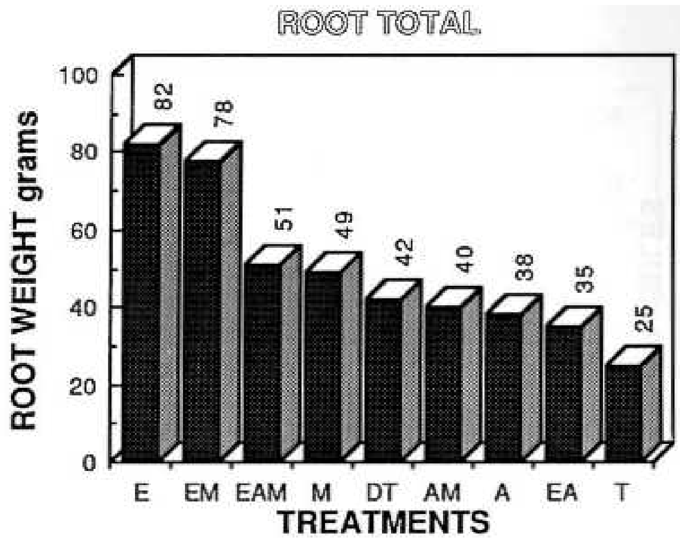

Fig. 5. Accumulated (1983-90) weight in grams of roots from 'Fuerte' avocado trees as affected by A= alfalfa; E= bovine manure; M= metalxyl; their combinations; T= control trees that did not receive A, E or M; DT= double-control trees that did not receive A, E or M and with traditional management. Puebla, Mexico.

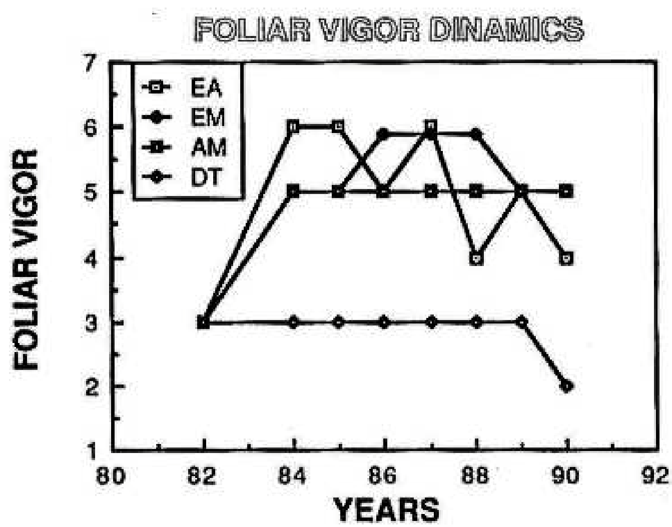

Fig. 6. Canopy or foliar vigor dynamics of 'Fuerte' avocado trees, graded with an arbitrary scale in which 1= dead tree, 2=very bad, 3= bad, 4= regular, 5= good and 6= excellent growth. Trees treated with A= alfalfa; E= bovine manure; M= metalxyl; DT= double-control trees that did not receive A, E or M, and with traditional management. Puebla, Mexico.

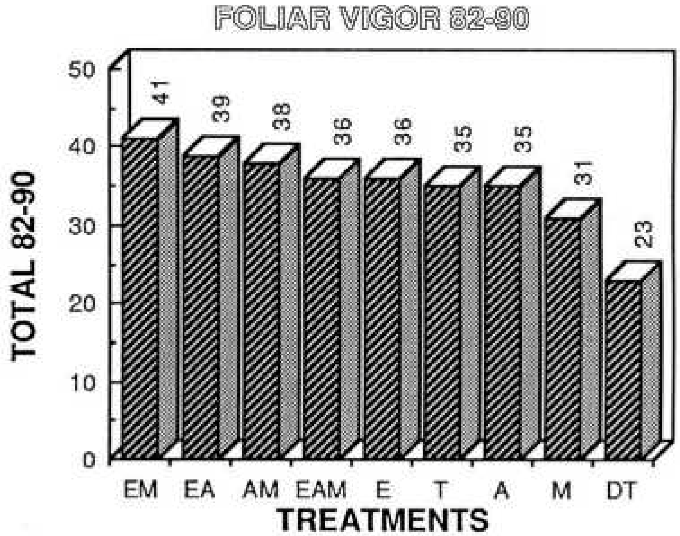

Fig. 7. Accumulated (1982-90) effect of A= alfalfa; E= bovine manure; M= metalxyl; their combinations; T= control trees that did not receive A, E or M and with modified management (irrigation, pruning and chemical fertilization); DT= double-control trees that did not receive A, E or M, and with traditional management, on canopy appearance of 'Fuerte' avocado trees, graded with an arbitrary scale in which 1= dead tree, 2=very bad, 3= bad, 4= regular, 5= good and 6= excellent growth. Puebla, Mexico.

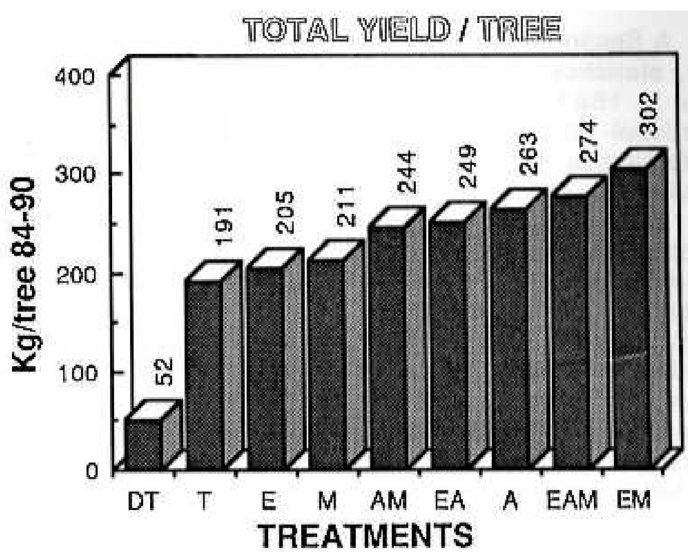

Fig. 8. Accumulated (1984-90) average kg of fruit per 'Fuerte' avocado tree as affected by A= alfalfa; E= bovine manure; M= metalxyl; their combinations; T= control trees with modified management and that did not receive A, E or M; DT= double-control trees that did not receive A, E or M and with traditional management. Puebla, Mexico.