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INTEGRATED MANAGEMENT OF AVOCADO: VALIDATION OF TECHNOLOGY IN PUEBLA, MEXICO.

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The state of Puebla is a probable center of domestication of avocado. Root rot caused by *Phytophthora cinnamomi* is the main parasitic limiting factor in this area. An integrated pest management experiment was established in 1982. The whole experimental plot was subjected to the following modifications in the general management: irrigation, pruning, chemical fertilization and control of aerial pests. Additionally the following contrasting treatments were applied: 1) Fresh bovine manure (E) 360 kg/ tree; 2) Alfalfa straw (A) 25 kg/ tree; 3) Metalaxyl (M) 2.5 g.a.i./ m^2; 4) EA; 5) EM; 6) AM; 7) EAM; 8) Control (T)(without addition of E, A or M); 9) Double control (DT)(without addition E, A or M and no modification of the cultural management). Experimental data accumulated from 1982 to 1990 showed that E treatment promoted the lowest incidence of *P. cinnamomi* in roots, the highest dry weight of roots, the highest number of bacteria and antagonistic fungi, the highest fruit production, foliage vigor and good macro and micro elements content in leaves and soil. Control and E treatments gave the best marginal return rate. This integrated technology (HVA) has been validated from 1992 to 1995 in Puebla, Mexico. HVA had several modifications in the general management (irrigation, pruning and chemical fertilization). Additionally, 70 kg of fresh bovine manure/ tree were added. HVA was compared with a traditional technology (TT) (no modification in the general management and without bovine manure) and also compared with groves with the best traditional technology (TAS) in the region. HVA and TAS showed the highest frequency of isolations of *Phytophthora cinnamomi* (HVA: 22 % = TAS: 19 % > TT= 12.7 %) and the highest accumulated root production (TAS: 45 g = HVA: 35 g > TT: 10 g). The high levels of infection were not detrimental to the growth and vigor of trees managed with HVA and TAS technology. The effect of root rot on foliage symptoms in TT trees was 91 %, which decreased to 9 % in TAS and down to 3 % in HVA. Higher total populations of other soil fungi occurred in HVA (22.45 x 50 propagules/ g soil). The genera more frequently found were *Phialophora*, *Fusarium*, *Aspergillus*, *Trichoderma*, *Penicillium*, *Botrytis and Rhizopus*. The total population of bacteria was higher in TAS (700 x 10^{13} cell/ ml) and HVA (457 x 10^{13} cell/ ml). The longer extension of wood bored by *Copturus aguacatae* was found in TT and TAS (TT: 19 cm/ m lineal = TAS: 6 cm/ m > HVA: 2.5 *cm/* m). HVA showed the highest foliage index (HVA: 4.3 m^2 foliage/ m^2 soil > TAS: 3.0 > TT: 2.2) and the least fruit abortion (HVA: 53 % < TAS: 80 % = TT: 78 %). Accumulated fruit production in HVA (9.2 ton/ ha) was 31 % higher than TAS (7 ton/ ha), and 460 % higher than TT (2 ton/ ha). The best net benefit in 1993 was found in HVA (44 %), higher than TAS (31 %) and TT (45 %). In 1994 net benefit in HVA was 55 %, and there were economical loses in TAS (-19 %) and TT (- 75 %)

Key Words: *Persea americana,* IPM, root rot, validation, *Phytophthora cinnamomi, Copturus aguacatae* .

Mexico is the largest avocado producer in the world. Among the world production in 1991 (1.3 million of ton) 52 % was produced in Mexico (FIRA and Banco de Mexico, 1991) (Fig. 1)

Puebla, a probable center of origin and domestication of avocado, is the third avocado producing State in Mexico. Avocado root rot caused by *Phytophthora cinnamomi* is the main parasitic limiting factor in this area. The fungus causes root rot, wilting, defoliation, and reduces the quantity and quality of fruit; finally attacked trees die (Broadbent and Baker, 1974; Téliz et al, 1989; Zentmyer, 1980). Avocado branch borer *(Copturus aguacatae),* usually associated with P. *cinnamomi ,* occurs in Puebla (Cabrera and Salazar, 1991; Valenzuela et al, 1985; Teliz et al, 1989; Muñiz, 1960). The fungus defoliates branches, which more exposed to sun, are warmer and preferred by the branch borer females for oviposition. The insect galleries destroy the internal tissues of the current year branches. Trees simultaneously attacked by *P. cinnamomi and* C. *aguacatae* decline faster in their vigor and productivity until they die. Damage by branch borers are not significant in trees with abundant foliage. Isolated control measures against *P. cinnamonii* have not been consistently effective, including biological control (Broadbent and Baker, 1974; Zentniyer, 1963), resistant rootstocks (Zentmyer, 1980) and chemical control, although more recently, the application of fosfonate has been reported as giving good results (Kotz6 et a], 1987; Pegg and Whiley, 1987; Young et al, 199 1; Whiley, 1991).

In Mexico, the work of Colegio de Posgraduados Interdisciplinary Research Group during 1982- 1990 showed that the incorporation of bovine manure, alone or mixed with alfalfa straw or with metalaxyl, combined with some modifications to the traditional groves management, reduced *P. cinnamomi and C. aguacatae* damage, promoted the best root growth and tree productivity, increased the populations of antagonistic fungi and bacteria, improved the foliage appearance and gave the best marginal return rate (Cabrera and Salazar, 1991; Jacobo et al., 1990; Téliz et al., 1991; Valenzuela et al., 1985). This integrated crop management (ICM) was validated in two commercial avocado groves during 1992-1995; this paper will show the benefit of ICM on the control of avocado root rot and of avocado branch borer, measured by the incidence of the two pests, and by the root weight, population dynamics of microorganisms antagonistic to *P. cinnamomi,* foliage area index, yield and by the marginal return rate.

MATERIALS AND METHODS

Four avocado groves (1 ha/ each) were selected in 1992 on the basis of age and variety (13-15 year-old 'Fuerte' trees), and with high incidence of avocado tristeza, branch borers, and very low productivity in Puebla. Two groves were managed with the local traditional technology (TT) and the other two were managed with the following ICM strategy: a) irrigation was modified from general flooding to individual tree basins, b) general pruning of trees at 1.5 in high from the soil, c) periodic fertilization every 5 to 6 months, d) rational control of other pests (scab, anthracnose, mites), e) incorporation of 70 kg of fresh bovine manure/ tree. Additionally, two other groves were included due to their best local management and productivity, whose management was not modified and which served as the local technology to surpass (TAS) (pruning of bored branches at the end of harvesting, in September-October, chemical fertilization every summer, 80-100 Kg of bovine and caprine manure; irrigation by general flooding, 84% copper oxicloride 1 1/ha, sprayed every year in February and April.

In each orchard 13 trees were selected in completely randomized design. The three types of groves were compared by the percentage of roots infected by *P. cinnamomi*, root weight, foliage area index, production of fruits and net income. Fungus incidence in the rhizosphere was obtained from a mixture of 10 soil sub samples; after weighting the roots, 20 to 30 small root pieces per tree were placed in PARPH medium (Jeffers and Martin, 1986). Tree vigor was evaluated by the dry root weight, fruit production (ton/ ha) and foliage index assessed with a foliage area analyzer (LAI-2000: Ll-COR®). The analyzer was placed at each of the four cardinal points, under the canopy, at 1.5 m above the soil. Total fungi population was estimated in I ml of soil suspension from the rhizoplane diluted 1:10 in 20 g agar/ 500 ml water+ 0.50 ml tergitol, 0.050 g streptomycin and 0.0025 g tetracycline clorhidrate. The most frequent fungal colonies were transferred to 25% corn meal agar, around a *P. cinnamomi* colony to measure their antagonism. Total bacteria population in the soil was estimated in 0.05 ml of a soil diluted 1: 1013 in nutritive agar. Borer incidence and damage was estimated in 50 cm of a current year branch terminal per cardinal point in the higher half of the canopy of 11 trees. The extension of galleries was measured and number of larvae was counted in each branch terminal. Total fruit yield and costs of management in 1993 in each grove were registered. Data was analyzed in a complete randomized blocks and regression between variables was performed.

RESULTS AND DISCUSSION

The highest accumulated root infection by *P. cinnamomi* was found in HVA (147-161%) and TAS (125-144 %) (Tukey, 0.05 %), whereas TT trees had the lowest root infection (56-62 %) (Fig. 2).

The higher root infection in HVA and TAS may be due to a vigorous root growth (Fig. 3) in soil improved in its physical and biological condition. Increment in succulent, more metabolically active feeder roots of trees treated with bovine manure give a higher and more susceptible substrate for fungal invasion (Teliz et al 1989; Zentmyer, 1980). The higher fungal root invasion in HVA and TAS did not affect tree vigor. Tree recuperation in HVA was very satisfactory; only 24 out of 440 trees did show tristeza symptoms (Fig. 7) and the accumulate fruit yield in 1993-94 was 460% superior to TT. In previous works, bovine manure gave the lowest pathogen population after the third year of its periodic incorporation, and from the fourth year on the response was consistent and stable throughout the years (Teliz et al 1989). The validation groves will be observed in the following years to confirm the previous results. Other factors related with the host and environment combined with the fungus are probably involved in the susceptibility, since TT trees showed the highest disease severity despite having the lowest root infection. Other root factors like suberization, presence of tannins, phenols and the nature and low concentration of root exudates, might be influencing the chemiotaxy and low efficiency in fungal infection.

Root weight

The highest accumulated root weight was observed in HVA plots (45 g/ tree) and TAS (35 g) (Fig. 3) probably due to the vegetative condition of the trees. Amount of roots is related with the trees canopy (Westwood, 1982). TAS and HVA trees had more foliage area index (Fig. 10) and did not have water stress. TT trees had the lowest amount of roots, probably due to the low tree vigor from compacted soils, water stress, scarce and chlorotic foliage (Fig. 10), and severe damage from branch borers (Fig. 8). Probably the low tree vigor incremented the severity of root rot, despite the pathogen incidence was low (Fig. 2).

Total fungi

Total fungi were significantly incremented after the incorporation of bovine manure in HVA groves, whereas in TAS and TT fungi populations were almost constant throughout the time (Fig. 4). Fungi genera most frequently isolated were *Phialophora, Fusarium, Aspergillus, Trichodenna, Penicillium, Botrytis and Rhizopus.* The effect of organic matter in the increment of populations and activity of microbial populations in the soil has been registered before (Patrick and Toussoun, 1965). This effect might be due to the continuous liberation of nitrates, nitrites, sulfates, phosphates, water vapor, oxygen and other organic constituents that nourish the soil micro flora (Chapman, 1965).

Population dynamics of total fungi in TAS and TT groves remained almost unchanged, despite the content of organic matter in some of these groves (1.6 - 7.6 %) was higher than RVA groves (3.0 - 3.9%). This might be due to the low water holding capacity and deficiency of air interchange that reduced the activity of saprophytic microorganisms in TT groves (Raney, 1965). The constancy of microbial population in TAS groves was probably due to the stabilization of organic matter. Soil microorganisms logarithmically increased during the first months after the incorporation of bovine manure, then the populations stabilized for a while and finally they declined. This behavior is due to the gradual decay of the organic matter that liberates organic metabolites, which are rapidly consumed by the soil microorganisms (Juarez et al, 1986).

Fungal antagonism against *P. cinnamomi*

P. cinnamomi is attacked by many antagonistic agents (Malajezuk and Theodorus, 1979). The antagonistic fungi isolated in Puebla were *Aspergillus, Trichoderma and Penicillium,* whose detrimental effect on *P. cinnamomi* has been previously reported (Sneh et al, 1977). The regression analysis between the isolated antagonistic fungi and *P. cinnamomi* was not significant; however, there was a relation (R^2= 0.743) between the total fungi in soil and the survival of *P. cinnamomi (Fig.* 5). These results do not coincide with those of Juarez et al (1986) found a correlation of *P. cinnamomi* only with antagonistic fungi. *In vitro* tests of antagonism do not detect the complex relations and interactions between soil microorganisms (comensalism, parasitism, predation, competence, antagonism, etc.) and the physic-chemical factors in soils (Malajezuk and Theodorus, 1979). It is interesting that total fungi populations were less abundant in TAS groves, however, they had the highest populations of *P. cinnamomi* and bacteria (Figs. 2 and 6).

Total bacteria.

The highest accumulated bacteria] populations occurred in TAS groves (621-790xl0^{13} propagules/ml), followed by TAS (363-562) and TT (100-250 x1013 propagules/ ml) (Fig. 6). It seems that bacterial populations were related with the soil and crop management which was more intensive in HVA and TAS than in TT groves. Jensen (1934) and Cook and Papendick (1972) found higher bacterial populations in soils enriched with organic matter than in virgin soils. Water stress in TT groves, evident by the severe necrosis and defoliation of branches, probably also reduced bacterial populations.

Incidence of tristeza

HVA groves showed the lowest tristeza incidence (2-4%), followed by TAS groves (7-12%), significantly lower than TT groves (88-95%) (Tukey, 0.05 %) (Fig. 7).

Tristeza symptoms in HVA trees disappeared by the effect of pruning which contributed to a better foliage-root balance (Figs. 3,7,10). Tristeza incidence in TT groves was increased by deficiencies in water and fertility management. Trees in TT groves had the lowest incidence of *P. cinnamomi* in roots (Fig. 2) but the highest visual incidence (Fig. 7). The low level of root infection in TT trees might be a limiting factor only in groves with poor management. High levels of inoculum. (Fig. 2) are not so limiting if the trees are well managed (HVA and TAS groves); these trees show abundant roots, foliage and acceptable yields (Figs. 3, 10 and 11).

Damage by *Copturus aguacatae*

Trees in TT groves had a significantly longer bored wood (16.6 - 20.8 cm) by meter of branch than trees in HVA groves (Tukey, 0.05 %) (Fig. 8). There were also significant differences in the number of borer larvae in 24 m of the current year wood: TT (103-116 larvae) > TAS (55-83) > HVA (3-30) (Tukey, 0.05 %) (Fig. 9).

The lack of significant correlation between branch borer damage and incidence of tristeza in this work might be due to the pruning of bored branches in TT-2 and TAS-2. Previous works have reported and indirect correlation (- 0.61 Spearman correlation coefficient) between tristeza symptoms and wood borer damage (Cabrera, 1989). Branches of trees affected by tristeza become defoliated and consequently warmer from sunlight; borer females prefer these warmer branches to oviposit on (Cabrera and Salazar, 1991). In this work trees with vigorous foliage did not show significant borer damage. Trees in TT groves had a very scarce foliage during the year (Fig. 10) and were severely attacked by the branch borer (Figs. 8 and 9). Trees in RVA groves had a very vigorous vegetative growth after the severe pruning and showed the lowest borer damage. Cabrera and Salazar (1991) also found the trees recovered from tristeza, with abundant foliage area were less damaged by *C. aguacatae.* These results verify the recommendation of a severe and uniform pruning of groves with high incidence of tristeza to recuperate their health, to obtain a faster equilibrium between foliage and root growth and to promote a more efficient cultural control of branch borers.

No relation was found between borer damage and the orientation of branches. Probably the scarce foliage and the exposition of the branches to sun heat in YF trees resulted in equal damage in the four cardinal points. The overgrowth of canopies in TAS trees and the compact and vigorous canopies in HVA trees influenced the lack of a pattern of damage.

Vigor of trees

Good vigor of HVA trees was related with the best index of foliage area index (IAF) (Fig. 10) and the highest yield (Fig. 11). HVA trees had the highest IAF (4.0 - 4.5'm2 foliage/ m2 soil), followed by TAS trees (2.3 - 3.2 m2/m2) and TT (1.8 - 2.2 m2/m2) (Tukey, 0.05 %) (Fig. 10). IAF is the most used and reliable estimate of the parameter of foliage structure and volume

(Welles and Norman, 199 1). Phytopathologically, IAF represents an estimate of the foliage density and therefore, an indicator of the recuperation of trees defoliated by *P. cinnamomi* and by a deficient management in the past. Diseased trees recovered satisfactorily in HVA groves based in the non significant disease incidence (Fig. 7), despite of having a substantial inoculum in the roots (Fig. 2). These trees have a vigorous vegetative growth and the best yield (Fig. 11). IAF has a quadratic relation with yield. The optimum IAF for the best yields has not been determined for avocado; it will be defined for 'Fuerte' avocado trees. This index will be fundamental for the criteria of pruning to standardize the volume and architecture of canopies to make more efficient the light energy reception and the physiological events like flower differentiation, fruit growth, etc.

The effect of a better management in yield is shown in Fig. 11. The accumulated yield in HVA groves (9.2 ton/ha) during 1993-94 was 31% superior than TAS (7 ton/ha) and 460% superior than TT (2 ton/ha). These results show the effectiveness of HVA management in the short-term recovery (24-30 months) of non-productive trees affected by *P. cinnamomi* and by a deficient management.

The global economical analysis shows that HVA trees had the largest difference between costs and income with a 55% net income; TAS trees had a net income of 31% in 1993 and -19% in 1994. Net income in TT trees was 20% in 1993 and -75% in 1994 (Fig. 12). TT trees had the lowest yields due to the scarce vigor of the trees, lowest index of foliage area, least shoot growth and root weight, the highest flower abortion and wood borer damage.

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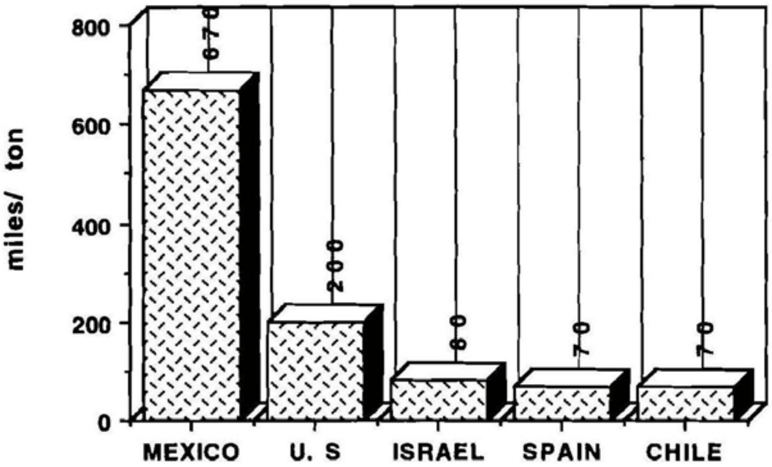

Fig. 1. Main avocado producing countries in 1991 (FIRA and Banco de Mexico, 1991).

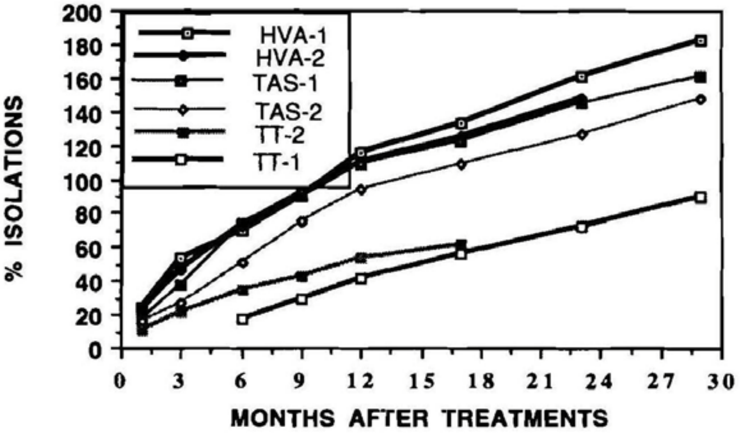

Fig. 2. Accumulated infection of *P. cinnamomi* in roots of avocado `'Fuerte'` trees under different management.

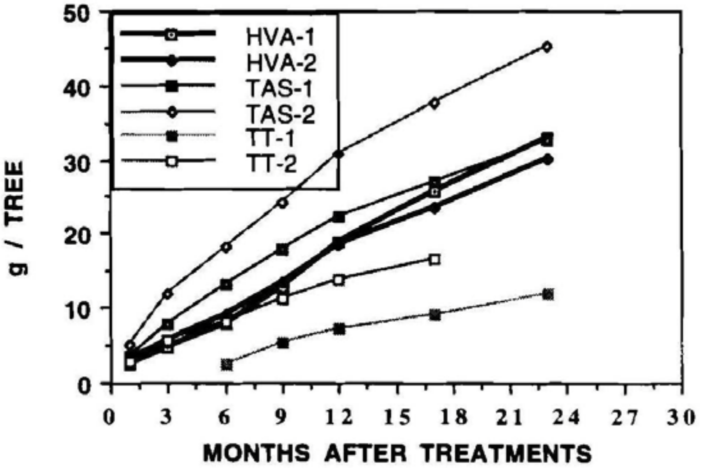

Fig. 3. Accumulated dry weight of roots of avocado 'Fuerte' trees under different manageme

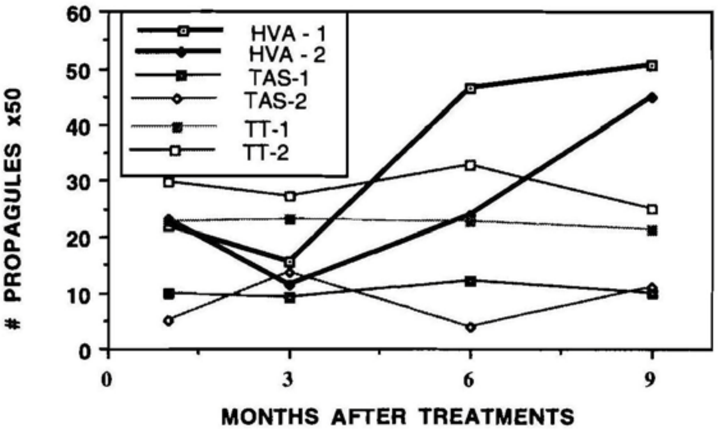

Fig. 4. Total fungi in the rhizoplane of trees, 1, 3, 6, and 9 months after the incorporation of bovine manure in groves under validation (HVA) compared with groves to surpass (TAS) and control groves (TT). Puebla, Mexico 1993.

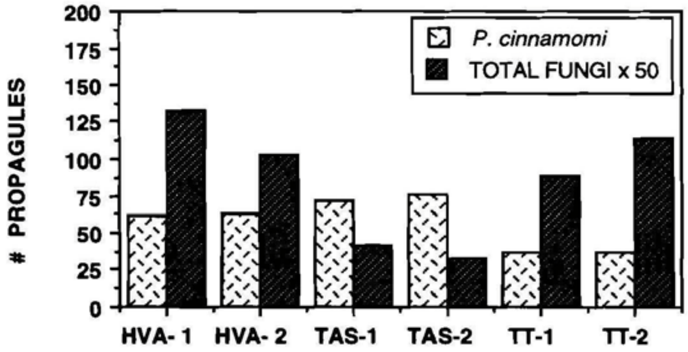

Fig. 5. Populations of *P. cinnamomi* and of total soil fungi in avocado groves under different management.

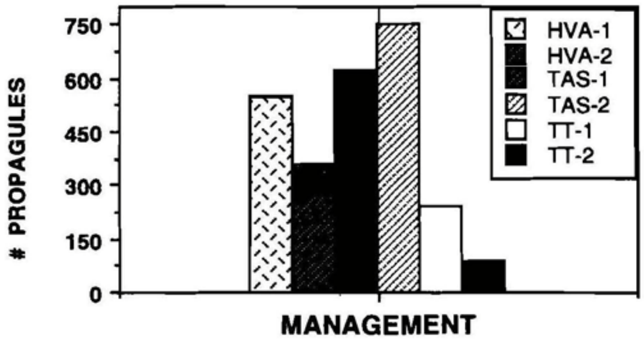

Fig. 6. Total accumulated bacteria in avocado groves under different management.

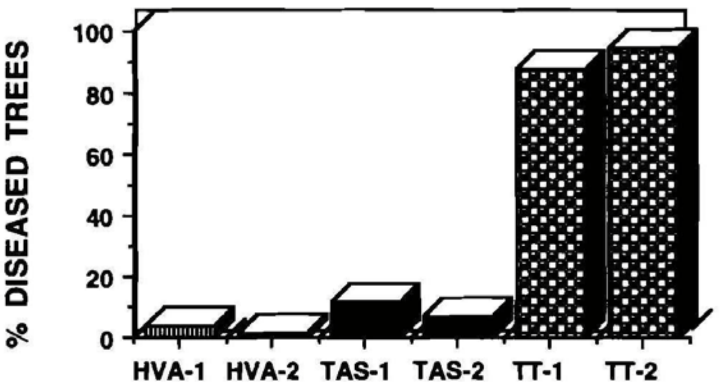

Fig. 7. Visual incidence of tristeza (*Phytophthora cinnamomi*) in avocado groves under different management. Puebla, Mexico. 1993 and 1994.

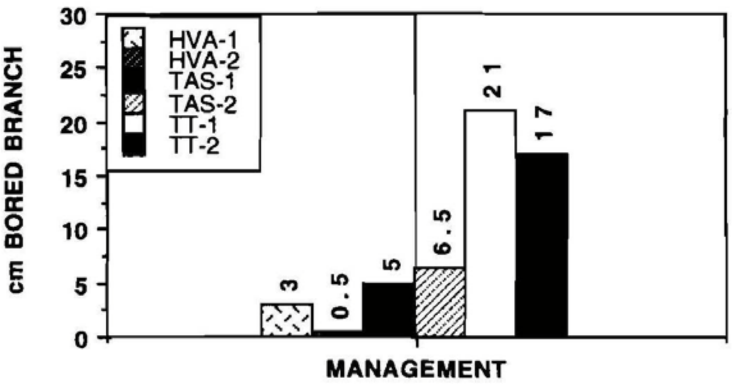

Fig. 8. Length of wood bored per meter of current year branch / tree in 'Fuerte' avocado trees under different management.

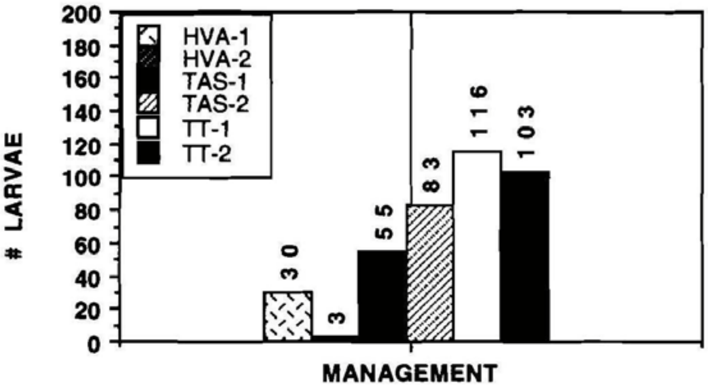

Fig. 9. Number of total larvae of *Copturus aguacatae* in 24 m of current year branches / grove, in 'Fuerte' avocado trees under different management.

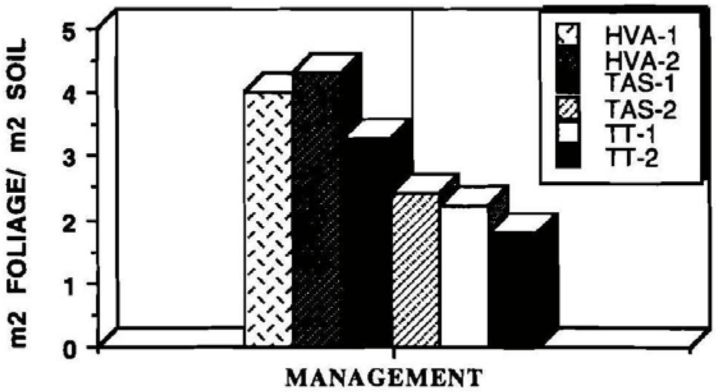

Fig. 10. Foliage area index of 'Fuerte' avocado trees under three managements. Puebla, 1993.

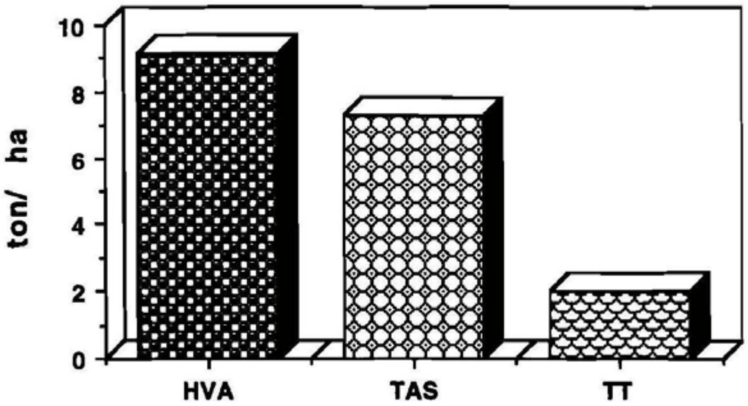

Fig. 11. Accumulated yield (1993-1994) of 'Fuerte' avocado trees under three managements.

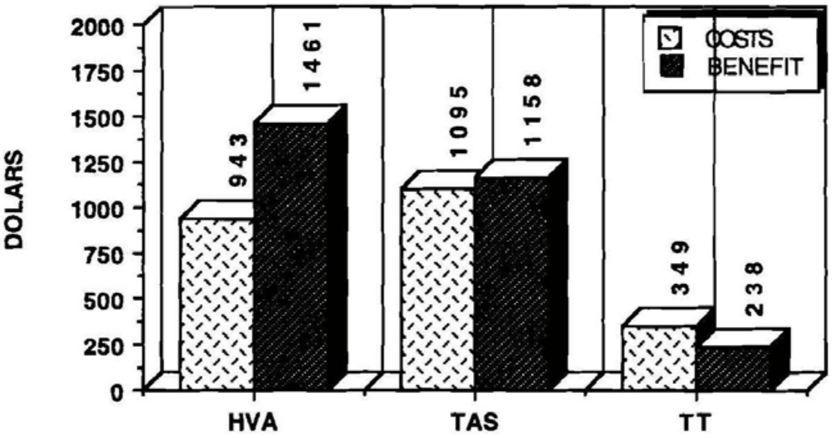

Fig. 12. Economical analysis of costs and benefits of 'Fuerte' avocado trees under three managements.