Inoculation of VA Mycorrhiza for the Improvement of Growth and Yield of Agricultural Crops, Fruit Trees and Forest Tree Species in Grassland Soil

Jocelyn D. Tambalo-Zarate
National Institutes of Biotechnology and
Applied Microbiology (BIOTECH)
University of the Philippines Los Baños
College, Laguna

and

Reynaldo E. de la Cruz
College of Forestry
University of the Philippines Los Baños
College, Laguna

ABSTRACT

Eighteen different crops were screened for their response to inoculation with three different VA mycorrhizal species and/or applied with complete fertilizer, grown in grassland soil.

Growth responses of plants inoculated with mycorrhiza and applied with 60-60-60 kg NPK/ha were always better than the uninoculated - unfertilized control and the plants that were treated with fertilizer alone. Inoculated plants were taller, had more shoots, roots, had higher cob/pod yield and grew more vigorously than the control and the seedlings that were fertilized alone. Fertilizer application alone did not improve the growth of the plants. The uninoculated and unfertilized control plants had consistently the poorest growth performance compared with the other treatments.

Plants highly responsive to mycorrhizal inoculation were the following: mungbean, eggplant, guava, papaya, ***A. manqium, P. falcataria, A. auriculiformis,***

kariskis, corn, peanut, soybean, citrus and raintree. Guyabano and mahogany were intermediately dependent on mycorrhiza whereas upland rice, cacao and lanka were not dependent on mycorrhiza.

It is concluded that growth of plants in infertile areas can be improved with mycorrhizal inoculation at planting and amendment with small amounts of fertilizer.

BACKGROUND

In the Philippines, the practice of indiscriminate logging, "kaingin", over grazing and other improper land use practices have helped bring about marginal uplands or acidic uplands. These comprise about 9.3 million hectares or 31% of the total land area of 30 million hectares (IRRI 1986). These soils are generally deep and permeable with good drainage and favorable structure, hence are pontentially arable. However, under local conditions, leaching, surface run off, crop removal of bases and continuous use of acid-forming fertilizers contribute to the build up of soil acidity. These often lead to poor plant survival and growth.

Application of high rates of fertilizers and liming have been done to amend the unfavorable soil conditions. However, these require large financial inputs. Acid soils usually have high buffering capacities such that they require large amounts of lime to neutralize the pH. The predominant sloping areas of these uplands make fertilizer and lime application impractical. Therefore, alternate fertilizer sources which are cheap and indigenous should be tapped. One such alternative is the use of beneficial microorganisms which form associations with the host plant, i.e. mycorrhiza.

A. Definition

The term mycorrhiza came from two German words "mykes" for fungus and "rhiza" for plant roots, hence mycorrhiza. This fungus-root relationship is a symbiotic association whereby the fungus invades and parasitises roots of the host plant but unlike other harmful parasites, it does not damage or kill the host but instead provides many physical and physiological benefits to the latter. In return, the fungus obtains its food and other growth requirements from the host plant.

B. Types of Mycorrhiza

Harley and Smith (1983) described about six types of mycorrhiza, namely: (1) Ectomycorrhiza; (2) Vesicular-arbuscular mycorrhiza (VA) or endomycorrhiza; (3) Ectendomycorrhiza; (4) Ericoid mycorrhiza; (5) Arbutoid and monotropoid mycorrhiza; and (6) orchid mycorrhiza. The six types of mycorrhiza differ in the kind of host plant they associate with, fungi involved and the manner of association. The first two types are the most common and will be discussed further.

1. Ectomycorrhiza

In ectomycorrhiza, the infected roots are usually enlarged, the outer surface covered with a compact fungal mantle, with fungal mycelia radiating outwards into the soil and with the fungus invading the cortical tissues but confined in between the cell walls. The fungi are basidiomycetes producing typical fruiting bodies such as mushrooms or puffballs. This kind of symbiotic association is usually found in forest tree species particularly those in the family Pinaceae, Fagaceae, Betulaceae, Myrtaceae and Dipterocarpaceae.

2. Endomycorrhiza

In endomycorrhiza or VA mycorrhiza, infected roots are not enlarged. The roots have to be examined under a microscope to detect infection. The fungus forms a loose network of hyphae on the root surface and may infect roots through root hairs or directly through epidermal cells. The fungi do not only invade the cortical tissues but may also penetrate cortical cells where they develop a complex hyphal branching system like small bushes called *arbuscules.* The arbuscule is the significant structure on the VAM complex because it is the preferential site for fungus/plant metabolite (food and nutrient) exchanges. Another common feature in the endomycorrhiza is the production of thin walled spherical to ovate structures called *vesicles*, which are caused by terminal swellings of a hypha of the VAM fungus. Vesicles are found in the inner and outer layers of the cortical parenchyma. The cytological organization of the vesicles (mostly rich in lipids) and the fact that their number frequently increase in old or dead roots suggest that they are mainly resting organs. Due to the presence of vesicles and arbuscules, this group of fungi is commonly called ***vesicular-arbuscular*** mycorrhiza or ***VA*** Mycorrhiza (VAM).

VA mycorrhiza are the most widely distributed type of mycorrhiza throughout the world. They are generally abundant in grasslands and savannas, shrubs, open woodlands, dense rainforests, semi- deserts and sand dunes (Hayman 1982). VA mycorrhizal associations occur in almost all photoautotropic green vascular plants. Exceptions are plants growing in water-logged conditions like lowland rice and plants belonging to the family Cruciferaseae (Mikola 1982). Most of our important agricultural, horticultural and forest tree species form mycorrhizal associations.

C. Benefits of Mycorrhizal Association

Mycorrhiza is able to improve plant growth because of the following:

1. **Increased absorption of nutrients.** The hyphae of these fungi are able to extend into the soil, considerably beyond the area explored by root hairs, thus effectively extending the zone of nutrient absorption for poorly mobile elements such as phosphorus (P), copper (Cu) and zinc (Zn) and other elements such as nitrogen (N), potassium (K), calcium (Ca) and other micronutrients.
2. **Increased drought resistance of the host plant because mycorrhiza aids in water absorption.** The presence of the fungal mycelia in the root promotes the absorption not only of nutrients but also of water.
3. **Biological control of pathogenic root infections** as in pathogenic fungi in pines, nematodes in tomato, nematodes in tobacco and in soybeans
4. **Enhanced activity of other microorganisms** such as phosphate- solubilizing bacteria, *Rhizobium* and *Azospirillum*. In the case of *Rhizobium* and *Azospirillum*, mycorrhiza provides the phosphorus required by nitrogen-fixing microorganisms thus promoting nodulation and nitrogen fixation.
5. **Production of growth promoting hormones** such as auxins and gibberellins and other growth promoting substances such as vitamins
6. **Accelerated mineral cycling** by enhancing the uptake and translocation of nutrients from decomposing leaves and other organic litter in the rhizosphere. Mycorrhiza may directly extract nutrients bound in organic matter and convert these to organic compounds within their tissues during metabolism. The organic to organic transfer of nutrients by

mycorrhiza is significant because it bypasses such processes as decomposition and mineralization. Therefore, mineral cycling will occur at a faster rate in the presence of mycorrhiza.

7. **Improved soil aggregation** by secreting mucilagenous substances which can serve as agents in soil aggregate formation. This leads to improved soil structure and, in effect, the water holding and nutrient holding capacity of the soil.

MATERIALS AND METHODS

A. Soil preparation

An infertile, phosphorus-deficient soil sample was collected from the grasslands of Carranglan, Nueva Ecija. The soil belonged to the Annam series whose predominant characteristics are soil acidity and reddish color due to the predominance of iron and aluminum oxides. The soil was passed through a 2-mm sieve to remove large stones, placed in size 8 pots (8 inches top diameter) and fumigated with methyl bromide for 48 hours in a fumigation chamber.

Initial soil chemical and mycorrhizal analyses are presented in Table 1. Analysis showed that the soil was weakly acidic but very low in organic matter, CEC and total nitrogen.

B. Treatments and Hosts

Eighteen separate hosts were used to determine the response to inoculation with three VA mycorrhizal species and/or application of complete fertilizers. The experiments were laid out in a completely randomized design (CRD) with eight replicates per treatment. The treatments were as follows:

1. Uninoculated and unfertilized control;
2. Fertilized with 60-60-60 kg N, P_2O_5 and K_2O/ha;
3. Inoculated with *Glomus etunicatum* + 60-60-60 kg NPK/ha;
4. Inoculated with *Glomus macrocarpum* + 60-60-60 kg NPK/ha; and
5. Inoculated with *Gigaspora margarita* + 60-60-60 kg NPK/ha.

The plant hosts used were classified accordingly as agronomic crops, fruit trees and forest tree species. The different crops were selected based on their importance for food, reforestation and other beneficial attributes they may offer.

Agronomic Crops

1. Upland rice (*Oryza Sativa*)
2. Corn (*Zea mays*)
3. Mungbean *(Vigna radiata)*
4. Peanut (*Arachis hyponaea*)
5. Soybean (*Glycine max*)
6. Eggplant (*Solanum melongena*)

Fruit trees

7. Guava *(Psidium guajava)*
8. Cacao (*Theobroma cacao*)
9. Langka (*artocarpus heterophylla*)
10. Citrus (*Citrus microcarpa*)
11. Papaya (*Carica papaya*)
12. Guyabano (*Annona muricata*)

Forest tree species

13. *Acacia mangium*
14. Mollucan sau *(Paraserianthes falcataria)*
15. Raintree (*Samanea saman)*
16. *Acacia auriculiformis*
17. Mahogany *(Swietenia marophylla)*
18. Kariskis

Split fertilizer application was done. At planting, 30-30-30 kg NPK/ha (computed in: grams fertilizer/kg soil/pot) was mixed with the soil prior to inoculation and seed planting. After one month, a second dose of 30-30-30 kg NPK/ha was applied in solution form after dissolving the fertilizer in water.

The mycorrhizal spores used in the experiment came from pot cultures of Pensacola Bahia grass. Initially, spores of *Glomus etunicatum, Glomus macrocarpum* and *Gigaspora margarita* were inoculated to seedlings of Bahia grass grown in small cups. After four months, the roots of the Bahia grass and soil were recovered and the above-ground biomass discarded. The infected roots were cut into small pieces and incorporated with the soil. The mycorrhizal soil inoculant for the experiment was calibrated to contain 200 spores per plant which also contained hyphae and infected roots. Inoculation was done by layering the soil inoculant 2-3 cm below the seed or seedling at planting.

Upland rice, corn, mungbean, soybean and peanut were directly seeded into pots. Seeds of the other host plants were first pregerminated in a seed box and then the seedlings were transplanted to pots when they were 2-3 cm tall.

Host plants were maintained for two months in the screenhouse, except for some agricultural crops (corn, peanut, mungbean ang soybean) which were harvested after the complete crop cycle. Watering was done every day and spraying of pesticide was done whenever necessary. Parameters measured for the duration of the experiments are presented in Table 2. Data gathered were statistically analyzed using the Analysis of Variance (ANOVA) and treatment means compared using Tukey's W-procedure.

RESULTS AND DISCUSSION

A. Total Biomass, Height, Cob/Pod Yield or Stem Diameter

Tables 3, 4 and 5 present the response of the 18 hosts to inoculation with different VA mycorrhizal species and/or applied with complete fertilizer. The uninoculated-unfertilized control consistently gave the poorest growth performance in terms of height, total biomass, pod/cob yield and stem diameter for all hosts screened. Plants fertilized with complete fertilizer alone were most often comparable with or slightly better than the uninoculated-unfertilized control plants. However, when plants were inoculated with either of the three VA mycorrhizal species and applied with fertilizer, growth rate was highest. Exceptions to these are upland rice, cacao, langka and guyabano. In these plants, growth of the plants treated with fertilizer alone was comparable to that of the inoculated plants or there was no significant difference among the five treatments.

The three VA mycorrhizal species were equally effective in promoting growth of the plants. Although *G. margarita* almost always gave a higher value in some parameters monitored, they were not statistically different.

Significant positive correlation between mycorrhizal infection and total biomass, height and cob/pod yield or stem diameter was observed on almost all plants. This means that the good height growth, heavy total biomass and good cob/pod yield were probably due to the high mycorrhizal infection in the inoculated plants. A not-significant correlation, on the other hand, signifies that mycorrhizal infection was not related to the height, total biomass and stem diameter growth observed in these plants.

B. Mycorrhizal Dependency

Tables 6,7 and 8 present the summary of the responses of the 18 hosts to inoculation with the three VA mycorrhizal species, their dependency on mycorrhiza and presence of host specificity. Total biomass, height and cob/pod yield and stem diameter of inoculated plants were compared with those of plants treated with fertilizer alone. The percentage increase was graded based on the classification of Ferguson (1984). In his discussion on mycorrhizal dependency, growth increases greater than 40% in a given soil fertility, means that these plants are highly dependent on mycorrhiza. A 10 - 40% increase means plants are intermediately dependent on mycorrhiza and less than 10% means the plants are not dependent on mycorrhiza.

Based on this classification, the 18 hosts were grouped into three. Plants highly responsive to mycorrhizal inoculation were the following: mungbean, eggplant, guava, papaya. *A. mangium, P. falcataria, A. auriculiformis* and kariskis. These plants were highly responsive to mycorrhizal inoculation and were observed to have high positive correlations between mycorrhizal infection and their total biomass. In all these crops, total biomass, height, nitrogen and phosphorus uptake were significantly improved with mycorrhizal inoculation.

Corn, peanut, soybean, citrus and raintree were also classified as highly dependent on mycorrhiza. Although their total biomass and cob/pod yield, nitrogen and phosphorus uptake were highly responsive to mycorrhizal inoculation, height of these plants, total biomass of citrus and stem diameter of raintree were only intermediately affected by mycorrhizal inoculation.

Guyabano and mahogany were found to be intermediately dependent on mycorrhiza. These plants have intermediate to no response in total biomass and/or height and stem diameter when inoculated with either of the three VA mycorrhizal species. Correlation analysis between growth parameters of these two crops and mycorrhizal infection showed lower positive correlation values than in the crops which were highly responsive to mycorrhizal inoculation.

The remaining plants (langka, upland rice and cacao) were classified as not dependent on mycorrhiza. Responses of these plants varied from intermediate, to no response at all to mycorrhizal inoculation. Correlation analysis showed that mycorrhizal infection was not related to the total biomass, height, stem diameter and nitrogen and phosphorus content and uptake of these plants.

C. Host Specificity and Host Preferences

Tables 6, 7 and 8 also show the evaluation of the presence of host specificity for all the three VA mycorrhizal species. Host specificity was defined by Harley and Smith (1983) as the condition wherein a given species of fungus forms mycorrhizal relationship only with a specific host plant. If the fungus forms mycorrhizal associations with many plants it is considered as "not specific". All the three VA mycorrhizal fungi were evaluated to be non-host specific. They all formed mycorrhizal infection as verified by the Gridline Intersect Method (Giovanetti and Mosse 1982) used in evaluating mycorrhizal infection. Even the non-mycorrhizal dependent crops such as upland rice, langka and cacao were observed to have mycorrhizal root infections. Mycorrhizal infection observed were usually in the form of vesicles and arbuscules.

The different responses of the hosts to the three VA mycorrhizal species may be due to the host preferences by the mycorrhizal fungi. This was also suggested by many researchers when one fungus improved growth of one plant better than another (Mosse 1975; Fox 1971-72). Mosse (1975) cited that the preferential association between certain plants and fungal species can be evaluated with respect to combinations which produced the greatest plant growth stimulation, the greatest colonization and maximum sporulation.

D. Fertilizer effect and large cotyledons

The possible reason why upland rice was not influenced by mycorrhizal inoculation was the very good response of the plant to fertilizer application. Rice plants responded greatly to the added fertilizer and with their fibrous root system, they were able to have access to the nutrients applied. Growth of the plant was no longer limited by the nutrient deficiency of the soil, thus mycorrhizal inoculation did not have any effect on the growth of the plant. This was similar to the report of Rhodes (1981) who stated that "if the supply of organic nutrients is not limiting the growth of non-mycorrhizal plants, then mycorrhizal inoculation will add nothing."

A common characteristic of plants not dependent on mycorrhiza and those only intermediately dependent on mycorrhiza, particularly cacao, mahogany and langka, is the very large cotyledons of their seeds. In the initial stages of seedling growth, the plants might have depended much on the stored food. Host photosynthates were channeled to the formation of the above-

ground biomass and not on root formation, such that the large food reserves may have delayed mycorrhizal association between the fungi and the plant. Furthermore, there might not have been enough infection sites for the fungus to enter and form mycorrhizal associations due to the relatively few and sparse roots.

E. Mycorrhizal Dependency Based on Percentage Relative Increase in Total Biomass

Figure 1 presents the mycorrhizal dependency of the 18 crops tested based on percentage relative increase in total biomass over the fertilizer alone treatment. Percentage relative increase in total biomass was computed by dividing the total biomass of the plant receiving fertilizer treatment alone over the average biomass of the inoculated plants then multiplied by 100. The higher the percentage relative increase over the fertilizer treated plants alone, the more the plant is not dependent on mycorrhiza. Plants not dependent on mycorrhiza had relative increases in total biomass of 90-107%, plants intermediately dependent on mycorrhiza had relative increases in total biomass of 76-87% and the plants dependent on mycorrhiza had 7-53% relative increase in total biomass over plants treated with fertilizer alone.

CONCLUSIONS AND RECOMMENDATIONS

1. It is concluded that growth of plants in very infertile areas can be improved with application of small amounts of fertilizer and inoculation with VA mycorrhiza.
2. The three VA mycorrhizal fungi were equally effective in improving growth of the plants and were not host specific. Thus, any of the three species can be used to inoculate plants and can still give good growth performance.
3. Further studies on factors which determine host preference should be done.
4. Further studies on the response of plants to mycorrhiza in other problem soils such as saline affected soils, mining areas and the like under Philippine conditions should be done to fully evaluate the potentials of mycorrhizal associations.

Table 1. Chemical and initial mycorrhizal population of Annam soil, collected from Carranglan, Nueva Ecija

SOIL PROPERTIES	ANALYSIS
pH	5.35
Organic Matter (%)	1.08
Total Nitrogen (%)	0.05
Available Phosphorus (ppm)	5.34
Exchangeable K (me/100 g)	1.71
Exchangeable Ca (me/100 g)	7.95
Exchangeable Mg (me/100 g)	3.06
CEC (me/100 g)	17.02
Native Mycorrhizal Population (organisms per gram air dry soil)	44.0

Table 2. Growth parameters measured, method used and time of measurement

Parameter	Method	Time of Measurement
Plant Height	From the base of the stem to the tip of the apical bud with a metric ruler	Monthly
Flowering date	Observation on the earliness of flowering between treatments	Duration of experiment
Stem diameter	Measured at the base of the root collar with a vernier caliper	2nd month
Pod/Cob Yield	Weighed using a Mettler balance after oven drying at 60^{0}C for 48 hours	Harvest
Root/Shoot/Nodule and total biomass	Weighed using a Mettler balance after oven drying at 60^{0}C for 48 hours	Harvest
Mycorrhizal infection	Taking fine root segments, preserving and fixing in Formalin - acetic-acid-solution (FAA) then clearing and staining using the procedure of Philipps and Hayman 1970. Infection count was done using the Gridline Intersect Technique by Giovanetti and Mosse 1980.	Harvest
Nitrogen Content	Analyzed using the Kjeldahl Method	Harvest
Nitrogen Uptake	Nitrogen content multiplied with the total plant biomass	Harvest
Phosphorus Content	Analyzed using the Molybdo-Vanadate Method	Harvest
Phosphorus Uptake	Phosphorus content multiplied with the total plant biomass	Harvest

Table 3. Responses of six agricultural crops to inoculation with three different VA mycorrhizal species

Agricultural Crops	Control	60-60-60	*Gl. etunicatum* 60-60-60	*Gl. macrocarpum* 60-60-60	*G. margarita* 60-60-60	Correlation with Myc. Infection
1. Upland rice						
Total biomass (g) *	1.96 b	10.82 a	10.33 a	11.48 a	11.62 a	0.18 ns
Tiller count (no/plt) *	3.00 b	7.00 a	7.00 a	8.00 a	7.00 a	0.18 ns
Height (cm) *	47.20 b	60.50 a	62.60 a	65.00 a	64.60 a	0.06 ns
2. Corn						
Total biomass (g) *	2.05 c	7.24 b	13.49 a	15.16 a	12.41 a	0.59 *
Cob yield (g) *	0.20 b	193.50 b	955.30 a	825.90 a	744.20 a	0.63 *
Height (cm) *	55.60 c	88.40 b	107.40 ab	112.90 a	107.80 a	0.53 *
3. Mungbean						
Total biomass (g) *	0.24 b	0.36 b	4.74 a	5.03 a	5.57 a	0.85 *
Pod yield (mg) *	0.10 b	163.90 b	2512.00 a	26.01 a	3157.00 a	0.84 *
Height (cm)	11.10 b	12.80 b	25.60 a	26.60 a	28.40 a	0.83 *
4. Peanut						
Total biomass (g) *	2.16 c	2.73 c	8.02 b	8.32 ab	9.91 a	0.93 *
Pod yield (g) *	0.82 b	1.18 b	3.79 a	3.42 a	3.53 a	0.81 *
Height (cm) ns	17.80	15.40	18.20	20.60	19.50	0.32 *
5. Soybean						
Total biomass (g) *	1.30 c	2.91 b	6.01 a	4.80 a	5.70 a	0.69 *
Pod yield (g) *	0.25 b	0.91 b	2.52 a	1.91 a	2.27 a	0.66 *
Height (cm) *	52.30 b	87.80 a	110.00 a	98.60 a	110.90 a	0.43 *
6. Eggplant						
Total biomass (g) *	0.03 b	1.63 b	6.33 a	6.51 a	5.62 a	0.92 *
Height (cm) *	1.80 b	6.30 b	15.00 a	14.40 a	14.20 a	0.89 *

Table 4. Responses of six fruit trees to inoculation with three different VA mycorrhizal species

FRUIT TREES	Control	60-60-60	*Gl. etunicatum* 60-60-60	*Gl. macrocarpum* 60-60-60	*G. margarita* 60-60-60	Correlation with Myc. Infection
1. Guava						
Total biomass (g) *	0.05 b	0.11 b	0.43 a	0.40 ab	0.43 a	0.60 *
Stem diameter (mm) *	1.20 b	1.30 b	2.00 ab	1.90 ab	2.20 a	0.61 *
Height (cm) *	3.30 c	6.80 bc	11.80 ab	12.30 ab	14.20 a	0.68 *
2. Cacao						
Total biomass (g) ns	1.08	*.92	1.74	2.10	1.55	0.23 ns
Stem diameter (mm) ns	4.90	6.10	6.10	6.20	5.70	0.19 ns
Heigth (cm) ns	16.10	18.30	17.50	18.80	17.10	0.16 ns
3. Langka						
Total biomass (g) ns	6.34	6.74	7.78	7.70	7.11	0.04 ns
Stem diameter (mm) ns	7.30	7.20	7.20	7.30	6.70	0.31 ns
Height (cm) ns	49.20	49.40	53.50	53.60	53.70	0.15 ns
4. Citrus						
Total biomass (g) *	0.23 b	0.24 b	0.31 b	0.72 a	0.72 a	0.57 *
Stem diameter (mm) *	1.20 b	1.70 ab	1.40 ab	1.60 a	2.10 a	0.40 *
Height (cm) *	5.70 b	5.70 b	8.10 b	11.00 ab	11.60 a	0.65 *
5. Papaya						
Total biomass (g) *	0.06 b	1.62 b	6.39 a	6.45 a	6.72 a	0.82 *
Stem diameter (mm) *	1.60 b	3.00 b	10.10 a	11.90 a	11.90 a	0.87 *
Height (cm) *	7.00 b	11.20 b	34.00 a	32.30 a	34.60 a	0.91 *
6. Guyabano						
Total biomass (g) ns	1.05	1.11	1.44	1.24	1.69	0.41 *
Stem diameter (mm) ns	4.20	3.70	4.10	3.80	4.40	0.12 ns
Height (cm) *	22.70 b	23.40 ab	27.00 ab	24.70 ab	28.30 a	0.47 *

Table 5. Responses of six forest trees to inoculation with three different VA mycorrhizal species

	FOREST TREES	Control	60-60-60	*Gl. etunicatum* 60-60-60	*Gl. macrocarpum* 60-60-60	*G. margarita* 60-60-60	Correlation with Myc. Infection
1	***A. manqium***						
	Total biomass (g) *	0.15 b	0.52 b	3.77 a	3.72 a	4.37 a	0.57 *
	Stem diameter (mm) *	1.10 b	1.00 b	2.80 a	2.70 a	3.20 a	0.66 *
	Height (cm) *	6.20 b	7.00 b	23.30 a	21.60 a	27.10 a	0.73 *
2.	***P. falcataria***						
	Total biomass (g) *	0.21 b	0.27 b	3.91 a	3.74 a	4.67 a	0.89 *
	Stem diameter (mm) *	1.40 c	1.20 c	3.60 b	3.60 b	4.20 a	0.93 *
	Height (cm) *	2.30 b	3.30 b	17.30 a	16.90 a	18.50 a	0.89 *
3.	**Raintree**						
	Total biomass (g) *	1.11 b	1.02 b	2.97 a	3.39 a	3.40 a	0.70 *
	Stem diameter (mm) *	2.80 b	3.10 ab	3.80 a	3.80 a	3.60 ab	0.50 *
	Height (cm) *	20.30 c	22.10 bc	31.70 ab	34.70 a	34.30 a	0.64 *
4.	***A. Auriculiformis***						
	Total biomass (g) *	0.20 c	0.47 bc	0.98 abc	1.34 a	1.13 ab	0.65 *
	Stem diameter (mm) *	1.20 b	1.40 b	2.00 ab	2.40 a	2.40 a	0.63 *
	Height (cm) *	10.50 c	12.10 bc	20.20 ab	22.90 a	21.20 a	0.63 *
5.	**Mahogany**						
	Total biomass (g) *	2.18 b	2.89 b	3.23 ab	3.08 ab	3.63 a	0.37 *
	Stem diameter (mm) ns	3.50	3.50	4.20	3.90	3.80	0.16 ns
	Height (cm) ns	24.70	22.60	24.00	22.00	25.30	-0.16 ns
6.	**Kariskis**						
	Total biomass (g) *	0.14 b	0.12 b	2.10 a	1.70 a	1.86 a	0.73 *
	Stem diameter (mm) ns	1.30 b	1.40 b	2.80 a	3.00 a	2.30 a	0.73 *
	Height (cm) *	5.10 b	5.60 bb	46.50 a	45.20 a	41.10 a	0.79 *

Table 6. Summary of the responses of six agricultural crops to inoculation with three different VA mycorrhizal species, their dependency on mycorrhiza and evaluation of the presence of host specificity

AGRICULTURAL CROPS	*Gl. etunicatum*		*Gl. macrocarpum*		*G. margarita*		MYCORRHIZAL DEPENDENCY
	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	
1. Upland rice							
Total biomass *	0	none	6	none	7	none	not
Tiller count *	0	none	14	interm.	0	none	dependent
Height *	4	none	7	none	7	none	
2. Corn							
Total biomass *	86	high	109	high	70	high	highly
Cob yield *	394	high	327	high	1447	high	dependent
Height *	21	interm.	28	interm.	22	interm.	
3. Mungbean							
Total biomass *	1217	high	1297	high	1447	high	highly
Pod yield *	1434	high	1488	high	1827	high	dependent
Height *	100	high	108	high	122	high	
4. Peanut							
Total biomass *	194	high	205	high	263	high	highly
Pod yield *	221	high	190	high	199	high	dependent
Height ns	18	interm.	34	interm.	27	interm.	
5. Soybean							
Total biomass *	106	high	65	high	96	high	highly
Pod yield *	177	high	110	high	149	high	dependent
Height *	25	interm.	12	interm.	26	interm.	
6. Eggplant							
Total biomass *	288	high	299	high	245	high	highly
Height *	138	high	129	high	125	high	dependent
Presence of host specificity	not specific		not specific		not specific		

Legend : 0-10% increase = not dependent
11-40% increase = intermediately dependent, >40% increase = highly dependent

Table 7. **Summary of the responses of six fruit trees to inoculation with three different VA mycorrhizal species, their dependency on mycorrhiza and evaluation of the presence of host specificity**

FRUIT TREES	*Gl. etunicatum*		*Gl. macrocarpum*		*G. margarita*		MYCORRHIZAL DEPENDENCY
	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	
1. **Guava**							
Total biomass *	291	high	264	high	291	high	highly
Height *	54	high	46	high	69	high	dependent
2. **Cacao**							
Total biomass ns	0	none	9	none	0	none	not
Height ns	0	none	3	none	0	none	dependent
3. **Langka**							
Total biomass ns	14	interm.	14	interm.	6	none	not
Height ns	8	none	9	none	9	none	dependent
4. **Citrus**							
Total biomass *	29	interm.	200	high	200	high	highly
Height *	42	high	93	high	191	high	dependent
5. **Papaya**							
Total biomass *	294	high	298	high	315	high	highly
Height *	203	high	188	high	209	high	dependent
6. **Guyabano**							
Total biomass ns	30	interm.	12	interm.	52	high	interme-
Height *	15	interm.	6	none	21	interm.	diately dependent
Presence of host specificity	not specific		not specific		not specific		

Legend : 0-10% increase = not dependent
11-40% increase = intermediately dependent, >40% increase = highly dependent

Table 8. Summary of the responses of six forest trees to inoculation with three different VA mycorrhizal species, their dependency on mycorrhiza and evaluation of the presence of host specificity

FOREST TREES	*Gl. etunicatum*		*Gl. macrocarpum*		*G. margarita*		MYCORRHIZAL DEPENDENCY
	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	% Inc. vs 60-60-60	Graded response	
1. ***A. Manqium***							
Total biomass *	625	high	500	high	740	high	highly
Height *	230	high	251	high	287	high	dependent
Stem diameter *	180	high	170	high	220	high	
2. ***P. falcataria***							
Total biomass *	1348	high	1285	high	1630	high	highly
Height *	424	high	412	high	461	high	dependent
Stem diameter *	200	high	200	high	250	high	
3. **Raintree**							
Total biomass *	191	high	232	high	233	high	highly
Height *	43	high	57	high	55	high	dependent
Stem diameter *	23	interm.	23	interm.	16	interm.	
4. ***A. auriculiformis***							
Total biomass *	109	high	185	high	140	high	highly
Height *	67	high	89	high	75	high	dependent
Stem diameter *	73	high	71	high	71	high	
5. **Mahogany**							
Total biomass *	12	interm.	7	none	26	interm.	interme-
Height ns	6	none	0	none	11	interm.	diately
Stem diameter *	20	interm.	11	interm.	9	none	dependent
6. **Kariskis**							
Total biomass *	1650	high	1317	high	1450	high	highly
Height *	812	high	786	high	706	high	dependent
Stem diameter *	87	high	100	high	53	high	
Presence of host specificity	not specific		not specific		not specific		

Legend : 0-10% increase = not dependent
11-40% increase = intermediately dependent, >40% increase = highly dependent

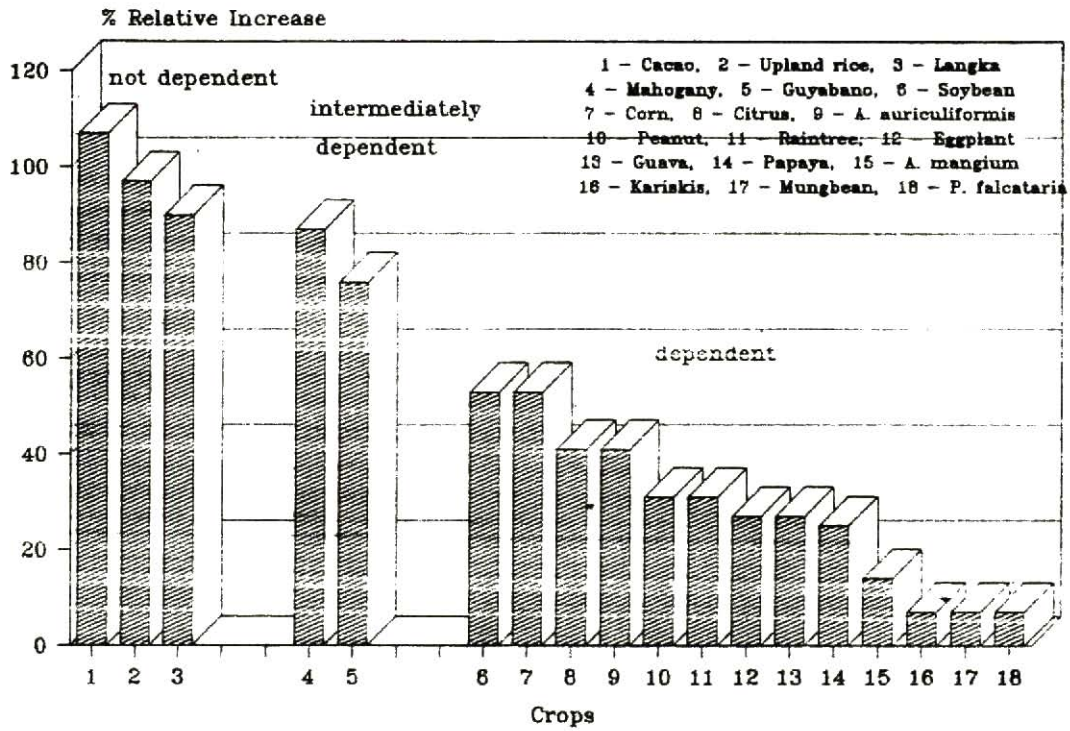

Figure 1. Mycorrhizal dependency of the 18 selected crops based on percentage relative increase of total biomass over the fertilizer alone treatment

REFERENCES

Ferguson, J.J. (Ed.) 1984. Application of mycorrhizal fungi in crop production. University of Florida, Fruit Crops Department, Gainesville, Florida.

Fox, J.A. and L. Spasoff. 1971-1972. Host range studies of *Endogone gigantea* in Proceedings of Varain Journal of Science 23: 121.

Giovannetti, M. and B. Mosse. 1980. An evaluation of techniques for measuring VA mycorrhizal infection in roots. New Phytologists 84: 489-500.

Hayman, D.S. 1982. Influence of soils and fertility on activity and survival of vesicular-arbuscular mycorrhizal fungi. Phytopathology 72: 1119-1125.

Harley, J.L. and S.E. Smith. 1983. Mycorrhizal symbiosis. Academic press. London, 483 p.

International Rice Research Institute (IRRI). 1986. Area and distribution of acid upland soils in Southeast Asia. In Annual Report for 1985. IRRI, Los Banos, Laguna, Philippines.

Mikola, P. 1982. Biology of ectomycorrhiza. IFS Provisional Report No. 12. Training Course on Mycorrhiza Research Techniques, Serdang, Malaysia pp. 49-58.

Mosse, B. 1975. Specificity in VA mycorrhizas. IN Endomycorrhizas. F.E. Sanders, B. Mosse and P.B. Tinker. (Eds.). Academic Press London, pp. 469-482.

Rhodes, L.H. 1981. The use of mycorrhiza in crop production systems. Outlook in agriculture 10: 275-281.