Chapter

Influence of Endomycorrhizal Fungi on the Growth of Tropical Plant Species

Juan Francisco Aguirre-Medina, Jorge Cadena-Iñigue and Juan Francisco Aguirre-Caden

Abstract

In Southeast Mexico, deforestation in tropical forests is considered an environmental concern. Deforestation favours the growth of plants that compete with species of interest, which generally present slow growth. In order to promote greater growth in less time of the forest species used in reforestation and two crops of regional interest, the effect of including *Rhizophagus intraradices* in the seed or the root system of seedlings were investigated to evaluate its influence on growth and allocation of dry matter in the aerial and radical part, in addition to the concentration of N, P and Ca. Also, two additional collections with morphological characteristics of *Glomus* sps were included in *T. donnell-smithii*. The results indicate that biofertilisation with *R. intraradices* induces increased growth and is differential in stem and root dry matter allocation over time, in addition to increasing nutrient content in plant tissue.

Keywords: tropical spices, endomycorrhiza, root and shoot growth, range relative growth, nitrogen and phosphate

1. Introduction

Forest ecosystems are affected by various environmental and anthropogenic factors such as drought and the establishment of annual crops; these actions have caused their degradation. The above situation has generated several reforestation programs in Mexico through the massive production of forest species in nurseries, however, when planted in the field, the survival of plants is less than 50%, due in part to the low quality of the plants produced in the nursery and the intermittent drought they face when taken to the field [1]. In such procedures, the strengthening of the radical development of the host plant through biofertilisation with microorganisms has not been considered. Under these conditions, it is possible that microorganisms help plants survive in adverse environmental conditions [2].

Some bacteria and fungi that live in the rhizosphere interact with species present in agroforestry systems and may or may not manifest themselves in some morphological or physiological attribute of anthropocentric interest of the host plant, especially in sustainable or low input production systems, but their effective incidence depends on the microorganism and environmental and soil conditions [3]. The interaction
of the plant with endomycorrhizal fungi stimulates its growth [4], even in adverse environmental conditions [3, 5], such as drought [6], presence of nematodes [7] and also activate defence mechanisms against various pathogens [8, 9].

Endomycorrhizal fungi interact symbiotically with more than 80% of terrestrial plants [10]. It is the most common symbiosis on earth [11] and important part of the development, maintenance and stability of ecosystems and represents an important mechanism for plant and reproductive development [12]. They can be found in all terrestrial ecosystems and their universality implies vast taxonomic diversity [13]. Native populations of endomycorrhizal fungi have favoured the sustainability of agricultural systems, while introduced ones may not be adapted to the environment and may have ecological specificity [14] or host preference [15]. In the rhizosphere, in addition to microorganisms, there are abundant root exudates that have a selective effect on soil microbiota [16].

When endomycorrhizal fungi are introduced in the seed or in the soil to colonise the root, the establishment of symbiosis is facilitated and the benefits are expressed in early stages [17], as an increase in growth and in the case of nursery plants, a decrease of time to be taken to the field. Symbiosis improves the supply, availability and physical access of nutrients to the plant [18].

Currently, endomycorrhizal fungi are considered essential organisms for the sustainable management of agriculture. In general, when new species are introduced to a region and adapt quickly to the new environment, the possibility that the species has the capacity in its root system to establish symbiosis with the microorganisms is considered. They are capable of linking to the development of the subway community [19].

Radical colonisation by endomycorrhizal fungi initiates with the exchange of carbon from the host plant to the fungus, and in turn, establishes by exploring the soil through mycelium the transport of nutrients to the root [20], such as phosphorus [2, 21, 22], water [20] and other nutrients to the plant. If Phosphorus (P) is not available for the initial development of the plant, it becomes limiting [23] and being a low mobility ion, hyphae can be the bridge for phosphorus supplementation [20] and by supplying it, growth is significantly influenced [2]. In addition, it improves the physical state of the soil by producing glomalin [20], to form more stable soil aggregates [24].

The beneficial effect of the application of endomycorrhizal fungi has been demonstrated in the increase of biomass in perennial crops such as *Leucaena leucocephala* (Lam.) De Wit [25, 26], *Theobroma cacao* L. [27], *Coffee arabica* L. [28], *Jatropha curcas* L. [29], *C. canephora* (Pierre) ex Froehner [30], *Tabebuia donnell-smithii* (Rose) Miranda [31], *Cedrela odorata* L. [32] and *Elaeis guineensis* Jacq [33].

2. Influence of endomycorrhizal fungi on plant growth

Understanding growth, as the irreversible increase in the size of an individual almost always associated with an increase in its complexity, helps us to identify the effect of endomycorrhizal fungi on symbiosis with the host plant. The analysis of plant growth represents the first step in the analysis of primary production [34] in its different components, which are those that regulate the final production. In this way, the yield understood as the phenotypic expression of anthropocentric interest, is the final result of the physiological processes that are reflected in the plant’s morphology [35].

The assignment of dry matter to the different structures of the plant, such as the root system, the stem and the foliar lamina are modified when endomycorrhizal fungi are included, either in soil or in substrates with the addition of other
components, such as bovine manure, from the poultry industry, or agro-industrial wastes, such as sugarcane bagasse, coffee husk, cocoa shell, among others. This symbiotic association between fungus and plant generates the enlargement of the root system and acts as a root complement [36]. Endomycorrhizal fungi, together with the rest of microorganisms, are fundamental in the cycle of nutrients, even more, when considering that the availability of nutrients is heterogeneous in soils.

Mycelium is the means of transporting nutrients and water to the plant and is elemental in soil exploration. Especially in conditions of exploitation of monocultures that generate through time, the “depletion zone” of nutrients near its root system. Also, the tillage exercised in these production systems breaks the mycelium of the fungus and diminishes the beneficial effect it has on the structure of the soil, affecting the diversity and productivity of the communities [37, 38]. In addition, the applications of agrochemicals adversely affect the diversity and abundance of endomycorrhizal fungi in agroecosystems [39], causing the decrease or loss in the functioning of the plant community [40, 41].

In these conditions, the mycelium of the fungus can explore spaces in the soil where roots do not reach, that is, explore areas beyond the known “depletion zone” of the root and increase the absorption surface by exploring greater volume of soil compared to non-mycorrhised roots. This fact is more relevant when considering that they have the capacity to transport nutrients that are not very mobile, such as phosphorus [42].

The preference of endomycorrhizal fungi to transport phosphorus has been documented [21, 43] and this nutrient is fundamental for plant growth, even more so when considering that it has low availability in tropical soils [44]. Its supply by the fungus favours plant growth, but the symbiosis can be reduced or inhibited if the P level in the soil is high and the plant root can absorb it by itself [45]. On the other hand, they cite that the efficiency in P absorption by the mycorrhisred roots is mainly due to an acceleration of the dissociation of insoluble phosphate and it is extracted by the mycorrhizae according to the needs of the host plant. In general, it has been established that mycorrhised plants favour the absorption and transport of P, Zn, Ca, S, Cu, and Mg and their effects are more noticeable in low fertility soils [47].

When endomycorrhizal fungi are introduced into plants, the response can be diverse, influenced either by plant metabolism or by root architecture [48] and the interaction is considered non-specific, because any species of endomycorrhizal can colonise a plant [49], however, in different crops of the same species, the induction of growth is differential, according to the endomycorrhizal fungus introduced [31] or according to the tillage. In some forest species the root volume increases [50], in others, it decreases [51], or it is also expressed in an increase in the thickness of the stem needed to be taken to the field in less time compared to non-biofertilised plants. Also, it decreases mortality after transplantation [17] and improves its survival capacity in adverse conditions [52].

The growth of biofertilised plants with endomycorrhizal fungi presents changes in their aerial and root structure since the beginning of their evaluation. Generally, the dry weight of the aerial part of the plants is greater than the dry weight of the root system (Figure 1).

The root system development of biofertilised plants shows little difference in growth in C. odorata at 28 and 56 days after sowing. In contrast, the growth of C. canephora, increases and in C. arabica, its growth decreased at 28 days. The decrease in the growth of the root system of the biofertilised plants with the endomycorrhizal fungus in comparison to the control could reflect the initial limitation in the interaction of both organisms due to the availability of carbohydrates. In this initial stage, energy is required to support the mechanisms of plant/fungi recognition that will lead to the establishment of symbiosis [53], and in the
following stages, it is likely that the hyphae of the fungus will replace the root hairs due to the increase of biomass in the aerial part of the plant. Otherwise, it would be expected that the treatments with higher root system would have higher absorption of nutrients from the soil. The above behaviour suggests greater transport of photosynthates to the aerial part.

In *T. donnell-smithii*, the root system of the biofertilised treatment is increased. The values found at 140 das (Figure 2) indicate an increase in aerial and root biomass in most of the species evaluated with the exception of *T. cacao*. In other results with *T. cacao*, [54] the effect of the increase in biomass with the same species was found between 84 and 112 days. On the other hand, [55], they report increases in biomass of *T. cacao* with the inoculation of endomycorrhizal fungi of the *Scutellospora* and *Glomus* in genera of *T. cacao* plants with evident differences with the control from 120 days after sowing.

In *C. arabica*, the 140 das is presented with a slight increase in the radical system of the biofertilised plants in comparison to the control. In the same species [28] in evaluation at 60 and 90 days, there is a decrease in the biomass in the root system with the biofertilisation of *R. intraradices* at 60 and 90 days and a similar biomass in the root system as the control at 180 days. In contrast, with *C. canephora*, *T. donnell-smithii*, and *C. odorata*, the increase in aerial and radical biomass was remarkable.

Figure 1.
Shoot and root growth of different tropical plant species with and without *Rhizophagus intraradices* in the greenhouse. Values are the average of four replications by sampling and treatment. The vertical bars indicate the standard error of the mean.
In *Leucaena leucocephala cv peru*, the radical system decreased with biofertilisation but the aerial biomass increased. It is probable that the plant responds better with other endomycorrhizal fungi.

The response of microorganisms in plant development reflects differential growth in time and between their organs. The greater or lesser allocation of biomass to some plant organs, seems to be influenced by the biofertilisation applied to its radical system and in almost all cases, after the ample development of an organ in a period of time, it tends to diminish in the following period, but with important increase in another plant organ.

The relative growth rate or the amount of dry matter produced per unit of time induced by the symbiosis with endomycorrhizal fungi presents the highest growth rate during the first 56 days after planting (days) (Table 1). In the period between 112 and 40 das, all species show a decrease in growth rate. This can be mainly related to the higher proportion of cells that do not divide in relation to those that do [56], whereas, in annual crops, the highest growth occurs around 30 days after biofertilisation with an increase in the mean relative growth rate [57] and leaf area [58].

In *T. cacao* L. and *C. canephora*, the relative growth rate presents a different effect between the control and *R. intraradices*. After the initial high growth with the endomycorrhizal fungus, it decreases during two months to continue again the increase of its growth. In the case of the control, the opposite happens, the initial increase in biomass is less, but it increases in the second and third sampling in *T. cacao* and the second in *C. canephora*. The above response is considered to be influenced by the demand for carbon sources [59].

In *T. donnell-smithii*, the response is different among fungal species. Some of them, such as *Glomus* sp. (Tea lemon), show a higher induction of initial growth and at the end of the evaluation, the growth was higher by *R. intraradices*. In this regard [60] cites differential response in growth [61] and, that plants have different responses to geographical isolations when the same species is inoculated.

On the other hand, in *C. odorata*, the growth rate was higher in the control on the evaluated dates. The physiological expression of plants seems to be related to their modular growth among their organs over time.
3. Content of P and other nutrients in plant tissue

In all tropical forest species biofertilised with the endomycorrhizal fungus, a higher content of phosphorus was found in their plant tissue even though a large part of the available phosphorus in the soil is fixed in the andosol soils (Table 2). Many studies have shown that mycorrhised plants have benefits in their association with endomycorrhizal fungi under phosphorus-deficient conditions, especially in the acid soils of the tropics [62–64].

P is captured by the external mycelium and subsequently transported through the hyphae or intraradical structures in the form of polyphosphate granules and finally the process of transfer by the bush to the host cells [65].

In C. arabica plants at 56 days after planting, P and Ca values are very similar and concentrations increase to 140 days in the plant biofertilised with R. intraradices. With other species of endomycorrhizal fungi such as Glomus clarum and Gigaspora margarita in coffee seedlings, the growth and absorption of phosphorus by the plant was favoured, as well as the increase in survival and field production [66].

In general, it has been established that mycorrhised plants favour the absorption and transport not only of P but also of Zn, Ca, S, Cu, and Mg. The mycorrhizae are more active in soils of low fertility, especially when there is a deficiency of phosphorus [47].

The N content in the tissue of the biofertilised plants at 56 das was higher in the control with C. arabica. At 140 days, it was higher in most species with the exception of C. canephora cocoa plants biofertilised with R. intraradices had higher nitrogen content during the whole evaluation. This fact demonstrates that the host plant’s root system is an extension of the plants’ absorption system and favours the capacity to transport nutrients, such as nitrogen [18].

| Plant species                  | Time (days after sowing) | 28–56 | 56–84 | 84–112 | 112–140 |
|--------------------------------|--------------------------|-------|-------|--------|---------|
| Cedrela odorata                | R. intraradices          | 0.126 | 0.042 | 0.054  | 0.021   |
| Tabeuba donnell-smithii        | R. intraradices          | 0.065 | 0.022 | 0.019  | 0.012   |
| Glomus sp. Te Limón           | R. intraradices          | 0.064 | 0.021 | 0.033  | 0.017   |
| Glomus sp. Vetiver            | R. intraradices          | 0.063 | 0.022 | 0.027  | 0.015   |
| Teobroma cacao                | R. intraradices          | 0.007 | 0.007 | 0.005   |
| Control                       | Control                  | 0.0087| 0.0087| 0.0072| 0.0084  |
| Teobroma cacao                | R. intraradices          | 0.0097| 0.0076| 0.0057| 0.0085  |
| Control                       | Control                  | 0.039 | 0.024 | 0.017  |
| Coffea canephora              | Control                  | 0.037 | 0.036 | 0.030  | 0.044   |

Values are the average of four replications by sampling and treatment.

Dry weight (g g\(^{-1}\) day\(^{-1}\)).
In the case of *T. donnell-smithii*, there are important differences between stem and root, in general, the highest N content was found in the root system. This difference in symbiosis effectiveness seems to depend more on the interaction with a soil type and crop conditions than with a particular host [67].

The benefits of transport of other nutrients and water, in addition to phosphorus to the plant, by mycorrhiza have been reported by several authors [68, 69].

Nowadays, the knowledge of microorganisms and their interaction with the rhizosphere has demonstrated the importance of symbiosis in the soil-plant system.

### 4. Radical colonisation

Plants with *R. intraradices* showed the highest initial mycorrhizal colonisation (45%) compared to (19%) in the control. The values of the control fluctuated

| Plant species               | Time (days)* | Nutrient (%) |
|-----------------------------|--------------|--------------|
|                            | N            | P            |
| *Cedrela odorata* L.        |              |              |
| Control                     | 140          | 2.50         | 0.11         |
| *R. intraradices*           | 140          | 3.11         | 0.19         |
| *T. donnell-smithii* R.     |              |              |
| Control                     | 140 (shoot)  | 0.74         | 0.08         |
|                            | 140 (root)   | 0.76         | 0.07         |
| *R. intraradices*           | 140 (shoot)  | 0.73         | 0.12         |
|                            | 140 (root)   | 0.94         | 0.08         |
| *T. cacao* L.               |              |              |
| Control                     | 28           | 1.95         | 0.27         |
|                            | 56           | 1.77         | 0.10         |
|                            | 140          | 1.70         | 0.10         |
| *R. intraradices*           | 28           | 2.62         | 0.33         |
|                            | 56           | 1.99         | 0.21         |
|                            | 140          | 1.83         | 0.11         |
| *C. arabica* L.             |              |              |
| Control                     | 56           | 1.98         | 0.13         |
|                            | 140          | 2.62         | 0.14         |
| *R. intraradices*           | 56           | 1.88         | 0.14         |
|                            | 140          | 2.84         | 0.19         |
| *C. canephora* P.           |              |              |
| Control                     | 140          | 3.75         | 0.07         |
| *R. intraradices*           | 140          | 3.55         | 0.131        |

Values are the average of four replications by sampling and treatment.

*Days after sowing.

**Table 2.**

*N, P and Ca content of different tropical species biofertilised with Rhizophagus intraradices under greenhouse conditions.*
between 4% (C. arabica) and 28% (T. donnell-smithii), in contrast with R. intraradices, the lowest value was also with C. arabica (18%) and the highest of 63, 57, 61 and 53% in T. donnell-smithii, C. canephora, L. leucocephala and C. odorata, respectively.

The radical colonisation in the controls confirms the presence of other endomycorrhizal fungi in the soils used, as part of the regional microbiota, but with less capacity to stimulate growth. Even though it has been indicated that the symbiosis lacks taxonomic specificity [70], there is a certain functional compatibility with the host plant, the substrate and the introduced microorganisms.

On the other hand, in biofertilised species, the speed of colonisation of R. intraradices is expressed as it has happened also in other annual and perennial crops [71] and consequently the photosynthetic activity increases after colonisation [20]. This fact suggests that the increase in the development of the host plant may be due to a greater capacity to absorb nutrients [32]. By introducing endomycorrhizal fungi attached to the seed, they have a greater chance of colonisation when the radicle emerges, unlike the fungi present in the substrate that may not be in the same proximity to the root system. However, it is expected that the symbiosis differs in the levels of colonisation [20] due to the interaction of environmental and management factors [2]. There are combinations of microorganisms that work best in a given host plant [70].

At the end of the evaluation (140 days) the percentage of colonisation in the control was 44% and in the treatment with R. intraradices, the average was 57%. The degree of benefit of the symbiosis may not be related to the percentage of colonisation.

5. Conclusions

The biofertilisation of tropical plants with R. intraradices favours the plant growth by increasing dry weight and the assignment of dry matter of the morphological and physiological components and the induction of growth is differential in time with respect to the organs evaluated, in some cases, it promotes greater aerial and radical growth and in others, it decreases the root system.

There are different periods in the vegetative growth of plants. At the beginning of the 28 to 56 days, the nutritional benefits are expressed by means of the increase in growth followed by a period of diminution and to continue in the following ones with the increase in biomass accumulation.

The content of nutrients such as phosphorus was always higher in the biofertilised plants.
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Author details

Juan Francisco Aguirre-Medina¹*, Jorge Cadena-Iñiguez² and Juan Francisco Aguirre-Caden¹

1 Autonomous University of Chiapas, Tapachula, Chiapas, Mexico
2 Postgraduate College, Texcoco, Mexico State, Mexico

*Address all correspondence to: juanf56@prodigy.net.mx

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References

[1] Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2005). Indicadores básicos del desempeño ambiental de México: [Internet]. Proyecto PNUD-SEMARNAT. México, D. F. [Accessed: 2013-02-12] http://app1.semarnat.gob.mx/dgeia/indicadores04/index.htm

[2] Andrade SAL, Mazzafera P, Schivinato MA, Silveira APD. Arbuscular mycorrhizal association in coffee. The Journal of Agricultural Science. 2009; 147(2): 105-115. DOI: https://doi.org/10.1017/S0021859608008344

[3] Qiu M, Zhang H, Wang G, Liu Z. Effects of nitrogen on plant-microorganism interaction. EurAsia J BioSci. 2008; 2, 4: 34-42. http://ejobios.org/download/effects-of-nitrogen-on-plant-microorganism-interaction.pdf

[4] Artursson V, Finlay RD, Jansson JK. Interactions between arbuscular mycorrhizal fungi and bacteria and their potential for stimulating plant growth. Environmental Microbiology. 2006; 8(1):1-10, DOI:10.1111/j.1462-2920.2005.00942.x

[5] Doubková P, Vlasáková E, Sudová R. Arbuscular mycorrhizal symbiosis alleviates drought stress imposed on *Knautia arvensis* plants in serpentine soil. Plant Soil. 2013; 370; 149-161. DOI: 10.1007/s11104-013-1610-7

[6] Augé RM. Arbuscular mycorrhizae and soil/plant water relations. Canadian Journal of Soil Science, 2004; 84(4): 373-381, https://DOI.org/10.4141/S04-002

[7] Dong LQ, Zhang KQ. Microbial control of plant-parasitic nematodes: a five-party Interaction. Plant and Soil. 2006; 288(1): 31-45. DOI: 10.1007/s11104-006-9009-3

[8] Harrier LA, Watson CA. The potential role of arbuscular mycorrhizal (AM) fungi in the bioprotection of plants against soil-borne pathogens in organic and/or other sustainable farming systems. Pest Management Science. 2004; 60 (2): 149-157. DOI: 10.1002/ps.820

[9] Jaizme-Vega MC, Rodríguez-Romero AS. Integración de microorganismos benéficos (Hongosmicorrícos y bacterias rizosféricas) en agrosistemas de las Islas Canarias. Agroecología, 2008; 3: 33-39. Retrieved from http://revistas.um.es/agroecologia/article/view/95491/91801

[10] Gianinazzi S, Gollotte A, Binet M, van Tuinen D, Redecker D, Wipf D. Agroecology: the key role of arbuscular mycorrhizas in ecosystem services. Mycorrhiza, 2010; 20: 519-530. https://doi.org/10.1007/s00572-010-0333-3

[11] Wang B, Qiu YL. Phylogenetic distribution and evolution of mycorrhizas in land plants. Mycorrhiza. 2006;16(5):299-363. DOI:10.1007/s00572-005-0033-6

[12] Read D. Plants on the web. Nature, 1998; 396: 22-23. https://doi.org/10.1038/23822

[13] Jaizme-Vega MC. Las micorrizas. Una simbiosis de interés para la agricultura. Revista Vida Rural. 2009; 288: 40-52. Retrieved from http://www.mapama.gob.es/ministerio/pags/Biblioteca/Revistas/pdf_ Vrural%2FVrural_2009_288_48_52.pdf

[14] Serralde OAM, Ramírez GMM. Análisis de poblaciones de micorrizas en maíz (*Zea mays*) cultivado en suelos ácidos bajo diferentes tratamientos agronómicos. Revista Corpoica, 2004; 5: 31-40. https://doi.org/10.21930/rcta.vol5_num1_art:22
[15] Daniell T, Husband JR, Fitter AH, Young JPW. Molecular diversity of arbuscular mycorrhizal fungi colonizing arable crops. FEMS Microbiology Ecology. 2001; 36(2-3): 203-209. DOI: 10.1111/j.1574-6941.2001.tb00841.x

[16] Offre P, Pavlo B, Siblot S, Gamalero E, Corberand T, Lemanceau P, Mougel C. Identification of bacterial groups preferentially associated with mycorrhizal roots of Medicago truncatula. Applied and Environmental Microbiology, 2007; 73, 913-921. DOI: 10.1128/AEM.02042-06

[17] Sieverding E. Ecology of VAM fungi in tropical agrosystems. Agriculture, Ecosystems & Environment, 1989; 29(1-4): 369-390. DOI: 10.1016/0167-8809(90)90303-U

[18] Barea JM, Azcon R, Azcon-Aguilar C. Mycorrhizosphere interactions to improve plant fitness and soil quality. Antonie van Leeuwenhoek Int. J. General Molecular Microbiol. 2002; 81(1-4): 343-351, DOI:10.1023/A:1020588701325

[19] Sanon A, AndrianjakaZN, Prin Y, Bally R, Thiouloise J, Comte G, Duponnois R. Rhizosphere microbiota interfere with plant–plant interactions. Plant Soil, 2009; 321: 259-278. DOI: 10.1007/s11104-009-0010-5

[20] Sylvia MD. Mycorrhizal symbioses. In: Sylvia MD, Fuhrmann JJ, Harte GP, Zuberer AD, editors. Principles and applications of soil microbiology. 2nd ed. New Jersey, USA. Pearson Prentice Hall. 2005. p. 263-282.

[21] Marschner H, Dell B. Nutrient uptake in mycorrhizal symbiosis. Plant Soil. 1994; 159; 89-102 https://doi.org/10.1007/BF00000098

[22] Richardson AE, Barea JM, McNeill AM, Prigent-Combaret C. Acquisition of phosphorus and nitrogen in the rhizosphere and plant growth promotion by microorganisms. Plant Soil. 2009; 321:305-339, DOI 10.1007/s11104-009-9895-2

[23] Tristão FSM, López ASA, Silveira APD. Fungos micorrízicos arbusculares na formação de mudas de cafeeiro, em substratos orgânicos comerciais. Bragantia, 2006; 65(4): 649-658. DOI: 10.1590/S0006-87052006000400016

[24] Rillig MC, Mummey DL. Mycorrhizas and soil structure. New Phytologist, 2006; 171(1): 41-53. DOI: 10.1111/j.1469-8137.2006.01750.x

[25] Ruiz-Torres GJ. La inoculación de Leucaena leucocephala con Glomus intraradices y su efecto en la asignación y calidad de la materia seca. [Tesis]. Facultad de Ciencias Agrícolas. Universidad Autónoma de Chiapas. 2005.

[26] Aguirre-Medina JF, Gálvez-López AL, Ibarra-Puón JC. Growth of Leucaena leucocephala (Lam.) de Wit biofertilized with arbuscular mycorrhizal fungi in the nursery. Revista Chapingo Serie Ciencias Forestales y del Ambiente. 2018; 24(1): 49-58. DOI: 10.5154/r.ch.scfa.2017.07.043

[27] Aguirre-Medina Juan Francisco, Mendoza-López Alexander, Cadena-Iñiguez Jorge, Avendaño-Arrazate Carlos H. Efecto de la biofertilización en vivero del cacao (Theobroma cacao l) con Azospirillum basilense tarrand, krieg et Döbereiner y Glomus intraradices Schenk et Smith. Interciencia. 2007; 32 (8): 541-546. Recuperado de: https://www.redalyc.org/articulo.oa?id=33932808

[28] Aguirre-Medina JF, Moroyoqui-Ovilla DM, Mendoza-López A, Cadena-Iñiguez J, Avendaño-Arrazate CH, Aguirre-Cadena JF. Hongo endomicorrízico y bacteria fijadora de...
nitrógeno inoculadas a Coffea arabica en vivero. Agronomía Mesoamericana. 2011; 22 (1): 71-80. https://www.scielo.sa.cr/pdf/am/v22n1/a09v22n1.pdf

[29] Díaz-Hernández BG, Aguirre-Medina JF, Díaz-Fuentes VH. Rendimiento de Jatropha curcas L. inoculada con micorriza y aplicación de composta de caña. Revista Mexicana de Ciencias Agrícolas. 2013; 4 (4):599-610. http://www.scielo.org.mx/pdf/remexca/v4n4/v4n4a9.pdf

[30] Ibarra-Puón, JC, Aguirre-Medina JF, Ley-De Coss A, Cadena-Iñiguez J, Zavala-MataA. Inoculación de Coffea canephora (Pierre) ex Froehner con Rhizophagus intraradices (Schenck et Sm.) Walker et Döbereiner en vivero. Revista Chapingo Serie Horticultura, 2014; 20(2); 201-213. DOI: 10.5154/r.rchsh.2013.09.027

[31] Aguirre-Medina JF, Culebro-Cifuentes F, Cadena-Iñiguez J, Aguirre-Cadena JF. Crecimiento de Tabebuia Donnell-Smithii (Rose) Inoculada con Hongos Micorrízicos y Azospirillum brasilense. Agrociencia. 2014; 48 (3):331-345. http://www.scielo.org.mx/pdf/agro/v48n3/v48n3a8.pdf

[32] Aguirre-Medina JF, Mina-Briones F, Cadena-Iñiguez J, Dardón-Zunun JD, Hernández-Sedas DA. Crecimiento de Cedrela odorata L. biofertilizada con Rhizophagus intraradices y Azospirillum brasilense en vivero. Revista Chapingo Serie Ciencias Forestales y del Ambiente. 2014; 20(3): 177-186. DOI: 10.5154/r.rchscfa.2014.01.001

[33] Garza-Hernández JM, Marroquín-Agreda FJ, Lerma-Molina JN, Ley de-Coss A, Toledo-Toledo E, Martínez-Solís M, Villalobos-Villalobos V, Aguirre-Medina JF. Biofertilizante micorrízico y fertilizante mineral en el crecimiento de Elaeis guineensis Jacq en vivero. AGROproductividad. 2016; 9 (2): 26-32. http://www.revistaagroproductividad.org/index.php/agroproductividad/article/view/717/586

[34] Kvet J, Ondok JP, Necas J, Jarvis PG. 1971. Methods of growth analysis. In: Plant photosynthetic production. Manual of Methods. Sestak Z, Catsky J, Jarvis PG. editors. The Hague Netherlands. p. 343-384.

[35] Kohashi-Shibata J. Fisiología. In: Engleman EM, Editor. Contribuciones al conocimiento del fríjol Phaseolus en México: Chapingo, México Colegio de Postgraduados; 1979. p. 39-58.

[36] Colozzi Filho A, Cardoso Elke. Detecção de fungos micorrízicos arbusculares em raízes de cafeeiro e de crotolária cultivada na entrelinha. Pesquisa Agropecuária Brasileira. 2000; 35(10): 2033-2042. https://DO1.org/10.1590/S0100-204X2000001000015

[37] Hijri B, Sykorova Z, Oehl F, Ineichen K, Mader P, Wiemkw A, Redecker D. Communities of arbuscular mycorrhizal fungi in arable soils are not necessarily low in diversity. Molecular Ecology 2006; 15: 2277-2289. DOI: 10.1111/j.1365-294X.2006.02921.x

[38] Dandan Z, Zhiwei Z. Biodiversity of arbuscular mycorrhizal fungi in the hot-dry Valley of the Jinsha River, Southwest China. Applied Soil Ecology. 2007; 37: 118-128. https://doi.org/10.1016/j.apsoil.2007.06.003

[39] Douds DD, and P Millner. Biodiversity of arbuscular mycorrhizal fungi in agroecosystems. Agric. Ecosystems Environ. 1999; 74: 77-93. https://doi.org/10.1016/B978-0-444-50019-9.50008-X

[40] Hart MM, Reader RJ. Taxonomic basis for variation in the colonization strategy of arbuscular mycorrhizal fungi. New Phytologist. 2002; 153: 335-344 https://nph.
Influence of Endomycorrhizal Fungi on the Growth of Tropical Plant Species
DOI: http://dx.doi.org/10.5772/intechopen.93993

[41] Munkvold LR, Kjoller M, Vestberg S, Rosendahl S, Jakobsen. Hight functional diversity within species of arbuscular mycorrhizal fungi. New Phytol. 2004; 164: 357-364. https://doi.org/10.1111/j.1469-8137.2004.01169.x

[42] Sylvia D, Fuhrmann J, Hartel P, Zuberer D. Principles and applications of soil microbiology. New Jersey USA: Ed. Prentice Hall Inc; 1999. 550 p.

[43] Zhu Y, Smith AF, Smith SE. Phosphorus efficiencies and responses of barley (Hordeum vulgare L.) to arbuscular mycorrhizal fungi grown in highly calcareous soil. Mycorrhiza. 2003; 13: 93-100. doi.org/10.1007/s00572-002-0205-6

[44] Rippstein G, Amezquita E, Escobar E, Grollier C. Condiciones naturales de la sabana. In: Rippstein G, Escobar G, Mota F, editors. Agroecología y Biodiversidad de las sabanas en los llanos orientales de Colombia. Cali Colombia: International Center for Tropical Agriculture. 2001. p. 1-21. https://cgspace.cgiar.org/bitstream/handle/10568/55160/agroecologia_y_biodiversidad.pdf?sequence=1&isAllowed=y

[45] Blanco F, Salas E. Micorrizas en la agricultura: contexto mundial e investigación realizada en Costa Rica. Agronomía Costarricense. 1997; 21(1): 55-67. Consultado el 15 de Agosto 2020 http://listas.exa.unne.edu.ar/biologia/fisiologia.vegetal/Micorrizas%20y%20nutricion%20mineral.pdf

[46] Miyasaka S, Habte M. Miyasaka SC, Habte M, Friday JB, Johnson EV. Manual on Arbuscular Mycorrhizal Fungus Production and Inoculation Techniques. College of Tropical Agriculture and Human Resources SCM-5. 2003; p.1-4. https://scholarspace.manoa.hawaii.edu/bitstream/10125/12454/SCM-5.pdf

[47] Gerdemann JW. Vesicular-Arbuscular mycorrhiza and Plant growth. Annual Review of Phytopathology, 1968; 6(1): 397-418. DOI: 10.1146/annurev.py.06.090168.002145

[48] Dodd J. 1999. Micorrizas. Recent advances in understanding the role of arbuscular mycorrhizas in plant production. In: Siqueira JO et al. editors. Interrelação fertilidade, biologia do solo e nutrição de plantas: Lavras Sbs/Ufla; 1999. p. 687-703.

[49] Molina M, MacHe L, Medina M. Importancia del manejo de hongos micorrizógenos en el establecimiento de árboles en sistemas silvopastoriles. Revista colombiana de ciencias pecuarias, 2005; 18(2): 162-175. https://www.researchgate.net/publication/262670903_Importance_of_mycorrhizae_

[50] Bowen GD, and AD Rovira. The Rhizosphere and its management to improve plant growth. Advances in agronomy. 1999; 66: 1-102. https://DOI.org/10.1016/S0065-2113(08)60425-3

[51] Mendoza López A. La biofertilización del cacao Theobroma cacao L. en etapa de vivero con Azospirillum brasilense Tarrand, Krieg et Dobereiner y Glomus intraradices Schenk70 et Smith. [Tesis]. Facultad de Ciencias Agrícolas Huehuetan Chiapas, México: Universidad Autónoma de Chiapas. 2003.

[52] Aguirre-Medina, J. F., Kohashi-Shibata, J., Trejo-López, C., Acosta Gallegos, J. A., & Cadena-Iñiguez J. (2005). Inoculación de Phaseolus vulgaris L. con tres microorganismos y su efecto en tolerancia a sequía. Agricultura Técnica en México, 31, 125-137. Retrieved from https://biblat.unam.mx/es/revista/agricultura-tecnica-en-mexico/9

[53] Bonfante-Fassolo P, and Perotto S. Plants and endomycorrhizal fungi.
The cellular and molecular basis of their interaction. In: Verma DP, Editor. Molecular signals in plant-microbe communications. Boca Raton, Fla, CRC press; 1992. p. 445-470.

[54] Mina Briones FO. Crecimiento de Cedrela odorata L. con diferentes microorganismos inoculados a la semilla en vivero. [Tesis]. Facultad de Ciencias Agrícolas, Huehuetán, Chiapas. México: Universidad Autónoma de Chiapas. 2013.

[55] Chulan HA, Martin K. The vesicular-arbuscular (VA) mycorrhiza and its effects on growth of vegetatively propagated Theobroma cacao L. Plant Soil. 1992; 144: 227-233. https://doi.org/10.1007/BF00012879

[56] Milthorpe FL, Moorby J. Introducción a la fisiología de los cultivos. Argentina: Ed. Hemisferio Sur; 1982. 259 p.

[57] Koucheki HK, Read DS. Vesicular-arbuscular mycorrhiza in natural vegetation systems. II. The relationship between infection and growth in Festuca ovina L. The New Phytologist. 1976; 77 (3): 655-666. https://doi.org/10.1111/j.1469-8137.1976.tb04658.x

[58] Allen MF, Moore TS Jr, Christensen M. Phytohormone change in Bouteloua gracilis infected by vesicular-arbuscular mycorrhizal. II. Altered levels of gibberellin-like substances and abscisic acid in the host plant. Canadian Journal of Botany. 1982; 60 (4): 468-471, https://DOI.org/10.1139/b82-063

[59] Sprent JI, de Faria SM. Mechanisms of infection of plants by nitrogen fixing organisms. Plant Soil. 1998; 110: 157-165. https://doi.org/10.1007/BF02226795

[60] Carling DE, Brown MF, Brown RA. Colonization rates and growth responses to soybean plants infected by vesicular-arbuscular fungi. Canadian Journal of Botany. 1979; 57(17): 1769-1772, https://DOI.org/10.1139/b79-218

[61] Bethlenfalvay GS. Mycorrhizae in the agricultural plant-soil system. Symbiosis, 1992; 14: 413-425. https://dalspace.library.dal.ca/bitstream/handle/10222/77317/VOLUME%2014-NUMBERS%201,2-3-1993-PAGE%20413.pdf?sequence=1

[62] Gyaneshwar P, Naresh Kumar, Parekh G, Lj, Poole P. Role of soil microorganisms in improving P nutrition of plants. Plant and Soil, 2002; 245: 83-93. https://doi. org/10.1023/A:1020663916259

[63] Smith S, Anderson I, Smith F. Mycorrhizal associations and phosphorus acquisition: from cells to ecosystems. Annual Plants Review. 2015; 48: 409-440. https://doi.org/10.1002/9781118958841.ch14

[64] Aguirre-Medina JF, Kohashi-Shibata J. Dinámica de la colonización micorrízica y su efecto sobre los componentes del rendimiento y el contenido de fósforo en frijol común. Agricultura Técnica en México. 2002; 28 (1): 23-33. https://biblat.unam.mx/es/revista/agricultura-tecnica-en-mexico/13

[65] Mosse B. Advances in the study of VA mycorrhiza. Ann. Rev. Phytopath. 1973; 11: 171-196. https://doi.org/10.1146/annurev.py.11.090173.001131

[66] Siqueira JO, Colozzi–Filho A, Saggion OJ, Guimaraes TG, Oliveira E. Crescimento de mudas e producao do cafeeiro sob influencia de fungos micorrizicos e superfosfato. Revista Brasileira Ciencia Solo. 1993; 17(1): 53-60. file:///C:/Users/JF%20Aguirre/Downloads/SiqueiraetalcrescimentodemudasRBCSv17n11993.pdf
Influence of Endomycorrhizal Fungi on the Growth of Tropical Plant Species
DOI: http://dx.doi.org/10.5772/intechopen.93993

[67] Azcón-G. de Aguilar C, Barea JM. Micorrizas. Investigación y Ciencia. 1980; 47: p. 8-16. https://www.investigacionyciencia.es/revistas/investigacion-y-ciencia/chaquete-90

[68] Rhodes LH, Gerdemann JW. Translocation of calcium and phosphate by external hifae of vesicular-arbuscular mycorrhiza. Soil Sci. 1978; 126 (2): 125-126. https://journals.lww.com/soilsci/Abstract/1978/08000/TRANSLOCATION_OF_CALCIUM_AND_PHOSPHATE_BYEXTERNAL.9.aspx

[69] Aguirre-Medina JF. Biofertilizantes microbianos: Experiencias agronómicas del programa nacional del INIFAP en México. Rosario Izapa, Chiapas México. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias 2006. 201 p. Retrieved from http://biblioteca.inifap.gob.mx:8080/jspui/handle/123456789/3633

[70] Aguirre-Medina JF, Aguirre-Cadena JF, Cadena-Iniguez J, Avendaño-Arrazate CH. Biofertilización en plantas de la selva húmeda tropical. México: Colegio de Postgrados. 2012. 99 p.

[71] Cuenca G, Cáceres A, Oirdobro G, Hasmy Z, Urdaneta C. Las micorrizas arbusculares como alternativa para una agricultura sustentable en áreas tropicales. Interciencia 2007; 32(1): 23-29. http://www.interciencia.org/v32_01/23.pdf