A Review on: The Effect of Agro Forestry Trees on Minimizing Infestation of Striga hermonthica Through the Enhancement of Arbuscular mycorrhiza *(*AM) with Sorghum in the Northern Part of Ethiopia

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Abstract
Sorghum is one of the major food grain crops in Ethiopia, especially in the northern part of the country. The production and productivity of sorghum is affected by the root hemi parasite *Striga hermonthica* (Del.) Benth. (Orobanchaceae). In Ethiopia it is limited integrated control measure have been carried out to combat *Striga.* Reasons for the limited success in *Striga* control include prolific seed production, monocropping, close coupling of its life cycle to that of its host, and the fact that effective control methods are not within the reach of farmers practicing subsistence agriculture (Oswald A.2005). Sustainable management systems targeting Striga management on cereals in general or sorghum in particular might benefit from managing this symbiotic interaction. Agro forestry trees have the capacity to enhance AM and symbiotic relationship between sorghum can blocks for Striga *hermonthica* so as not to get any communication with its host.
Keywords: AM symbiotic, Striga hermonthica

1. Introduction

Agrofoerstry is a land use system and practice in which forest trees, livestock, and arable land are integrated on the same unit of land and managed to give yield on a sustainable basis either simultaneously or sequentially. The integration can be linear, mixed, or even in blocks in an arrangement based on specific objectives and appropriate technology required for a particular place. Several traditional systems exist in Ethiopia, and there are new technologies started by several institutions at a national level across different land use systems. (Jiru.1990.) Growing *Faidherbia albida* as a permanent tree crop, on farmlands with cereals, vegetables and coffee underneath or in between, is an indigenous agro forestry system in the highlands of Eastern Ethiopia. The results of an investigation in to the effects of the presence of *F. albida* on farmlands on the yield of maize *(Zea mays L.)* and sorghum *(Sorghum bicolor L.Moench)* statistically significant increase in crops yields by 56% on average was found for the crops under the tree canopies compared to those away from the trees. In Ethiopia acute household energy and feed demands have caused severe environmental and socio-economic threats. Multipurpose tree species have considerable role in addressing such multifaceted demands in the mixed crop-livestock production systems. Studies on AM fungi symbiosis, particularly the diversity and occurrence of the indigenous communities in agroforestry systems, may form the initial basis for utilization. Agroforestry trees may differ in their effects on fungal species diversity and occurrence (Mnyazi, 2004). Incorporation of leaf biomass from agroforestry trees into the system may provide favorable conditions and support a highly diversity of AM fungi and also investigated the vertical distribution of AM fungal spores under agroforestry. AM fungal spores were found in the deep soil layers of agroforestry systems than in monocultural coffee plantation soils. In agricultural field of standing farm trees, spore abundance found to be higher under the tree canopy than in monoculture crops. Pande and Tarafdar, (2003) reported spore densities of field standing neem (*Azadirachta indica* L.) trees in agroforestry systems in different agricultural zones of Rajasthan, Similarly, Zebene and Hultén, (2002) also reported, higher number of spores under the canopy of *Cordia africana* and *Millettia ferruginea* grown in sorghum fields. In general agroforestry trees plays a land mark role in creating a medium for AM. Symbiosis relationship between AM and Sorghum which is created as a result of Agro forestry tree is very common, and AM has an effect on germination, attachment and subsequent growth and development of Striga hermonthica. Reviewing the indirect effect of agro forestry tree on Striga (the effect of AM on growth and development Striga hermonthica) is the main aim of this paper.

2. Agro forestry trees, sorghum and Fungi associations
2.1 AM and plant association

Mycorrhiza is a mutualistic symbiosis between plant and fungus localized in a root or (root-like structure) in which energy moves primarily from plant to fungus and inorganic resources move from fungus to plant (Allen, 1991). Mycorrhizal associations vary widely in form and function. In the tropics, the two most common associations are the arbuscular endomycorrhizas (AM) formed by Zygomycete fungi, and the ectomycorrhizas (ECM) formed by Basidiomycetes, Ascomycetes, and a few Zygomycetes (Dell, 2002). Ectomycorrhizae (EM) forms a thick sheath of fungal hyphae around the plant roots, making an obvious change in the morphology of

the root (Wiedenhoeft and Hopkins, 2006). The diagnostic feature is the presence of hyphae between root cortical cells producing a netlike structure called the Hartig net (Haselwandter and Bowen, 1996), and many ectomycorrhizae also have a sheath, or mantle, of fungal tissue that may completely cover the absorbing root (usually the fine feeder roots). This mantle can vary widely in thickness, color, and texture depending on the particular plant-fungus combination and the mantle increases the surface area of absorbing roots and often affects fine-root morphology, resulting in root bifurcation and clustering, contiguous with the mantle are hyphal strands that extend into the soil. Normally the fungus does not penetrate the endodermis or the stele. Under EM association lack root hairs and the outer cortical cells are radially elongated, suggesting a hormone interaction (Haselwandter and Bowen, 1996). The association of EM is mainly with trees not with agricultural crops. It is more important in multipurpose woodlots and taungya agroforestry practice. Arbuscular mycorrhizas (AM) fungi or glomeromycotan mycorrhiza, are the most widely spread and common root-fungus associations (Brundrett, 2004). They are by far the most common mycorrhiza type, infecting the great majority (about 80%) of higher plants (Smith and Read, 1997). AM fungi occur ubiquitously due to its great potential of ecological adaptation (Kleikamp, 2002). Morphologically, these fungi have a network of hyphae that grow within the roots of plants and extend out into the soil. Unlike the ectomycorrhizal fungi, AM fungi actually penetrate the walls of root cells and form intracellular structures. AM fungi develop a highly branched arbuscule, acacia canopy shaped within root cortical cells, and the fungus initially grows between cortical cells, but soon penetrates the host cell wall and grows within the cell. Vesicles are like small bags or sacs sequestered within or between plant cells and are implicated in energy storage and possibly as propagules for the fungus, whereas arbuscules are small tree-like collections of branched hyphae that occur within the plant cells (Wiedenhoeft and Hopkins, 2006). The original taxonomy of the AM fungi was based on the morphology of the large soil-borne spores which were found near colonized plant host's roots (Simon *et al.,* 1993). A number of studies have shown that agriculture reduces the diversity of the AM fungi community (Daniell *et al.,* 2001; Oehl *et al.,* 2003). This has been attributed to physical disturbance from tilling (Kabir *et al.,* 1997) the effects of supplemental fertilizers (Linderman and Davis, 2004) and the use of fungicides and soil fumigants (Menge, 1982), all of which reduce the abundance and or diversity of AM fungi. Generally low input and low till agricultural systems have a higher abundance and diversity of AM fungi than their traditional counterparts (Douds and Millner, 1999; Galvez *et al.,* 2001). Similarly, returning crop residues to soil might stimulate an increased spore population, and application of farmyard manure increases densities of AM fungal spores, although it depends on soil types. Organically farmed system had a similar AM fungal diversity to nearby native grassland (Oehl *et al.,* 2003). It has also been shown that the presence of agricultural weeds can increase the abundance of beneficial AM fungi in the fields (Vatovec *et al.,* 2005). High spore and AM populations found during the dry season, under low input agriculture, low tillage agricultural systems and plant phenology (Guadarrama, 1999; Douds and Millner 1999). In the natural forests, high abundance and diversity of AM fungi found, where there was no disturbance on the vegetation cover. Tropical rain forests display high species diversity and complex community structure, and they are a major distribution area for AMF in the world (Zhao *et al.,* 2001) and in the dry soil in Afromontane moist forest ecosystem of 14 coffee shade tree species.

2.2 AM Root Colonization

AM fungi exist in the soil as spore or as vegetative propagules in root fragments. Species of AM fungi have been reported to lack host specificity as a consequence of this a given fungal propagules obtained from an annual plant can also readily establish on a perennial plants. Similarly a given plant root system can be infected by different group of AM fungal species. Resting spore of the fungus, germinating or extra radical hyphae in the soil or hyphae associated with root fragments are infective propagules where the fungal development can start (Brundrett *et al*., 1996). Usually association starts when the soil hyphae contact a root of potential host. Penetration takes place between the epidermal cell and often forms an appressorium (Brundrett *et al*., 1996). The successful establishment of mycorrhiza on host root depends on the interaction between the symbiont and environmental factors such as soil moisture, pH and soil fertility. Manipulation of agricultural systems to favor AM fungi colonization must occur only if there is clear evidence that AM fungi make a positive contribution to yield or are vital for maintenance of ecosystem health and sustainability (Ryan *et al*., 2002). Mycorrhizal dependency of a given plant can be altered by many variables such as soil type, soil phosphorus content, mycorrhizal species etc. (Menge *et al.,* 1987). As soil conditions profoundly affect root growth and sometimes root hair production in the same species, it is highly likely that the extent of the mycorrhizal response will differ from soil to soil independent of soil phosphate status (Haselwandter and Bowen, 1996). It is widely accepted that plants with highly branched root system (Gramineae) are less mycotrophic (less dependent on the fungi for normal growth) than those with coarser roots (e.g. cassava, onion) (Dodd, 2000). Root branching determines plant dependence on the symbiosis. Over 10% of plants (including complete plant families e.g. Chenopodiaciae and Brassicaceae) are non-mycorrhizal and these plants compensate by developing extensively branching root system architectures (Dodd, 2000). They include many of the crops used in Europe today e.g. oil

seed rape (canola). Root characteristics have been little studied with species used in agro forestry but many tree species do have low rooting intensities and poorly developed root hairs and respond well to mycorrhizal infection over a wide range of soil phosphate (Haselwandter and Bowen, 1996). Jasper *et al.* (1989a) observed relatively coarse rooting systems and few root hairs in *Acacia concurrens* and *A. saligna*, attributing their large mycorrhizal responses to this. The extent of mycorrhiza infection in root systems is also known to be influenced by environmental conditions; the most important being the age of the plants, the level of phosphate (P) in the soil relative to the requirements of the plant and the capacity of the population of mycorrhiza propagules in the soil to form mycorrhiza, light, temperature and others (Smith and Read, 1997; Smith, 2003; Azcón and Ocampo, 1981). Nevertheless, mycorrhizal infection can also be related with plant factors such as nutrient content in the root exudates; this parameter seems to be regulated by P concentration in the root (Azcón and Ocampo, 1981). Zebene and Hultén, (2002) reported, different levels of root colonization in the roots of *Cordia africana* and *Millettia ferruginea* grown in enset, coffee-enset and maize fields. Agriculturally adapted AM fungi have been shown to be slower to infect, faster to sporulate and to produces fewer arbuscles (Johnson, 1993;). Tillage disturbs the hyphal network, which delays the AM fungi infectivity rate on plant roots in the coming season (Friberg, 2001). The use of native mycorrhizal as a potential source of AM inoculum was considered a preferential strategy for ensuring the successful re-establishment of native shrub species in semi-arid degraded soil (Caravaca *et al.*, 2003b). Bell *et al.* (2003) found that the susceptibility of Acacia seedlings to colonization by AM fungi appeared to be seasonal. Seasonal patterns in the formation of mycorrhiza have also been said to vary considerably from year to year (Allen *et al.*, 1981). Colonization increased with increasing daytime temperatures and day length. There is generally a good correlation between the levels of infection of the root and the mycorrhizal response. This can be affected by several factors such as, differences in plant susceptibility to infection, differences in inoculum potential, the type of inoculum can affect the speed of infection and therefore the response (Haselwandter and Bowen, 1996) and AM fungi differ markedly in their response to high soil phosphate and to such factors as soil pH (Abbott and Robson, 1985).

2.3. Association of AMF and Roles on crop growth

There is a growing body of evidence that AM can increase plant growth, especially in infertile soils, and that such growth-increases are the result of an enhanced ability of infected roots to absorb nutrients (Gerdemann, 1968). In so doing the hyphae of AM fungi have the potential to greatly increase the absorbing surface area beyond the root into the surrounding soil to improve the uptake of poorly mobile ions such as P, Zn and Cu where by their uptake depends on the root density per volume of soil. Investigators have developed improved inoculation techniques and their results tend to fit a consistent pattern. Using nonsterile soil as an inoculum, (Asai, 1943), demonstrated that mycorrhizal plants grew faster than non-mycorrhizal plants. (Peuss, 1958), using infected roots as inoculum, obtained increases growth of mycorrhizal tobacco grown in a fallow soil and in a subsoil., and Meloh (1961, 1963) showed that the growth of maize and oats could be improved by AM fungi. Gerdemann (1964) also demonstrated improved growth in maize. (Habte and Fox 1989) found a range of responses of *L. leucocephala* to inoculation from a 1.5 times to 7 times increase in shoot growth due to inoculation at 48 days, depending on the soil used. Similarly, (Purcino *et al.* 1986) obtained a doubling of growth with this species from inoculation with three AM fungi, and Cornet and Diem (1982) recorded a 1.6 fold increase with *A. raddiana* and a 6.6 times increase with *A. holosericea*. There are notable cases of growth depression apparently caused by AM fungi in "non-host" species or in host's species when phosphate availability is high (Mosse 1973; Peng et al. 1993).

2.4. AM and Soil fertility

Three main components are involved in AM association: 1) the soil, 2) the fungus and 3) the plant. The fungal component involves the fungal structure within the cell of the root and the extraradical mycelium in the soil. The extraradical mycelium in the soil may be quite extensive under some conditions, but does not form any vegetative structures (Smith and Read, 1997). Its primary function is the absorption of resources from the soil. The increased efficiency of mycorrhizal roots versus non-mycorrhizal roots is caused by the active uptake and transport of nutrients by mycorrhiza. AM have been shown to improve productivity in soils of low fertility (Jeffries, 2002) and are particularly important for increasing the uptake of slowly diffusing ions such as PO_4^{3-} (Jacobsen *et al.*, 1992) immobile nutrients such as P, Zn and Cu (Lambert *et al.*, 1979; George *et al.*, 1994; George *et al.*, 1996; Ortas *et al.*, 1996; Liu *et al.*, 2002) and other nutrients such as Cadmium (Guo *et al.*, 1996). Under drought conditions the uptake of highly mobile nutrients such as NO_3^- can also be enhanced by mycorrhizal associations (Ázcón *et al.*, 1996; Subramanian and Charest, 1999). In legume plants the importance of AM symbiosis has been attributed to high P requirements on the nodulation and N_2 fixation process, which requires enhanced P uptake (Barea and Ázcón Aguilar, 1983). Improved P nutrition has been shown to increase in infertile and P fixing soils of the tropics (Dodd, 2000). Mycorrhizal fungi can also improve absorption of N

from NH_4^+ -N mineral fertilizers, transporting it to the host plant (Ames *et al.,* 1983; Johansen *et al.,* 1993). Its transport and absorption can also increase biomass production in soils with low potassium, Calcium and Magnesium (Liu *et al.,* 2002). Mycorrhizal fungi can potentially influence soil aggregation at different levels, namely plant communities, plant roots (individual host), and effects mediated by the fungal mycelium itself (Rillig *et al.,* 2006). Interest in AM fungi has tended to focus on their role in directly influencing the growth of the host plant. However, they also have a direct effect on soil structure, which is especially important in an agricultural context, where cultivations, trafficking and low levels of soil organic matter all tend to result in damaged soil structure (Gosling *et al.,* 2006). AM fungi increase soil aggregation by means of the physical action of the hyphae and the production of polysaccharides by the fungus or associated microfiora (Tisdall and Oades, 1979). Thus they add to soil stability (Tisdall, 1994) and improve the soil structure (Forster, 1990). The extra-radical mycelium (ERM) provides a physical structure which can entangle soil particles and lead to micro- then macro-aggregate production. The recent finding that a glycoprotein called *'Glomalin'* is produced by AM fungi soil-based mycelium and is a major binding agent in soils adds further weight to the importance of AM fungi in stabilizing soils and hence ecosystems (Dodd, 2000). Whether glomalin is important or not, general hyphal exudation and rapid hyphal turnover provide C to other soil microorganisms indirectly promoting aggregate stability (Dodd, 2000). The overall effect of hyphal enmeshment and C inputs can be a significant increase in soil structural stability, though the range of results, from positive, to neutral and negative suggests dependency on the host/fungal combination (Gosling *et al.,* 2006). The toxicity of metals depends on the concentrations in which they are present in the soil (Smith and Read, 1997). These metals can arise from a variety of sources in the form of acid rain, dust containing these metals, wash waters from polluted soils or from atmospheric factors produced as a result of mining, smelting, burning of fossil fuels, industrial or agricultural activities and incineration of municipal waste (Gaur and Adholeya, 2004). AM fungi alleviate plant stunting caused by toxic metals by binding to these metals in the root zone with the aid of the extra-radical mycelium and altering the plant cells ability to capture the metals (Smith and Read, 1997). The polyphosphates produced by AM fungi are proposed to be the reason behind this sequestration (Khan ,2005).

2.5. Relationship between Striga *hermonthica,* AM and sorghum

In the absence of AM fungal inoculation, there is higher numbers of S. hermonthica shoots emergence. Mycorrhizal sorghum plants also influences attachment and emergence of *Striga*. These results are consistent with (Lendzemo *etal*; 2005). Field inoculation with arbuscular mycorrhizal fungi reduces *Striga hermonthica* performance on cereal crops and has the potential to contribute to integrated *Striga* management. AM fungal inoculation reduced the number and biomass of Striga (figure 1) (Lendzemo, 2004). However, the lower in numbers of Striga and biomass due to AM fungal inoculation did not show in a significant increase in grain yield of the cereals. A further confounding factor could be that not all AM fungal species are equally effective in decreasing Striga performance. The multi-functionality of AM symbiosis is enhancing the performance of the plants through other mechanisms than increased nutrient uptake (Newsham et al., 1995b).
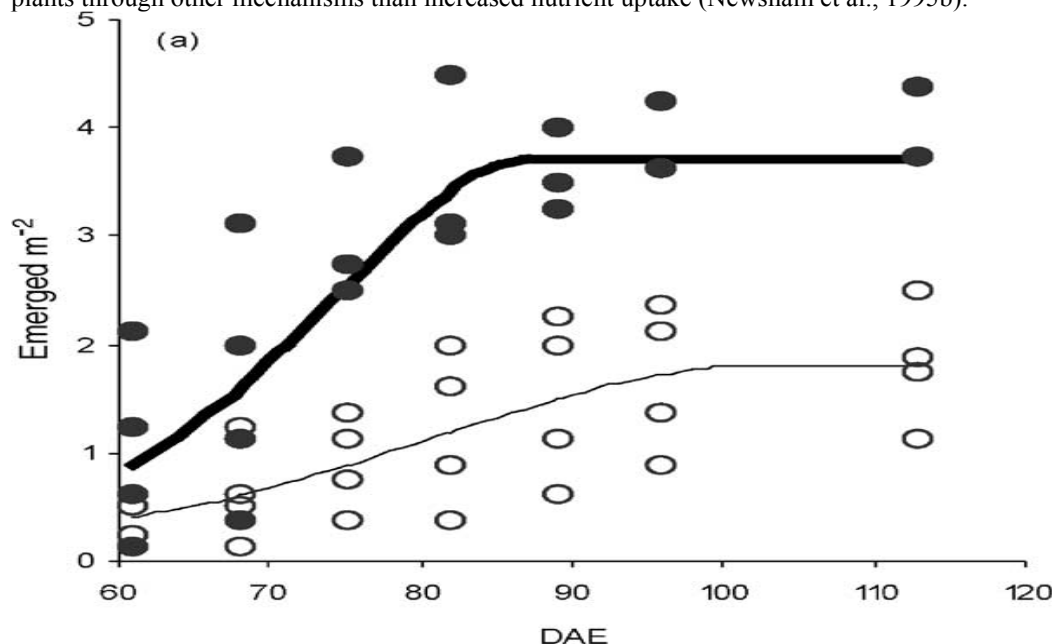
Source (Lendzemo Etal, 2004): Figure 5emergence Pattern Of S. hermonthica Over Time Without AM Addition (Closed Circles) And With AM Addition (Open Circles). Observed (Points) And Those Described By

The Beta Growth Function (Curve).

Root colonization by arbuscular mycorrhizal (AM) fungi reduces stimulation of seed germination of the plant parasite Striga hermonthica. AM fungi have found to be a significant influence on Striga performance with reduced and/or delayed germination (Lendzemo, 2004), attachment (Lendzemo, 2004), and emergence (Lendzemo and Kuyper, 2001; Gworgwor and Weber, 2003). On the other hand, AM fungi had a direct positive effect on the yield of the sorghum and compensated for the damage afflicted by Striga (Lendzemo and Kuyper, 2001; Gworgwor and Weber, 2003). Symbiotic relationship between sorghum and AM fungi is very common (DeMars and boerner, 1995). When sorghum roots colonized by arbuscular mycorrhizal (AM) fungi the growth and development of *S. hermonthica is influenced.* Sorghum Colonization by AM fungi reduced attachment and emergence of *S. hermonthica* on sorghum (Lendzemo *etal*, 2005). The mechanisms for the lower performance of *Striga* on cereal crops upon AM fungal colonization are unknown. If the roots of cereal crops are colonized by AM fungi it reduces seed germination of S. *hermonthica* because so as to germinate *Striga* seeds in the soil require signal molecules that are exuded by the roots of their hosts, called germination stimulants. These signal molecules belong to the class of the strigolactones **(**Bouwmeester *etal*, 2003). This molecule has been identified as signal molecules in the interaction between plant roots and AM fungi. The double role of strigolactones (it induces for both AM and Striga *hermonthica*) suggests the earliest interaction between sorghum roots and AM fungi blocks in order not to get communication between Striga and sorghum consequently without getting signal it would have not been development of haustoria formation and not any attachment for growth and development with host (Besserer *etal*,2006).

Conclusion

Agroforestr*y* can be considered as one the best option to improve soil fertility, increase sorghum productivity and control striga through the enhancement of AM and AM have mechanism to control Striga hermonthica.

References

Abbot, L.K., and Robson, A.D. 1991. Factors influencing the occurrence of vesicular Arbuscular mycorrhizas. Agriculture, Ecosystems and Environment 35: 121-150.

Abbott, L.K., and Robson, A.D. 1982. The Role of Vesicular Arbuscular Mycorrhizal Fungi in Agriculture and the Selection of Fungi for Inoculation. Aust. J. Agric. Res., 33: 389-408.

Allen, M.F., Smith, W.K., Moorejr, T.S., and Christensen, M. 1991. Comparative water relations and photosynthesis of mycorrhizal Bouteloua gracilis H.B.K. lag ex Steud. New Phytologist 88: 683-693.

Asai, T. 1943. Uber die Mykorrhizenbildung der leguminosenPflanzen. Jpn J Bot 13:463.

Azcón, R., and Ocampo, J.A. 1981. Factors affecting the vesicular-arbuscular infection and mycorrhizal dependency of thirteen wheat cultivars. New Phytol. **87**: 677–685.

Azcón, R., Gomes, M. and Tobart, R. 1996. Physiological and nutritional responses by Lactuca sativa L. to nitrogen sources and mycorrhizal fungi under drought stress conditions. Biol. Fert. Soils 22:156-161.

Barea, J.M., and Azcon-Aguilar, C. 1983. Mycorrhizas and their significance in nodulating nitrogen fixing plants. Adv. Agron. 36:1-54.

Bell, J., Wells, S., Jasper, D.A., Abbott, L.K. 2003. Field inoculation with arbuscular mycorrhizal fungi in rehabilitation of mine sites with native vegetation, including Acacia sp. Aus. System. Bot. 16(1): 131-138.

Besserer A, Puech-Pagès V, Kiefer P, Gomez-Roldan V, Jauneau A, Roy S, Portais JC, Roux C, Bécard G, Séjalon-Delmas N. 2006. Strigolactones stimulate arbuscular mycorrhizal fungi by activating mitochondria. PloS Biol.;4:1239–1247.

Bouwmeester HJ, Matusova R, Zhongkui Sun, Beale MH.2003. Secondary metabolite signaling in host-parasitic plant interactions. Curr Opin Plant Biol.;6:358–364.

Brundrett, M., Bougher, N., Dell, B., Giove, T., Malajczuk, N. 1996. Working with mycorrhiza in forestry and agriculture. ACIAR Monograph 32. 374pp

Brundrett M. 2004. Diversity and classification of mycorrhizal associations. Biol.Rev. 79:473-495.

Caravaca, F., Figueroa, D., Azcon-Aguilar, C., Barea, J.M., Roldan, A. 2003b. Medium-term effects of mycorrhizal inoculation and composed municipal waste addition on the establishment of two Mediterranean shrub species under semi-arid field conditions. Agric. Ecosys. Environ. 97(1-3):95-105.

Cornet, F., and Diem, H.G. 1982. Etude comparative de I'efficacit6 des souches de Rhizobium d" Acacia isole~s de sols du Stn~gal et effect de la double symbiose Rhizobium-Glomus mosseae sur la croissance de Acacia holosericea et A. raddiana. Revue Bois et For~ts des Tropiques, 198: 3-15.

Daniell, T.J., Husband, R., Fitter, A.H., and Young, J.P.W. 2001. Molecular diversity of arbuscular mycorrhizal fungi colonizing arable crops. Fems microbiology ecology 36(2-3): 203-209.

Dell, B. 2002. Role of Mycorrhizal Fungi in Ecosystems. CMU. Journal Vol. 1(1) 47.

Dodd, J.C. 2000. The role of arbuscular mycorrhizal fungi in agro-and natural ecosystems. Outlook on

Agriculture 29 (1): 55-62.

Douds, D.D., and Millner, P.D. 1999. Biodiversity of arbuscular mycorrhizal fungi in agroecosystems.Agriculture,Ecosystems and Environment. 74: 77–93.

Forster, SM., 1990. The role of microorganisms in aggregate formation and soil stabilization: Types of aggregation, Arid Soil Res. Rehab., 4: 85-98.

Friberg, S. 2001. Distribution and diversity of arbuscular mycorrhizal fungi in traditional agriculture on the Niger inland delta, Mali, West Africa. CBM: Skriftserie 3:53-80.

Galvez, L., Jr. Douds, D.D., Drinkwater, L.E., Wagoner, P. 2001. Effect of tillage and farming system upon VAM fungus populations and mycorrhizas and nutrient uptake of maize. Plant Soil 228:299-308.

Gaur, A., and A. Adholeya. 2004. Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. Curr. Sci. 86:528-534.

George, E., Gorgus, E., Schmeisser, A., and Marschner, H. 1996. A method to measure nutrient uptake from soil by mycorrhizal hyphae. In Mycorrhizas in Integrated System from Genes to plant Development (eds) Azcon-Aguilar and JM Barea). Luxembourg. European Community.

George, E., Romheld, V., and Marschner, H. 1994. Contribution of mycorrhizal fungi to micronutrient uptake by plants. In Biochemistry of Metal Micronutrients in the Rhizosphere (eds) J.A. Monthey, D.E Crowley and D.G.Luster pp93-109. Bocaraton FL CRC Press.

Gosling, P., Hodge, A., Goodlass, G., and Bending, G.D. 2006. Arbuscular mycorrhizal fungi and organic farming. Agriculture, Ecosystems and Environment 113: 17–35.

Guadarrama, P., and Alvarez-Sanchez, F.J. 1999. Abundance of Arbuscular mycorrhizal fungi spores in different environments in a tropical rain forest, Veracruz, Mexico. Mycorrhiza 8:267-270.

Guo, Y., George, E., and Marschner, H. 1996. Contribution of an arbuscular mycorrhizal fungus to uptake of Cadmnium and Nickel in bean by maize plants. Plant Soil 184:195-205.

Gworgwor,N.A. and weber ,H.C.2003. Arbuscular mycorrhizal fungi-parasite host interaction for control of striga hermonthica in sorghum (sorghum bicolor). Mycorrhiza 13:277-281.

Haselwandter, K., and Bowen, G.D. 1996. Mycorrhizal relations in trees for agroforestry and land rehabilitation. Forest Ecology and Management 81: 1-17.

Jacobsen, I., Abbott, L.K., and Robson, A. 1992. External hyphae of Vesicular Arbuscular Mycorrhizal fungi associated with Trofoluim subterraneum L. I. Spread of hyphae and phosphorus inflow into roots. New Phytol. 120:371-380.

Jasper, D.A., Abbott, L.K., and Ronson, A.D. 1989a. acacias respond to addition of phosphorus and to inoculation with VA mycorrhizal fungi in soils stockpiled during mineral sand mining. Plant Soil, 115: 99-108.

Jeffries, P. 2002. Use of mycorrhiza in agriculture. Crit. Rev. Biotechnol. 5:319- 357

Johnson, N.C. 1993. Can fertilization of soil select less mutualistic mycorrhiza? Ecological applications 3(4): 749-757.

Kabir, Z., Ohalloran, I.P., Fyles, J.W., and Hamel, C. 1997. Seasonal changes of arbuscular mycorrhizal fungi as affected by tillage practices and fertilization.

Khan, A.G., 2005, Role of soil microbes in the rhizospheres of plants growing on trace metal

contaminated soils in phytoremediation. J. Trace Elem. Med. Biol. 18: 355–364

Kleikamp, B. 2002. Studies on arbuscular mycorrhiza (AM) in the Alentejo (Portugal) using pea mutants resistant to AM fungi as a control tool for field conditions. Ph.D. thesis. Witzenhausen.

Lambert, D.H., Baker, D.E., and Cole, H Jr. 1979. The role of mycorrhizae in the interactions of phosphorus with zinc, copper and other elements. Soil Sci. Soc. Am. J. 43:976-980.

Lendzemo VW, Kuyper TW.2001. Effects of arbuscular mycorrhizal fungi on damage by Striga hermonthica on two contrasting cultivars of sorghum, Sorghum bicolor. Agric Ecosyst Environ.;87:29–35.

Lendzemo VW. The tripartite interaction between sorghum, Striga hermonthica, and arbuscular mycorrhizal fungi. Wageningen University; 2004. p. 112. Ph.D. Thesis.

Lendzemo VW, Kuyper TW, Kropff MJ, Van Ast A. 2005.Field inoculation with arbuscular mycorrhizal fungi reduces Striga hermonthica performance on cereal crops and has the potential to contribute to integrated Striga management. Field Crops Res.91:51–61.

Linderman, R.G., and Davis, E.A. 2004. Evaluation of commercial inorganic and organic fertilizer effect son arbuscular mycorrhiza formed by glomus intraradics. Horttechnology 14(2): 196-202.

Liu, A., Hamel, C., Elmi, A., Costa, C., and Smith, D.L. 2002. Concentrations of K, Ca and Mg in maize colonised by arbuscular mycorrhizal fungi under field conditions. Can. J. Soil Sci. 82(3): 271- 278.

Menge, J.A., Johnson, E.L.V., and Pi.att, R.G. 1987. Mycorrhizal dependency of several citrus cultivars under three nutrient regimes. New Phytologist, 81, 533-559.

Menge, J.A. 1982. Effect of soils fumigants and fungicides on vascular-arbuscular fungi. Phytopathology 72(8): 1125-1132.

Mosse, B. 1973. Plant growth responses to vesicular-arbuscular mycorrhiza. IV. In soil given additional phosphate. New Phytol 72:127–136.

Mnyazijewfi, J. 2004. The taxonomy and ecology of arbuscular mycorrhizal fungi (AMF) in Agroforestry systems I Malawi. Doctoral thesis.

Newsham, K.K., Fitter, A.H., Watkinson, A.R., 1995b. Multi- functionality and biodiversity in arbuscular mycorrhizas. Trends Ecol. E 10, 407–411.

Oehl, F., Sieverding, E., Ineichen, K., Mader, P., Boller, T., and Wiemken, A. 2003. Impact of landuse intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of central Europe. Applied and Environmental Microbiology 69(5): 2816-2824.

Ortas, I., Harries, P.J., and Rowell, D.I. 1996. Enhanced uptake of phosphorus by mycorrhizal sorghum plants as influenced by form of nitrogen. Plant Soil 184:255-264.

Oswald A. 2005.Striga control—Technologies and their dissemination. Crop Prot.24:333–342.

Peng, S., Eissenstat, D.M., Graham, J.H., Williams, K., Hodge, N.C. 1993. Growth depression in mycorrhizal Citrus at high-phosphorus supply. Plant Physiol 101:1063–1071.

Rillig, M.C., and Mummey D.L. 2006. Mycorrhizas and soil structure. New Phytologist171: 41–53.

Ryan, M.H., Norton, R.M., Kirkegaard, J.A., McCormick, K.M., Knights, S.E., Angus, J.F. 2002. Increasing mycorrhizal colonisation does not improve growth and nutrition of wheat on vertsols in south-eastern Australia. J. Agric. Res. 53(10):1173-1181.

Simon, L., Bousquet, J., Levesque, C., and Lalonde, M. 1993. "Origin and diversification of endomycorrhizal fungi and coincidence with vascular land plants". Nature 363: 67-69.

Smith, S., Smith, A., and Jakobsen, I. 2003. "Mycorrhizal fungi can dominate phosphorus supply to plant irrespective of growth response". Plant Physiology 133: 16-20.

Smith. S.E., and Read, D.J. 1997. Mycorrhizal symbiosis (second edition). Academic Press, London, UK.

Subramanian, K.S., and Charest, C. 1999. Acquisition of N by external hyphae of an arbuscular mycorrhizal fungus and its impact on physiological responses in maize under drought-stressed and well watered conditions. Mycorrhiza 9:69-75.

Tisdall, J.M. and Oades, J.M., 1979. Stabilization of soil aggregates by the root system of ryegrass. Aust. J. Soil Res., 57: 429-441.

Tisdall, J.M., 1994. Possible role of soil microorganisms in aggregation in soils. In: A.D. Robson, L.K. Abbott and N. Malajczuk (Editors), Management of Mycorrhizas in Agriculture, Horticulture and Forestry. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp. 115-121.

Vatovec, C., Jordan, N., Herd, S. 2005. Responsiveness of certain agronomic weed species to arbuscular mycorrhizal fungi. Renewable agriculture and foor systems 20(3): 181-189.

Wiedenhoeft, A.C., and Hopkins. W.G. 2006. Plant nutrition. Pp 88-99.

Zebene, A., and Hultén, H. 2002. Arbuscular mycorrhizal colonisation of Cordia africana and Millettia ferruginea trees in the traditional agroforestry land use systems of Sidama, southern Ethiopia. Acta Universitatis Agriculturae Sueciae. SILVESTRIA 263, Appendix IV, (submitted to Plant and Soil) pp. 20.

Zhao, W.Z., Xia, Y.M., Qin, X.Z., Li, X.W., Cheng, L.Z., Sha, T., Wang, G.H. 2001. Arbuscular mycorrhizal status of plants and the spore density of Arbuscular mycorrhiza fungi in the tropical rain forest of Xishungbanna, southwest China. Mycorrhiza 11: 159-162.