PAPER • **OPEN ACCESS**

Forest conversion into cacao agroforestry and cacao plantation change the diversity of arbuscular mycorrhizal fungi

To cite this article: N Edy *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **270** 012015

View the article online for updates and enhancements.



IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 111.198.233.31 on 21/09/2019 at 02:52

IOP Conf. Series: Earth and Environmental Science **270** (2019) 012015 doi:10.1088/1755-1315/270/1/012015

Forest conversion into cacao agroforestry and cacao plantation change the diversity of arbuscular mycorrhizal fungi

N Edy[1], E K Zakaria[2], I Lakani[1], Hasriyanti[1]

[1] Department of Agrotechnology, Faculty of Agriculture, Tadulako University
Jl. Soekarno-Hatta Km 9, Palu Central Sulawesi, Indonesia 94118
[2]Student at the Department of Agrotechnology, Faculty of Agriculture, Tadulako University. Jl. Soekarno-Hatta Km 9, Palu Central Sulawesi, Indonesia 94118

E-mail: nuredy01@gmail.com

Abstract. Arbuscular mycorrhizal fungi (AMF), a plant root-fungus association, has been studied widely across different ecosystems. However, little information provided in tropical land use systems. Here, we studied the diversity of AMF in the forest, cacao agroforestry, and cacao plantation. A preliminary survey was done to estimate the AMF richness and diversity. This study reveals an interesting fundamental finding where AMF richness and diversity were significantly higher in the plantation compared to the natural ecosystem. AMF communities were significantly affected mixed vegetation in the forest and became a generalist in an agroecosystem of the cocoa plantation. Presented results indicate that AMF diversity and community structure are influenced by vegetation and ecological conditions.

1. Introduction

There Since arbuscular mycorrhizal fungi beneficially contribute as an ecosystem services provider [1] to the growth of many perennial crops [2] and sustainability in agroecology as well as natural ecosystems [3], it is interesting to cover the diversity of AMF along a tropical land-use gradient.

In a mutualistic symbiosis of plant root-AMF [4,2], the plant receives phosphorous (P), nitrogen (N) and carbon (C) from soil by the fungus, while the plant translocate carbon to the fungus [5–7]. The unique fungal extraradical mycelia of AMF can build a network on plant roots to available nutrients that not possible reached by normal roots [8–11]. AMF-plant symbiosis involved the difficult essential nutrient acquisition, for example, P [12], which is one of the difficult nutrients to uptake by roots without associated with AMF. Some studies also reported the role of AMF in plant-pathogen protection in the rhizosphere [13–15].

Plant-AMF association can be found in varying natural [3,16–18] and managed[19–22] ecosystems. However, little information covers tropical regions.

The diversity of mycorrhiza affected by field conditions. It is because each type of plant can give a different response to different mycorrhiza [23,24]. Moreover, AMF species is also related to soil properties [25,26], farming management [27–30] and environmental factors [31].

The land conversion has been reported to decrease soil ability to support plant growth. For example, damage the soil structure which begins with a decrease in soil aggregate stability [32,33], decreased soil

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

organic matter and plant root activity [34–36] and influence on soil microorganisms [35], and decline the plant root vitality in supporting ecosystem functionality [37].

Forest conversion into managed plantations and agroforestry cacao in Central Sulawesi established in the last four decades [38,39]. The increasing world demands on cocoa and its derivate products have become a driver for the forest conversion into cacao plantations and agroforestry cacao. In this study, we addressed the hypothesis that forest conversion into the managed plantation of cacao and agroforestry cacao reduce AMF richness and diversity.

2. Material and Method

2.1. Study Site and Sampling

The study was located in three different land uses forest, agroforestry cacao, and cacao plantation in Palolo regency, Central Sulawesi, Indonesia. In each land use, five plots were installed (40 × 40 m). A preliminary study was conducted to find the maximum number of tree fine roots in different land uses. Soil cores were collected in four distances from the tree (0.5, 1, 1.5, and 2 m) and replicated 5 times. Here we found that 1 m distance from the tree was the highest number of fine roots. Therefore, all soil core then collected as suggested by the preliminary study. In each plot, 5 soil cores were collected from random 5 trees. Thus we had 375 samples (3 different land uses x 5 plots x 5 trees x 5 soil cores). The soil core dimension was 0.05 m diameter and 0.20 m depth. The soil cores were stored at 4°C before used.

2.2. Isolation and Identification of Mycorrhiza

Soil cores collected, then separated from their roots. AMF identification was based on spore following by wet pour-filter continued by centrifugation [40]. A total of 10 grams soil diluted in 100 ml water and stirred, then sieved with 200, 125, 63, and 20 µm sieving respectively. Each sieved material centrifuged (3,500 rpm) then re-sieved using filter paper to isolate the spore. Spore characteristics identified and counted with a microscope. Taxonomical AMF was done in a gnus level followed by methodology introduced by Schüßle *et al*, and Redecker *et al.* [41,42].

2.3. Data Analysis

Colour The number of spores was counted based on the genus. In order to calculate our sampling effort, the rarefaction curve was developed [43]. Species richness of AMF was measured per land use systems, continued by Shannon, Simpson, Dominance indices [44] as equations:

- Shannon index (*H'*) (equation 1)

$$H' = -\sum p_i \ln p_i$$

- Simpson index (D) (equation 2)

$$D = \sum \frac{n_i(n_i - 1)}{N(N - 1)}$$

- Dominance index (equation 3)

$$C = \sum Pi^2 = \sum (ni/N)^2$$

Where n_i is the number of individuals of taxon *i,* p_i is the proportion of the *i*-th species, *N* is the total number of species, *H*' is Shannon's. Simpson and Dominance indices range from 0 (all taxa are equally present) to 1 (one taxon completely dominates the community). In the Shannon index, *H'* varies from 0

for communities with a single taxon to high values for communities with many taxa. The diversity indices were calculated using PAST statistics version 2.17 [45]. To compare the difference of diversity among the land uses, one way ANOVA was calculated by R statistics version R 3.4.3 (R core team, 2014) continued by Tukey's honestly significant difference test.

AMF community was estimated by non-metric multi-dimensional scaling (NMDS). The NMDS plot was created using PAST 2.17c [45]. One way multivariate analysis of variance PERMANOVA, Anderson et al. [45] was used to distinguish the AMF community related to the land use systems. Bray-Curtis similarity index was used to measure the distance.

3. Results and discussion

3.1. AMF spore abundance in different land use systems

A total of 9,209 AMF spores were collected. Rarefaction curve (Figure 1) showed the number of samples analyzed was sufficient to estimate the AMF spore diversity in each land use. Rarefaction curves that show an increase indicate most of the species still have to be found. In this study, the curve shows a line, implies that sampling is more likely to produce only a few additional species [47]. The most abundant AMF was founded in cacao plantation, followed by cacao agroforestry, and forest respectively (Figure 2).

Since intensive farming practices decline the AMF abundance and effectiveness [48–50], we expected that frequent fertilizer and fungicide applications would decrease the species richness and abundance of AMF. It is, however, interesting to find that the species richness of AMF higher in managed plantation compared to forest ecosystems. According to González-Cortés et al (2012), the number of vegetation in old plantation might be the reason for the AMF host. Trees also had higher preferences for AMF host compared uncanopied plants [51,52]. In Central Sulawesi, cacao plantations are mostly owning by local farmers. Traditional farming systems are common where we can find other lower plants in the plantations. Having a higher abundance of AMF in cacao plantations might be supported by those mixed vegetations and host preferences of AMF.

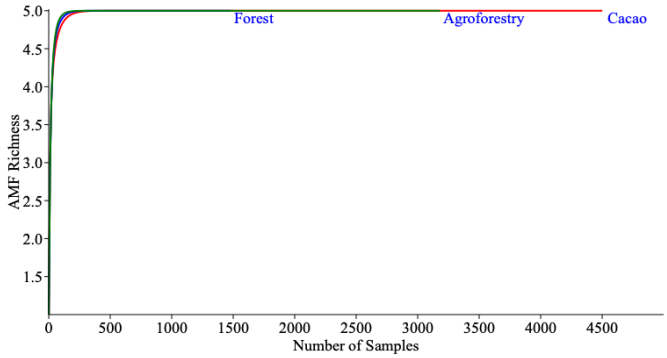

Figure 1. AMF richness accumulation in forest (n=125), agroforestry (n=125), and cacao plantation (n=125).

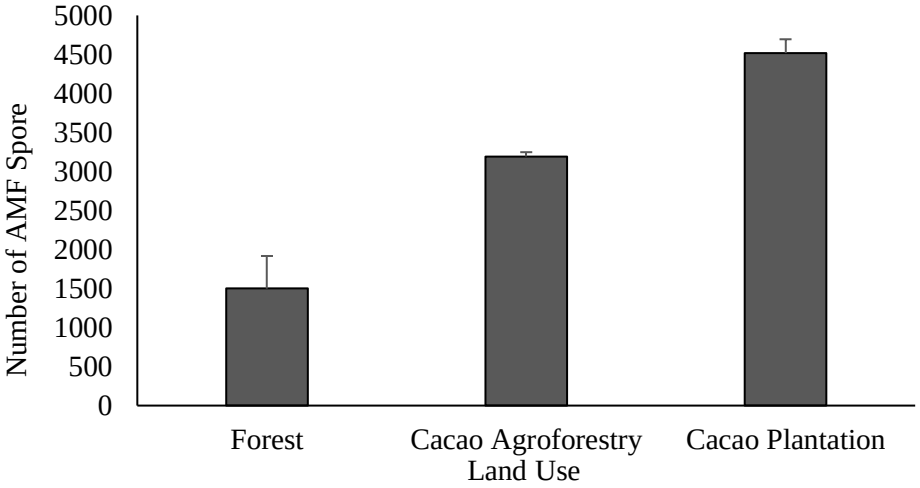

Figure 2. The number of AMF spores in different land uses.

3.2. AMF diversity

The AMF richness was higher in the managed plantation of cacao and cacao agroforestry compared to forest system (Table 1). We detected Glomus, Gigaspora, Scutellospora, Acaulospora, and number of unidentified AMF. Glomus was the most abundant genera of AMF detected among land uses. The diversity indices of land uses were compared. Shannon, Dominance and Simpson diversity indices showed that forest site had slightly lower diversity than cacao plantation and cacao agroforestry (Tabel 2).

Table 1. The AMF richness in different land use systems

Genera	Land uses		
	Forest	Cacao Agroforestry	Cacao Plantation
Glomus	1128	2385	3180
Gigaspora	97	180	219
Scutellospora	30	82	72
Acaulospora	108	194	573
Undetermined	136	352	473

Table 2. The diversity of AMF along different land use systems. Data shows means (n= 125 ± SD). Different letters in the same column indicate significant differences between land use systems with P< 0.05.

Land Use	Shannon		Dominance		Simpson	
Forest	3.02	(0.29)^{a}	0.06	(0.02) ^{a}	0.94	(0.02) ^{a}
Agroforestry cacao	3.22	(0.22)^{b}	0.05	(0.02) ^{ab}	0.95	(0.02) ^{ab}
Cacao plantation	3.35	(0.29)^{b}	0.05	(0.01) ^{b}	0.95	(0.01) ^{b}

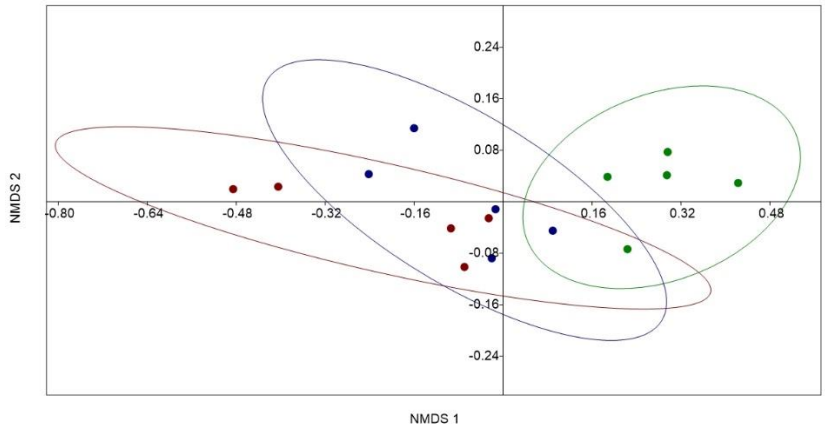

Figure 3. The NMDS plot of AMF diversity in different land uses (forest in green, cacao agroforestry in blue, and cacao plantation in brown; n=5).

AMF fungal communities were significantly different only in the forest (P = 0.01) and cacao agroforestry (P = 0.008) after PERMANOVA and NMDS ordination (Figure 3). Cacao plantation did not show a significant effect on AMF communities. AMF communities in the forest mostly separated from cacao plantations and cacao agroforestry communities. The distribution of AMF indicates that mixed trees in forest and agroforestry were greater than the plantation. Among all AMF we found, Glomus was the most distributed in all land uses. It is not surprising since many reports dedicate Glomus as generalist AMF [53–55].

We noted that AMF richness and diversity were lower in natural ecosystems compared to cacao plantation and cacao agroforestry. Similar finding with the previous studies see, for example, [56,57] Possible mechanisms imply this finding that different soil chemical properties lead the diversity of AMF in different ecosystems [58,59]. The rhizosphere environmental conditions, driven by abiotic and biotic variables are possible to be the reason for AMF community distribution [60–62]. Moreover, several environmental factors affect AMF communities along a tropical land-use gradient. Soil moisture, temperature, rainfall, and plant communities are factors affected the AMF dispersal [63–65].

As a fundamental survey, this study has pronounced the diversity of AMF in different land use systems are influenced by various conditions. Thus, another study has to be developed to investigate environmental factors related to the network distribution of AMF communities in different tropical land uses. Sharping the identity of AMF is another case to be answered. Since we found numbers of undetermined AMF, it is interesting to find more deeply the novel specificity of AMF in tropical regions.

4. Conclusion

This study highlights the AMF diversity affected by land use system associated with plant diversity and environmental factors. Higher species richness and diversity of AMF spore in monospecific plantation suggest increasing of functional diversity of AMF induce by agricultural input in farming systems.

References

[1] Gianinazzi S, Gollotte A, Binet M-N, van Tuinen D, Redecker D and Wipf D 2010 Agroecology: the key role of arbuscular mycorrhizas in ecosystem services *Mycorrhiza* **20** 519–30
[2] Smith S E and Read D J 2008 *Mycorrhizal symbiosis* (Amsterdam; Boston Academic Press)
[3] Dodd J C 2000 The Role of Arbuscular Mycorrhizal Fungi in Agro- and Natural Ecosystems *Outlook Agric.* **29** 55–62

[4] Peterson R L and Massicotte H B Mycorrhizas : Anatomy and Cell Biology
[5] Bonfante P and Genre A 2010 interactions in mycorrhizal symbiosis *Nat. Commun.* **1** 1–11
[6] Smith S E and Smith F A 2012 Fresh perspectives on the roles of arbuscular mycorrhizal fungi in plant nutrition and growth *Mycologia* **104** 1–13
[7] Veresoglou S D, Chen B and Rillig M C 2012 Arbuscular mycorrhiza and soil nitrogen cycling *Soil Biol. Biochem.* **46** 53–62
[8] Neumann E and George E 2010 Nutrient Uptake: The Arbuscular Mycorrhiza Fungal Symbiosis as a Plant Nutrient Acquisition Strategy *Arbuscular Mycorrhizas: Physiology and Function* (Dordrecht: Springer Netherlands) pp 137–67
[9] Feddermann N, Finlay R, Boller T and Elfstrand M 2010 Functional diversity in arbuscular mycorrhiza – the role of gene expression, phosphorous nutrition and symbiotic efficiency *Fungal Ecol.* **3** 1–8
[10] Fellbaum C R, Gachomo E W, Beesetty Y, Choudhari S, Strahan G D, Pfeffer P E, Kiers E T and Bücking H 2012 Carbon availability triggers fungal nitrogen uptake and transport in arbuscular mycorrhizal symbiosis. *Proc. Natl. Acad. Sci. U. S. A.* **109** 2666–71
[11] Hodge A, Helgason T and Fitter A H 2010 Nutritional ecology of arbuscular mycorrhizal fungi *Fungal Ecol.* **3** 267–73
[12] Smith S E, Jakobsen I, Grønlund M and Smith F A 2011 Roles of arbuscular mycorrhizas in plant phosphorus nutrition: interactions between pathways of phosphorus uptake in arbuscular mycorrhizal roots have important implications for understanding and manipulating plant phosphorus acquisition. *Plant Physiol.* **156** 1050–7
[13] Wehner J, Antunes P M, Powell J R, Mazukatow J and Rillig M C 2010 Plant pathogen protection by arbuscular mycorrhizas: A role for fungal diversity? *Pedobiologia (Jena).* **53** 197–201
[14] Sikes B A 2010 When do arbuscular mycorrhizal fungi protect plant roots from pathogens? *Plant Signal. Behav.* **5** 763–5
[15] Bothe H, Turnau K and Regvar M 2010 The potential role of arbuscular mycorrhizal fungi in protecting endangered plants and habitats *Mycorrhiza* **20** 445–57
[16] Davison J, Öpik M, Zobel M, Vasar M, Metsis M and Moora M 2012 Communities of Arbuscular Mycorrhizal Fungi Detected in Forest Soil Are Spatially Heterogeneous but Do Not Vary throughout the Growing Season ed J A Gilbert *PLoS One* **7** e41938
[17] Parkash V, Tamuli A K, Saikia A J and Teron R 2015 Ph ton Distribution and diversity of arbuscular mycorrhizal fungi along with soil
[18] González-Cortés J C, Vega-Fraga M, Varela-Fregoso L, Martínez-Trujillo M, Carreón-Abud Y and Gavito M E 2012 Arbuscular mycorrhizal fungal (AMF) communities and land use change: The conversion of temperate forests to avocado plantations and maize fields in central Mexico *Fungal Ecol.* **5** 16–23
[19] Lumini E, Orgiazzi A, Borriello R, Bonfante P and Bianciotto V 2009 Disclosing arbuscular mycorrhizal fungal biodiversity in soil through a land-use gradient using a pyrosequencing approach *Environ. Microbiol.* **12** 2165–79
[20] Martinez T N and Johnson N C 2010 Agricultural management influences propagule densities and functioning of arbuscular mycorrhizas in low- and high-input agroecosystems in arid environments *Appl. Soil Ecol.* **46** 300–6
[21] Bainard L D, Klironomos J N and Gordon A M 2011 Arbuscular mycorrhizal fungi in tree-based intercropping systems: A review of their abundance and diversity *Pedobiologia (Jena).* **54** 57–61
[22] Bainard L D, Bainard J D, Hamel C and Gan Y 2014 Spatial and temporal structuring of arbuscular mycorrhizal communities is differentially influenced by abiotic factors and host crop in a semi-arid prairie agroecosystem *FEMS Microbiol. Ecol.* **88** 333–44
[23] Bai G, Bao Y, Du G and Qi Y 2013 Arbuscular mycorrhizal fungi associated with vegetation and soil parameters under rest grazing management in a desert steppe ecosystem *Mycorrhiza*

23 289–301
[24] Hausmann N T and Hawkes C V 2010 Order of plant host establishment alters the composition of arbuscular mycorrhizal communities *Ecology* **91** 2333–43
[25] Antoninka A, Reich P B and Johnson N C 2011 Seven years of carbon dioxide enrichment, nitrogen fertilization and plant diversity influence arbuscular mycorrhizal fungi in a grassland ecosystem *New Phytol.* **192** 200–14
[26] Oehl F, Laczko E, Bogenrieder A, Stahr K, Bösch R, van der Heijden M and Sieverding E 2010 Soil type and land use intensity determine the composition of arbuscular mycorrhizal fungal communities *Soil Biol. Biochem.* **42** 724–38
[27] Säle V, Aguilera P, Laczko E, Mäder P, Berner A, Zihlmann U, van der Heijden M G A and Oehl F 2015 Impact of conservation tillage and organic farming on the diversity of arbuscular mycorrhizal fungi *Soil Biol. Biochem.* **84** 38–52
[28] Lin X, Feng Y, Zhang H, Chen R, Wang J, Zhang J and Chu H 2012 Long-Term Balanced Fertilization Decreases Arbuscular Mycorrhizal Fungal Diversity in an Arable Soil in North China Revealed by 454 Pyrosequencing *Environ. Sci. Technol.* **46** 5764–71
[29] van der Gast C J, Gosling P, Tiwari B and Bending G D 2011 Spatial scaling of arbuscular mycorrhizal fungal diversity is affected by farming practice *Environ. Microbiol.* **13** 241–9
[30] Brito I, Goss M J, de Carvalho M, Chatagnier O and van Tuinen D 2012 Impact of tillage system on arbuscular mycorrhiza fungal communities in the soil under Mediterranean conditions *Soil Tillage Res.* **121** 63–7
[31] Hazard C, Gosling P, van der Gast C J, Mitchell D T, Doohan F M and Bending G D 2013 The role of local environment and geographical distance in determining community composition of arbuscular mycorrhizal fungi at the landscape scale *ISME J.* **7** 498–508
[32] Spohn M and Giani L 2011 Impacts of land use change on soil aggregation and aggregate stabilizing compounds as dependent on time *Soil Biol. Biochem.* **43** 1081–8
[33] Fokom R, Adamou S, Teugwa M C, Begoude Boyogueno A D, Nana W L, Ngonkeu M E L, Tchameni N S, Nwaga D, Tsala Ndzomo G and Amvam Zollo P H 2012 Glomalin related soil protein, carbon, nitrogen and soil aggregate stability as affected by land use variation in the humid forest zone of south Cameroon *Soil Tillage Res.* **120** 69–75
[34] Haghighi F, Gorji M and Shorafa M 2010 A study of the effects of land use changes on soil physical properties and organic matter *L. Degrad. Dev.* **21** n/a-n/a
[35] Mao R and Zeng D-H 2010 Changes in Soil Particulate Organic Matter, Microbial Biomass, and Activity Following Afforestation of Marginal Agricultural Lands in a Semi-Arid Area of Northeast China *Environ. Manage.* **46** 110–6
[36] Deng L, Liu G and Shangguan Z 2014 Land-use conversion and changing soil carbon stocks in China's 'Grain-for-Green' Program: a synthesis *Glob. Chang. Biol.* **20** 3544–56
[37] Sahner J, Budi S W, Barus H, Edy N, Meyer M, Corre M D and Polle A 2015 Degradation of root community traits as indicator for transformation of tropical lowland rain forests into oil palm and rubber plantations *PLoS One* **10**
[38] Maertens M, Zeller M and Birner R 2006 Sustainable agricultural intensification in forest frontier areas **34** 197–206
[39] Myers N, Mittermeier R A, Mittermeier C G, Fonseca G A B and Kent J 2000 Biodiversity hotspots for conservation priorities **403** 853–8
[40] Brundrett M, Bougher N, Dell B, Grove T, Malajczuk N, Brundrett M, Bougher N, Dell B, Grove T and Malajczuk N 1996 Working with Mycorrhizas in Forestry and Agriculture
[41] Schüßler A and Walker C 2010 *The Glomeromycota A species list with new families and new genera*
[42] Redecker D, Schüßler A, Stockinger H, Stürmer S L, Morton J B and Walker C 2013 An evidence-based consensus for the classification of arbuscular mycorrhizal fungi (Glomeromycota) *Mycorrhiza* **23** 515–31
[43] Hurlbert S H 1971 The Nonconcept of Species Diversity A Critique and Alternative

Parameters *Ecology* **52** 577–86
[44] Magurran A E 1988 *Ecological Diversity and Its Measurement* (Dordrecht: Springer Netherlands)
[45] Hammer D A T, Ryan P D, Hammer Ø and Harper D A T 2001 *Past: Paleontological Statistics Software Package for Education and Data Analysis* 4 8-18
[46] Anderson M J, Crist T O, Chase J M, Vellend M, Inouye B D, Freestone A L, Sanders N J, Cornell H V., Comita L S, Davies K F, Harrison S P, Kraft N J B, Stegen J C and Swenson N G 2011 Navigating the multiple meanings of β diversity a roadmap for the practicing ecologist *Ecol. Lett.* **14** 19–28
[47] Gotelli N J and Colwell R K *Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness*
[48] Douds D D and Millner P D 1999 Biodiversity of arbuscular mycorrhizal fungi in agroecosystems *Agric. Ecosyst. Environ.* **74** 77–93
[49] Menéndez A, Scervino J and Godeas A 2001 Arbuscular mycorrhizal populations associated with natural and cultivated vegetation on a site of Buenos Aires province, Argentina *Biol. Fertil. Soils* **33** 373–81
[50] Mäder P, Edenhofer S, Boller T, Wiemken A and Niggli U 2000 Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation *Biol. Fertil. Soils* **31** 150–6
[51] Pande M and Tarafdar J . 2004 Arbuscular mycorrhizal fungal diversity in neem-based agroforestry systems in Rajasthan *Appl. Soil Ecol.* **26** 233–41
[52] Prasad R and Mertia R S 2005 Dehydrogenase activity and VAM fungi in tree-rhizosphere of agroforestry systems in Indian arid zone *Agrofor. Syst.* **63** 219–23
[53] Manoharan L, Rosenstock N P, Williams A and Hedlund K 2017 Agricultural management practices influence AMF diversity and community composition with cascading effects on plant productivity *Appl. Soil Ecol.* **115** 53–9
[54] Holste E K, Holl K D, Zahawi R A and Kobe R K 2016 Reduced aboveground tree growth associated with higher arbuscular mycorrhizal fungal diversity in tropical forest restoration *Ecol. Evol.* **6** 7253–62
[55] Chen X W, Wong J T F, Chen Z T, Leung A O W, Ng C W W and Wong M H 2018 Arbuscular mycorrhizal fungal community in the topsoil of a subtropical landfill restored after 18 years *J. Environ. Manage.* **225** 17–24
[56] ÖPIK M, MOORA M, LIIRA J and ZOBEL M 2006 Composition of root-colonizing arbuscular mycorrhizal fungal communities in different ecosystems around the globe *J. Ecol.* **94** 778–90
[57] Moora M, Davison J, Öpik M, Metsis M, Saks Ü, Jairus T, Vasar M and Zobel M 2014 Anthropogenic land use shapes the composition and phylogenetic structure of soil arbuscular mycorrhizal fungal communities *FEMS Microbiol. Ecol.* **90** 609–21
[58] Jansa J, Erb A, Oberholzer H-R, Šmilauer P and Egli S 2014 Soil and geography are more important determinants of indigenous arbuscular mycorrhizal communities than management practices in Swiss agricultural soils *Mol. Ecol.* **23** 2118–35
[59] De Beenhouwer M, Van Geel M, Ceulemans T, Muleta D, Lievens B and Honnay O 2015 Changing soil characteristics alter the arbuscular mycorrhizal fungi communities of Arabica coffee (Coffea arabica) in Ethiopia across a management intensity gradient *Soil Biol. Biochem.* **91** 133–9
[60] Nath M, Bhatt D, Prasad R and Tuteja N 2017 Reactive Oxygen Species (ROS) Metabolism and Signaling in Plant-Mycorrhizal Association Under Biotic and Abiotic Stress Conditions *Mycorrhiza - Eco-Physiology, Secondary Metabolites, Nanomaterials* (Cham: Springer International Publishing) pp 223–32
[61] Lin G, McCormack M L and Guo D 2015 Arbuscular mycorrhizal fungal effects on plant competition and community structure ed R Phillips *J. Ecol.* **103** 1224–32

[62] Kumar M, Prasad R, Kumar V, Tuteja N and Varma A 2017 Mycorrhizal Fungi Under Biotic and Abiotic Stress *Mycorrhiza - Eco-Physiology, Secondary Metabolites, Nanomaterials* (Cham: Springer International Publishing) pp 57–69

[63] Johnson N C, Hoeksema J D, Bever J D, Chaudhary V B, Gehring C, Klironomos J, Koide R, Miller R M, Moore J, Moutoglis P, Schwartz M, Simard S, Swenson W, Umbanhowar J, Wilson G and Zabinski C 2006 From Lilliput to Brobdingnag: Extending Models of Mycorrhizal Function across Scales *Bioscience* **56** 889–900

[64] Kivlin S N, Hawkes C V. and Treseder K K 2011 Global diversity and distribution of arbuscular mycorrhizal fungi *Soil Biol. Biochem.* **43** 2294–303

[65] Davison J, Moora M, Öpik M, Adholeya A, Ainsaar L, Bâ A, Burla S, Diedhiou A G, Hiiesalu I, Jairus T, Johnson N C, Kane A, Koorem K, Kochar M, Ndiaye C, Pärtel M, Reier Ü, Saks Ü, Singh R, Vasar M and Zobel M 2015 FUNGAL SYMBIONTS. Global assessment of arbuscular mycorrhizal fungus diversity reveals very low endemism. *Science* **349** 970–3