

Arbuscular mycorrhizal fungal symbiosis with *Sorbus torminalis* does not vary with soil nutrients and enzyme activities across different sites

Mostafa Moradi⁽¹⁾, Anoshirvan Shirvany⁽¹⁾, Mohammad Matinizadeh⁽²⁾, Vahid Etemad⁽¹⁾, Hamid Reza Naji⁽³⁾, Hazandy Abdul-Hamid⁽³⁾, Samira Sayah⁽¹⁾

Effects of soil chemical properties on arbuscular mycorrhizal fungal (AMF) symbiosis with wild service tree (*Sorbus torminalis* L. Crantz) were examined with the aim of assessing the root colonization rate at three forest sites in northern Iran. Soil characteristics including pH, available phosphorus (P), potassium (K), organic matter, total nitrogen, acid and alkaline phosphatase activities, CaCO₃, spore density (SD) and AMF colonization of soil and root samples were analyzed. The study sites were investigated in spring and autumn to highlight the effects of varying soil chemical properties on AMF colonization. K, pH, root colonization, SD and acid phosphatase activity showed no significant differences among sites and seasons, while total nitrogen, P, organic matter and alkaline phosphatase activities showed significant differences among sites and seasons. AMF colonization rate was more than 51% and 32% of roots in spring and autumn, respectively. No correlation between root colonization and soil chemical parameters in spring and autumn were detected. There was no correlation between percentage of AM root colonization and SD nor other soil parameters in spring and autumn. SD and CaCO₃ were significantly negatively correlated in spring and autumn. Despite differences in soil characteristics, results showed that SD and root colonization were not significantly different among sites. We concluded that wild service trees had strong symbiosis with AMF, while soil properties might not have a significant effect on the symbiosis. Therefore, the use of AMF colonized seedlings can be considered as an appropriate method for reforestation and conservation of this rare tree species.

Keywords: Arbuscular Mycorrhizae, Soil Nutrients, Colonization, Soil Enzyme, *Sorbus torminalis*

Introduction

Arbuscular mycorrhizal fungi (AMF) play a critical role in the early establishment of land plants (Redecker et al. 2000). They can improve the host plants growth (Wu et al. 2011), improve plant nutrient and water uptake, enhance plant tolerance to environmental stresses, including metal tolerance, and are abundant in the plant rhizosphere inter-

face (Smith & Read 2008, Xu et al. 2008, Barea et al. 2011). AMF are important micro-organisms which contribute to plant diversity and ecosystem functions (Van der Heijden et al. 1998). About 80% of higher plants have associations with arbuscular mycorrhizae (Smith & Read 2008). These associations lead to better phosphorous (P) absorption (Rooney et al. 2011) and the fungi

can supply up to 80% of P and 25% of nitrogen (N) to the host plants (Marschner & Dell 1994). In turn, the fungi are highly dependent on their host plants for carbon nutrition (Smith & Read 1997). P is an important element which is actively supplied to host plants by AMF. The amount of P influx into colonized roots can be three to five times higher than non-mycorrhizal roots (Smith et al. 2003).

Some soil characteristics have significant influences on the development of mycorrhizal fungi in roots, such as potassium (K), nitrogen (Treseder 2004), pH (Isobe et al. 2007), and compaction (Waltert et al. 2002), as well as climatic conditions and host plant effects (Kivlin et al. 2011). Increasing soil acidity or alkalinity was also a detrimental factor to AMF sporulation in field soils (Isobe et al. 2007). AMF also affect soil enzymes (Huang et al. 2009, Wu et al. 2011) by increasing activities such as dehydrogenase, phosphatase and urease (Huang et al. 2009).

Wild service tree (*Sorbus torminalis* L. Crantz) is widely distributed across Europe, north-western African forests, and south-western Asia (Nicolescu et al. 2009). It is also a rare, protected tree species found in the northern forests of Iran at elevations between 170 to 2700 m a.s.l., where it can reach up to 34 m in height (Pourmajidian 2000). Different species of the genus *Sorbus* are found in association with both arbuscular mycorrhizal and ecto-mycorrhizal fungi (Raspe et al. 2000).

In this study, we hypothesized that AMF colonization of specific plants can vary significantly between sites with different soil characteristics. A comprehensive study was conducted to determine how AMF colonization of a wild service tree (*Sorbus torminalis*) was influenced by soil nutrients and enzyme activities at three different sites. A better understanding of AMF relationships with the wild service tree and its role in nutrient absorption and soil enzymes will enable better management of the tree stands in terms of nutrient uptake and more vigorous tree growth.

Materials and methods

Study sites and sampling

The study was conducted in a natural mixed forest of northern Iran consisting of *Fagus orientalis* Lipsky, *Carpinus betulus* L., and *Acer cappadoecicum* Gled along with a minor population of *Sorbus torminalis*. According to differences in aspect, slope, elevation, precipitation and some soil edaphic features, three sites were selected for this study: Kheiroud, Lalis, and Takrin (Tab. 1).

Five *S. torminalis* trees were randomly se-

□ (1) Department of Forestry, Faculty of Natural Resources, University of Tehran, Karaj (Iran); (2) Research Institute of Forests and Rangelands, Tehran (Iran); (3) Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia (UPM), Serdang, Selangor (Malaysia)

@ Mostafa Moradi (moradi4@gmail.com)

Received: Jan 06, 2014 - Accepted: May 24, 2014

Citation: Moradi M, Shirvany A, Matinizadeh M, Etemad V, Naji HR, Abdul-Hamid H, Sayah S, 2015. Arbuscular mycorrhizal fungal symbiosis with *Sorbus torminalis* does not vary with soil nutrients and enzyme activities across different sites. iForest 8: 308-313 [online 2014-09-03] URL: <http://www.sisef.it/iforest/contents/?id=ifor1236-008>

Communicated by: Gianfranco Minotta

Tab. 1 - Basic information of the study sites.

Site	Aspect	Elevation (m a.s.l.)	Latitude N	Longitude E	Slope (%)	Rainfall (mm)	Soil Texture	Temperature (°C)		
								Min	Max	Mean
Kheiroud	S	1000	36° 40'	51° 43'	30-70	1457	clay	7	25	16
Lalis	N-NW	1700	36° 32'	51° 23'	0-60	731	clay	-10	29	10
Tarkin	N	1500	36° 28'	51° 51'	30-80	1085	clay-silt	-13	32	10

lected from each of the three sites. Five root and soils samples were collected at the crown projection area at the bottom of each tree in spring and autumn. Fine roots and soil samples were collected to a depth of 15 cm after removal of forest litter and organic horizon. Samples were bulked, air-dried, sieved (< 2 mm), sealed in plastic bags, and stored at 4 °C until further analyses.

Soil chemical parameters

Soil pH was measured in a soil:deionized water suspension of 1:2.5. Due to their alkaline nature, P content in the soil samples was determined using the method developed by Olsen et al. (1954).

Soil K was extracted using the neutral ammonium acetate method (Morwin & Peach 1951) and was quantified using a flame photometer. Soil organic carbon (%) was determined according to the Walkley & Black (1934) method. In addition, soil organic carbon was converted to soil organic matter (OM, %) using a factor of 1.724. Total nitrogen (TN, %) was determined using the conventional standard Kjeldhal procedure (Bremner & Mulvaney 1982).

The method of Ohlinger (1996) was used to measure acid and alkaline phosphatase activities using *p*-nitrophenyl as substrate. Analyses were conducted in duplicate with one non-substrate control. Results were expressed as $\mu\text{g } p\text{-nitrophenol g}^{-1} \text{ h}^{-1}$ at 37 °C.

AMF root colonization and spore density

The five root samples from each site were carefully washed to remove soil and organic particles. Root samples were then cut into

pieces of one cm and preserved in FAA buffer (5 ml formalin: 5 ml acetic acid in 90 ml of 70% alcohol). Roots were stained using 0.05% trypan blue in lactophenol (Phillips & Hayman 1970) and mounted on a petri dish with grid-line intersects. Root length colonization was measured under a dissecting microscope (Olympus CH2) using the method proposed by Giovannetti & Mosse (1980) and intraradical status of hyphae, arbuscules and vesicles was used to determine root length colonization.

AMF spores were extracted by wet sieving (sieves of size 500 and 38 μm), and decanting (Gerdemann & Nicolson 1963), followed by centrifugation in water. For estimation of the AMF spore density (SD) in soil surrounding each host tree, 15 g sub-samples of soils in two replications were analyzed, and all spores were counted. Average of the two sub-samples was taken and expressed as number of AMF spores per gram soil sample (g^{-1}).

Data analysis

Statistical analysis was conducted using the package SPSS® v. 16 for Windows. Data was subjected to one-way analysis of variance followed by Tukey's test ($\alpha = 0.05$) to detect differences in variable means among the three sites. Student *t* test was used to determine acid and alkaline phosphatase activity differences between seasons. The relationship between soil chemical characteristics and AMF colonization were determined by Pearson's correlation coefficients. Magnitude of correlations were interpreted according to Guilford's rule-of-thumb (Guilford 1973) as follows: (i) $r < 0.20$: negligible correlation;

(ii) $0.20 < r < 0.40$: weak correlation; (iii) $0.40 < r < 0.70$: moderate correlation; (iv) $0.70 < r < 0.90$: strong correlation; (v): $r > 0.90$: very strong correlation.

Results

Soil N, P, K, pH and OM

Average values of the soil nutrients at the three sites are presented in Tab. 2. Pearson's correlation coefficients (*r*) for each feature in spring and autumn are presented in Tab. 3 and Tab. 4.

The value of total nitrogen in the soil was significantly higher for Tarkin than for the other areas in both seasons ($p < 0.01$ - Tab. 2). The mean values of total nitrogen as a critical soil component in Kheiroud and Lalis were in the same range with no significant differences between them. The values of total nitrogen between the spring and autumn seasons in all sites were not significantly different.

The P showed no significant differences among Kheiroud and Tarkin during spring and autumn seasons. On the other hand, significant differences among these two sites and Lalis were observed ($p < 0.05$). In general, the highest amount of P was observed in the autumn samples from Lalis.

The mean values of exchangeable K for the sites ranged between 312.23 (Kheiroud) and 566.41 (Lalis) in spring, and between 311.73 (Kheiroud) and 532.05 (Lalis) in autumn. This represents 81.4% and 70.7% differences between minimum and maximum values of K in spring and autumn, respectively. No significant differences were found between K values observed in the Kheiroud and Tarkin sites compared to Lalis. In addition, no significant differences were evident between spring and autumn for all sites.

Soil pH was a significant factor in the three sites during spring and autumn. The lowest pH in this study was 6.15 at Lalis and the highest was 8.75 at Kheiroud.

Concerning OM, Tarkin had the highest values during spring and autumn. There was a significant difference among values for Tarkin and Lalis in the spring. In autumn however, significant differences ($p < 0.05$) were observed among Tarkin and Kheiroud (Tab. 3).

Root length colonization and SD

The average colonization rates for all sites

Tab. 2 - Mean soil parameters in different seasons at the three study sites. (TN): total nitrogen; (P): phosphorous; (K): potassium; (OM): organic matter; (RC): root colonization; (SD): spore density; (A.P): acid phosphatase; (ALP): alkaline phosphatase. (*): $\mu\text{g } p\text{-nitrophenol g}^{-1} \text{ h}^{-1}$. Means within columns (in separate sites) followed by the same letters were not significantly different ($p > 0.05$) after Tukey's test.

Site	Season	TN (%)	P (ppm)	K (ppm)	pH	OM (%)	RC (%)	SD (N/g)	A.P*	ALP*
Kheiroud	Spring	0.25 ^a	7.16 ^a	312.23 ^a	7.99 ^a	8.29 ^{ab}	59.0 ^a	69 ^a	499.51 ^a	627.76 ^{ab}
	Autumn	0.22 ^a	8.64 ^a	311.70 ^a	7.93 ^a	8.13 ^a	38.5 ^a	81 ^a	554.96 ^a	608.24 ^a
Tarkin	Spring	0.44 ^b	10.02 ^{ab}	315.60 ^a	7.69 ^a	12.72 ^a	60.0 ^a	56 ^a	825.06 ^a	837.77 ^b
	Autumn	0.43 ^b	9.46 ^a	342.10 ^a	7.62 ^a	14.15 ^b	42.0 ^a	79 ^a	891.62 ^a	843.00 ^a
Lalis	Spring	0.18 ^a	12.22 ^b	566.40 ^a	7.32 ^a	6.64 ^b	61.0 ^a	50 ^a	597.95 ^a	408.94 ^a
	Autumn	0.28 ^a	14.66 ^b	532.10 ^a	7.05 ^a	9.52 ^{ab}	44.5 ^a	77 ^a	872.85 ^a	563.00 ^a

during the spring and autumn seasons are presented in Tab. 2. Over all the sites, AMF colonization rates in spring and autumn showed an average of about 60 and 41.6%, respectively. Root colonization in spring and autumn ranged between 51.0-68.5% and 32.4-55.3%, respectively. No significant differences among the three sites were detected ($p > 0.05$), but root colonization was significantly different between the two seasons in each site ($p < 0.01$).

Concerning AMF spore numbers, results showed that there was no significant difference in SD among sites during the spring and autumn seasons (Tab. 2).

Soil acid and alkaline phosphatase

As shown in Tab. 2, acid phosphatase activity showed no significant difference among the sites during spring and autumn, but alkaline phosphatase activity showed a significant difference among Lalis and Tarkin in the spring ($p < 0.05$). In autumn, there were no significant differences among the sites (Tab. 2). Moreover, no significant differences were observed between acid and alkaline phosphatase activities in spring and autumn (Tab. 4).

The degree of variation observed indicates that the studied parameters were not equally variable among the sites (Tab. 2).

Correlation of soil chemical properties, SD and root length colonization

The Pearson's correlation coefficients between soil chemical properties, SD and root length colonization are presented in Tab. 5.

There was a significant and positive relationship between K and P in autumn ($r = 0.670$; $p < 0.01$) with moderate magnitude (Tab. 3), while there was no correlation between them in spring ($p > 0.05$ - Tab. 6).

There was a non-significant decrease in pH values from Kheiroud to Lalis (Tab. 2, $p > 0.05$).

A negative correlation with moderate magnitude was observed between pH and soil P in spring ($r = 0.571$, Tab. 1). However, this correlation was not significant in autumn ($p > 0.05$).

There was a significant negative correlation between SD and CaCO_3 in spring and autumn (Tab. 6 and Tab. 3). However, root colonization was not significantly correlated with soil chemical and physiological parameters (Tab. 5).

No significant correlations between SD and other soil parameters between spring and autumn seasons were detected except for CaCO_3 . As shown in Tab. 6 and Tab. 3, there was significant positive correlation between AMF spore density and slope in both spring and autumn seasons. No significant differences were observed between SD and elevation (Tab. 6 and Tab. 3).

The correlation coefficient between soil al-

Tab. 3 - Correlation coefficients between soil parameters in autumn. (TN): total nitrogen; (P): phosphorous; (K): potassium; (OM): organic matter; (SD): spore density; (A.P): acid phosphatase; (Al.P): alkaline phosphatase; (Elev): elevation; (*): $p < 0.05$. (**): $p < 0.01$.

Parameter	P	OM%	pH	TN%	K	CaCO_3	A.P	Al.P	SD	Elev	Slope%
P	1	-	-	-	-	-	-	-	-	-	-
OM%	.161	1	-	-	-	-	-	-	-	-	-
pH	-.080	-.032	1	-	-	-	-	-	-	-	-
TN%	.179	.844**	.090	1	-	-	-	-	-	-	-
K	.670**	.089	-.050	.168	1	-	-	-	-	-	-
CaCO_3	-.362	-.422	.470	-.424	-.367	1	-	-	-	-	-
A.P	.457	.739**	-.514*	.603*	.384	-.553*	1	-	-	-	-
Al.P	.104	.730**	.549*	.741**	-.035	.077	.233	1	-	-	-
SD	-.030	.091	-.434	.030	.048	-.577*	.181	-.368	1	-	-
Elev	.594*	.312	-.416	.280	.487	-.537*	.574*	.055	.420	1	-
Slope%	-.340	.376	-.113	.447	-.249	-.501	.162	.068	.752**	-.018	1

Tab. 4 - Acid and alkaline phosphatase differences between seasons. Values are means \pm SE. Means were not significantly different between spring and autumn ($p > 0.05$) after Student's *t* test.

Season	Acid phosphatase (A.P)	Alkaline phosphatase (Al.P)
Spring	640.83 \pm 56.90	624.82 \pm 61.45
Autumn	773.14 \pm 68.01	671.41 \pm 54.37

Tab. 5 - Correlation coefficients between root colonization and soil parameters in spring and autumn. (TN): total nitrogen; (P): phosphorous; (K): potassium; (OM): organic matter; (SD): spore density; (A.P): acid phosphatase; (Al.P): alkaline phosphatase; (Elev): elevation.

Root colonization	pH	P	OM%	TN%	CaCO_3	K	A.P	Al.P	SD	Elev	Slope%
Spring	-.425	.201	-.114	-.126	-.207	.155	-.025	-.240	-.090	.158	-.015
Autumn	-.146	.216	.091	.025	-.326	-.145	.011	-.006	.043	.402	.090

Tab. 6 - Correlation coefficients between soil parameters in spring. (TN): total nitrogen; (P): phosphorous; (K): potassium; (OM): organic matter; (SD): spore density; (A.P): acid phosphatase; (Al.P): alkaline phosphatase; (Elev): elevation; (*): $p < 0.05$; (**): $p < 0.01$.

Parameter	pH	P	OM%	TN%	K	CaCO_3	A.P	Al.P	SD	Elev	Slope%
pH	1	-	-	-	-	-	-	-	-	-	-
P	-.571*	1	-	-	-	-	-	-	-	-	-
OM%	.320	.008	1	-	-	-	-	-	-	-	-
TN%	.254	-.009	.977**	1	-	-	-	-	-	-	-
K	-.345	.506	.036	-.284	1	-	-	-	-	-	-
CaCO_3	.484	-.462	-.298	-.297	-.352	1	-	-	-	-	-
A.P	-.103	.165	.776**	.747**	.523	-.496	1	-	-	-	-
Al.P	.563*	-.220	.884**	.882**	-.240	.091	.612*	1	-	-	-
SD	-.152	-.060	.210	.235	.130	-.515*	.172	-.040	1	-	-
Elev	-.498	.628*	-.016	-.032	.481	-.511	.314	-.220	.230	1	-
Slope%	-.052	-.113	.450	.560*	-.253	-.513	.291	.272	.814**	-.018	1

kaline phosphatase and pH was positive and significant in the spring with $r = 0.563$ ($p < 0.05$ - Tab. 3). In addition, the soil acid and alkaline phosphatase in relation to OM and TN were significantly correlated ($p < 0.01$). The magnitude of correlations between these factors was very high (Tab. 6 and Tab. 3).

Discussion

The significant effect of AMF on plant growth and leaf mineral concentrations has been previously documented (Motosugi et al. 2002). Our result showed that despite differences in soil properties in the studied sites, no significant differences in SD and root length colonization were observed. In a similar study on *Araucaria angustifolia*, Moreira et al. (2006) showed similar rates of root colonization in spring. A reasonable colonization rate is usually about 40% (Thonar et al. 2011). In the present study, based on observation of vesicle, arbuscule and mycelia in roots, AMF colonization rates were more than 51% and 32% of roots in spring and autumn, respectively. These results confirm a high level of symbiosis between wild service trees and AMF in spring. As mentioned earlier, the highest colonization rate was observed in spring. This response was similar to several earlier reports (Rodríguez-Echeverría et al. 2008, Closa & Goicoechea 2011).

Forest plantation management could greatly benefit from the use of wild service tree with high levels of root colonization by AMF, in particular in arid environments (Liu et al. 2007). Indeed, previous reports have demonstrated the tolerance of wild service tree to arid environmental conditions (Paganová 2008). Additionally, no significant correlations between root colonization and soil chemical parameters in spring and autumn were observed, consistently with several previous findings (Matevz et al. 2013, Gai et al. 2012, Closa & Goicoechea 2011, Rodríguez-Echeverría et al. 2008).

Usually, spore density of AMF can be related to root colonization (Muthukumar et al. 2003), nutrient status (Mendoza et al. 2002), elevation (Gai et al. 2012), pH and soil P (Li et al. 2005, Minggui et al. 2012). However, in the present study no relationship between the percentage of AM colonization and spore density was found, according to previous literature reports (Becerra et al. 2009). Similar results were observed for other soil parameters with negative correlations between spore density and CaCO_3 in spring and autumn. Due to the same root colonization rates in the studied sites, no significant correlation between root colonization and spore density was expected. Trees in Kheiroud were located in areas with high pH and CaCO_3 which negatively influences AMF and spore density. Similar results were reported by Labidi et al. (2011). As stated by Mendoza et al. (2002), the SD level is related to nutrient

status, especially nitrogen content. While a direct correlation between N and SD was not observed in this study, both N and SD were positively correlated with slope across all sites.

According to Yong et al. (2007), we found that root AMF colonization was affected by environmental conditions and host plants. Our results showed that available soil P in spring was significantly different among Lalis and Kheiroud, while in autumn Lalis was significantly different from the other two sites. Since there was no significant difference in root colonization among sites, soil available P differences can be attributed to the soil pH, that was the lowest in both seasons in Lalis compared to Tarkin and Kheiroud. Furthermore, pH had a significant negative correlation with available P. Zhao et al. (2011) stressed that available P increases with decreasing pH. It should be noted that in calcareous soil, P is retained by Ca ions and in acid soils it is retained by Fe and Al ions (Hisinger 2001).

There was a significant difference in total nitrogen among Tarkin and the other two sites for both seasons. In addition, the results indicated that the organic matter, the most important nitrogen source (Gairola et al. 2012), was higher in Tarkin than in the other sites. Moreover, we observed a significant correlation between total nitrogen and the organic matter, according to Gairola et al. (2012).

Factors such as temperature, moisture content (Kirschbaum 1995, Kane et al. 2005), elevation (Dai & Huang 2006), precipitation and geographical aspects (Griffiths et al. 2009) significantly affect soil OM content. For example, it is known that OM soil levels in north-facing slopes (as in Tarkin) are higher as a consequence of its lower decomposition rate (Quideau 2002). Since Kheiroud, Tarkin and Lalis are located in south, north, and northwest slopes, respectively, we hypothesize that the aforementioned differences in total nitrogen between Tarkin and the other two sites may be attributed to the higher amount of organic matter in Tarkin (as a consequence of its aspect) rather than other factors.

Several authors have reported that soil K content is influenced by elevation, total nitrogen, and organic matter (Basumatary & Bordoloi 1992, Gairola et al. 2012). In the present study, no significant differences among sites and no significant correlations between K and soil chemical properties were detected, according to previous findings by Paudel & Sah (2003).

It is reported that AMF colonization could result in higher acid and alkaline phosphatase activities, leading to higher P, N and K content in plant leaves (Amaya-Carpio et al. 2009). However, in the present study we did not found significant differences among sites

in autumn as for such enzyme activities. On the other hand, alkaline phosphatase activity in Lalis was significantly different from that in Tarkin in spring. Such difference could be attributed to the effect of soil pH. Indeed, it has been documented that acid phosphatase activity is higher in acidic soils, while alkaline phosphatase activity was higher in calcareous or neutral soils (Dick & Tabatabai 1984). The importance of soil availability of N, pH, moisture content and total soil carbon in acid and alkaline activities has also been suggested (Dick et al. 2000, Sardans et al. 2008, Hamman et al. 2008, Hryniewicz et al. 2009). In our study, there were significant correlations between the above enzyme activities and OM, TN, pH and CaCO_3 . Highest acid and alkaline phosphatase activity from Tarkin in both seasons was likely due to the higher amount of OM and TN in this site.

Conclusion

Wild service tree is a rare species in the northern forest of Iran. This species is important due to its economic and ecological value. Our results revealed that different soil chemical properties did not have significant effect on root colonization and spore density in the studied sites. Despite the strong differences in site conditions, our results revealed that up to 68% of roots of wild service trees could be colonized by AMF. Since this species is tolerant to direct sunlight and short-time water deficits, the use of wild service trees colonized by AMF could help in afforestation plans, particularly in arid areas.

Acknowledgements

We would like to thank the staff of Iranian forest, range and watershed organization. This study was partly supported by University of Tehran.

References

- Amaya-Carpio L, Davies FTJr, Fox T, He C (2009). Arbuscular mycorrhizal fungi and organic fertilizer influence photosynthesis, root phosphatase activity, nutrition, and growth of *Ipomoea carnea* ssp. *fistulosa*. *Photosynthetica* 47 (1): 1-10. - doi: [10.1007/s11099-009-0003-x](https://doi.org/10.1007/s11099-009-0003-x)
- Barea JM, Palenzuela J, Cornejo P, Sánchez-Castro I, Navarro-Fernández C, López-arcía A, Estrada B, Azcón R, Ferrol N, Azcón-Aguilar C (2011). Ecological and functional roles of mycorrhizas in semi-arid ecosystems of Southeast Spain. *Journal of Arid Environments* 75 (12): 1292-1301. - doi: [10.1016/j.jaridenv.2011.06.01](https://doi.org/10.1016/j.jaridenv.2011.06.01)
- Basumatary A, Bordoloi PK (1992). Forms of potassium in some soils of Assam in relation to soil properties. *Journal of the Indian Society of Soil Science* 40 (3): 443-446.
- Becerra GA, Cabello M, Zak RM, Bartoloni N (2009). Arbuscular mycorrhizae of dominant plant species in Yungas forests, Argentina. *My-*

- ecologia 101 (5): 612-621. - doi: [10.3852/08-176](https://doi.org/10.3852/08-176)
- Bremner JM, Mulvaney CS (1982). Nitrogen total. In: "Method of soil analysis - part 2: chemical and microbiological methods (2nd edn)" (Miller RH, Keeney DR eds). Agronomy series no. 9, American Society for Agronomy and Soil Sciences, Madison, WI, USA, pp. 595-624.
- Closa I, Goicoechea N (2011). Infectivity of arbuscular mycorrhizal fungi in naturally regenerating, unmanaged and clear-cut beech forests. *Pedosphere* 21 (1): 65-74. - doi: [10.1016/S1002-0160\(10\)60080-X](https://doi.org/10.1016/S1002-0160(10)60080-X)
- Dai W, Huang Y (2006). Relation of soil organic matter concentration to climate and altitude in zonal soils of China. *Catena* 65: 87-94. - doi: [10.1016/j.catena.2005.10.006](https://doi.org/10.1016/j.catena.2005.10.006)
- Dick WA, Cheng L, Wang P (2000). Soil acid and alkaline phosphatase activity as pH adjustment indicators. *Soil Biology and Biochemistry* 32 (13): 1915-1919. - doi: [10.1016/S0038-0717\(00\)00166-8](https://doi.org/10.1016/S0038-0717(00)00166-8)
- Dick WA, Tabatabai MA (1984). Kinetic parameters of phosphatases in soils and organic waste materials. *Soil Science* 137 (1): 7-15. - doi: [10.1097/00010694-198401000-00002](https://doi.org/10.1097/00010694-198401000-00002)
- Gai JP, Tian H, Yang FY, Christie P, Li XL, Klironomos JN (2012). Arbuscular mycorrhizal fungal diversity along a Tibetan elevation gradient. *Pedobiologia* 55: 145-151.
- Gairola S, Sharma CM, Ghildiyal SK, Suyal S (2012). Chemical properties of soils in relation to forest composition in moist temperate valley slopes of Garhwal Himalaya, India. *The Environmentalist* 32 (4): 512-523. - doi: [10.1007/s10669-012-9420-7](https://doi.org/10.1007/s10669-012-9420-7)
- Gerdemann J, Nicolson T (1963). Spores of mycorrhizal Endogone species extracted from soil by wet sieving and decanting. *Transactions of the British Mycological Society* 46 (2): 235-244. - doi: [10.1016/S0007-1536\(63\)80079-0](https://doi.org/10.1016/S0007-1536(63)80079-0)
- Giovannetti M, Mosse B (1980). An evaluation of techniques for measuring vesicular-arbuscular mycorrhizal infection in roots. *New Phytologist* 84 (3): 489-500. - doi: [10.1111/j.1469-8137.1980.tb04556.x](https://doi.org/10.1111/j.1469-8137.1980.tb04556.x)
- Griffiths RP, Madritch MD, Swanson AK (2009). The effects of topography on forest soil characteristics in the Oregon Cascade Mountains (USA): implications for the effects of climate change on soil properties. *Forest Ecology and Management* 257 (1): 1-7. - doi: [10.1016/j.for eco.2008.08.010](https://doi.org/10.1016/j.for eco.2008.08.010)
- Guilford JP (1973). *Fundamental statistics in psychology and education*. McGraw-Hill, New York, USA, pp. 546.
- Hamman ST, Burke IC, Knapp EE (2008). Soil nutrients and microbial activity after early and late season prescribed burns in a Sierra Nevada mixed conifer forest. *Forest Ecology and Management* 256 (3): 367-374. - doi: [10.1016/j.for eco.2008.04.030](https://doi.org/10.1016/j.for eco.2008.04.030)
- Hisinger P (2001). Bioavailability of soil inorganic P in the rhizosphere as affected by root-induced chemical changes: a review. *Plant and Soil* 237 (2): 173-195. - doi: [10.1023/A:1013351617532](https://doi.org/10.1023/A:1013351617532)
- Hryniewicz K, Baum C, Leinweber P (2009). Mycorrhizal community structure, microbial biomass P and phosphatase activities under *Salix polaris* as influenced by nutrient availability. *European Journal of Soil Biology* 45 (2): 168-175. - doi: [10.1016/j.ejsobi.2008.09.008](https://doi.org/10.1016/j.ejsobi.2008.09.008)
- Huang H, Zhang S, Wu N, Luo L, Christie P (2009). Influence of *Glomus etunicatum* / *Zea mays* mycorrhiza on atrazine degradation, soil phosphatase and dehydrogenase activities, and soil microbial community structure. *Soil Biology and Biochemistry* 41 (4): 726-734. - doi: [10.1016/j.soilbio.2009.01.009](https://doi.org/10.1016/j.soilbio.2009.01.009)
- Isobe K, Aizawa E, Iguchi Y, Ishii R (2007). Distribution of arbuscular mycorrhizal fungi in upland field soils of Japan. 1. Relationship between spore density and the soil environmental factor. *Plant Production Science* 10 (1): 122-128. - doi: [10.1626/pss.10.122](https://doi.org/10.1626/pss.10.122)
- Kane ES, Valentine DW, Schuur EA, Dutta K (2005). Soil carbon stabilization along climate and stand productivity gradients in black spruce forests of interior Alaska. *Canadian Journal of Forest Research* 35 (9): 2118-2129. - doi: [10.1139/x05-093](https://doi.org/10.1139/x05-093)
- Kirschbaum MUF (1995). The temperature dependence of soil organic matter decomposition, and the effect of global warming on soil organic storage. *Soil Biology and Biochemistry* 27 (6): 753-760. - doi: [10.1016/0038-0717\(94\)00242-S](https://doi.org/10.1016/0038-0717(94)00242-S)
- Kivlin SN, Hawkes CV, Treseder KK (2011). Global diversity and distribution of arbuscular mycorrhizal fungi. *Soil Biology and Biochemistry* 43 (11): 2294-2303. - doi: [10.1016/j.soilbio.2011.07.012](https://doi.org/10.1016/j.soilbio.2011.07.012)
- Labidi S, Calonne M, Ben JF, Debiane D, Rezzoui S, Laruelle F, Tisserant B, Ferjani GA, Lounès HSA (2011). Calcareous impact on arbuscular mycorrhizal fungus development and on lipid peroxidation in monoxenic roots. *Phytochemistry* 72: 2335-2341. - doi: [10.1016/j.phytochem.2011.08.016](https://doi.org/10.1016/j.phytochem.2011.08.016)
- Li LF, Yang AN, Zhao ZW (2005). Seasonality of arbuscular mycorrhizal symbiosis and dark septate endophytes in a grassland site in southwest China. *FEMS Microbiology Ecology* 54: 367-373. - doi: [10.1016/j.femsec.2005.04.011](https://doi.org/10.1016/j.femsec.2005.04.011)
- Liu J, Wu L, Wei S, Xiao X, Su C, Jiang P, Song Z, Wang T, Yu Z (2007). Effects of arbuscular mycorrhizal fungi on the growth, nutrient uptake and glycyrrhizin production of licorice (*Glycyrrhiza uralensis* Fisch). *Plant Growth Regulation* 52 (1): 29-39. - doi: [10.1007/s10725-007-9174-2](https://doi.org/10.1007/s10725-007-9174-2)
- Marschner H, Dell B (1994). Nutrient uptake in mycorrhizal symbiosis. *Plant and Soil* 59: 89-102. [online] URL: <http://link.springer.com/article/10.1007/BF00000098>
- Matevz L, Katarina H, Tomislav R, Marjana R (2013). Distribution and diversity of arbuscular mycorrhizal fungi in grapevines from production vineyards along the eastern Adriatic coast. *Mycorrhiza* 23 (3): 209-219. - doi: [10.1007/s00572-012-0463-x](https://doi.org/10.1007/s00572-012-0463-x)
- Mendoza RE, Goldmann V, Rivas J, Escudero V, Pagani E, Collantes MB, Marbán L (2002). Arbuscular mycorrhizal fungi populations in relationship with soil properties and host plant in grasslands of Tierra del Fuego. *Ecologia Austral* 12: 105-116.
- Minggui G, Ming T, Qiaoming Z, Xinxin F (2012). Effects of climatic and edaphic factors on arbuscular mycorrhizal fungi in the rhizosphere of *Hippophae rhamnoides* in the Loess Plateau, China. *Acta Ecologica Sinica* 32 (2): 62-67. - doi: [10.1016/j.chnaes.2011.12.005](https://doi.org/10.1016/j.chnaes.2011.12.005)
- Moreira M, Baretta D, Mui TS, Cardoso EJBN (2006). Spore density and root colonization by arbuscular mycorrhizal fungi in preserved or disturbed *Araucaria angustifolia* (Bert.) O. Ktze. ecosystems. *Scientia Agricola* 63 (4): 380-385. - doi: [10.1590/S0103-90162006000400009](https://doi.org/10.1590/S0103-90162006000400009)
- Morwin HD, Peach PM (1951). Exchangeability of soil potassium in sand, silt and clay fractions as influenced by the nature of complementary exchangeable cations. *Soil Science Society of America Journal* 15: 125-128. - doi: [10.2136/sssaj1951.036159950015000C0026x](https://doi.org/10.2136/sssaj1951.036159950015000C0026x)
- Motosugi H, Yamamoto Y, Naruo T, Kitabyashi H, Ishi T (2002). Comparison of the growth and leaf mineral concentrations between three grapevine rootstocks and their corresponding tetraploids inoculated with an arbuscular mycorrhizal fungus *Gigaspora margarita*. *Vitis* 41:21-25. [online] URL: <http://www.vitis-vea.de/admin/volltext/e046314.pdf>
- Muthukumar T, Sha LQ, Yang XD, Cao M, Tang JW, Zheng Z (2003). Distribution of roots and arbuscular mycorrhizal associations in tropical forest types of Xishuangbanna, southwest China. *Applied Soil Ecology* 22 (3): 241-253. - doi: [10.1016/S0929-1393\(02\)00156-7](https://doi.org/10.1016/S0929-1393(02)00156-7)
- Nicolescu VN, Hochbichler E, Coello Gomez J, Ravagni S, Giullietti V (2009). Ecology and silviculture of wild service tree (*Sorbus torminalis* (L.) Crantz): a literature review. *Die Bodenkultur* 60 (3): 35-44. [online] URL: http://www.valbro.uni-freiburg.de/pdf/poster_nicolescu.pdf
- Ohlinger R (1996). Acid and alkaline phosphomonoesterase activity with the substrate p-nitrophenyl phosphate. In: "Methods in Soil Biology" (Schinner F, Kandeler E, Ohlinger R, Margesin RE eds). Springer-Verlag, Berlin, Germany, pp. 210-214.
- Olsen SR, Cole CV, Watanabe FS, Dean LA (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate. *USDA Circular* 939: 1-19.
- Paganová V (2008). Ecological requirements of wild service tree (*Sorbus torminalis* [L.] Crantz.) and service tree (*Sorbus domestica* L.) in relation with their utilization in forestry and landscape. *Journal of Forest Science* 54 (5): 216-226.
- Paudel S, Sah JP (2003). Physiochemical characteristics of soil in tropical Sal (*S. robusta* Gaertn) forest in eastern Nepal. *Himalayan Journal of Sciences* 1 (2): 107-110. [online] URL: <http://www.nepjol.info/index.php/HJS/article/viewArticle/207>
- Phillips JM, Hayman DS (1970). Improved procedures for clearing and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid as-

- assessment of infection. Transactions of the British Mycological Society 55 (1): 158-161. - doi: [10.1016/S0007-1536\(70\)80110-3](https://doi.org/10.1016/S0007-1536(70)80110-3)
- Pourmajidian M (2000). A study on the silvicultural characteristics and reproduction methods of *Sorbus torminalis* (L.) Crantz in western Mzandaran (Iran). PhD thesis, University of Tarbiyat Modares, Tehran, Iran, pp. 257.
- Quideau SA (2002). Organic matter accumulation. In: "Encyclopedia of Soil Science". Marcel Dekker Inc., New York, USA, pp. 891-894.
- Raspe O, Findlay C, Jacquemart AL (2000). *Sorbus aucuparia* L. Journal of Ecology 88 (5): 910-930. - doi: [10.1046/j.1365-2745.2000.00502.x](https://doi.org/10.1046/j.1365-2745.2000.00502.x)
- Redecker D, Kodner R, Graham LE (2000). Glo-malean fungi from the Ordovician. Science 289: 1920-1921. - doi: [10.1126/science.289.5486.1920](https://doi.org/10.1126/science.289.5486.1920)
- Rodriguez-Echeverria S, Gera Hol WH, Freitas H, Eason WR, Cook R (2008). Arbuscular mycorrhizal fungi of *Ammophila arenaria* (L.) Link: Spore abundance and root colonization in six locations of the European coast. European Journal of Soil Biology 44 (1): 30-36. - doi: [10.1016/j.ejsobi.2007.01.003](https://doi.org/10.1016/j.ejsobi.2007.01.003)
- Rooney DC, Prosser JI, Bending GD, Baggs EM, Killham K, Hodge A (2011). Effect of arbuscular mycorrhizal colonisation on the growth and phosphorus nutrition of *Populus euramericana* c.v. Ghoy. Biomass and Bioenergy 35 (11): 4605-4612. - doi: [10.1016/j.biombioe.2011.08.015](https://doi.org/10.1016/j.biombioe.2011.08.015)
- Sardans J, Penuelas J, Ogaya R (2008). Experimental drought reduced acid and alkaline phosphatase activity and increased organic extractable P in soil in a *Quercus ilex* Mediterranean forest. European Journal of Soil Biology 44 (5-6): 509-520. - doi: [10.1016/j.ejsobi.2008.09.011](https://doi.org/10.1016/j.ejsobi.2008.09.011)
- Smith SE, Read DJ (1997). Mycorrhizal symbiosis (2nd ed). Academic Press, San Diego, USA, pp. 605.
- Smith SE, Read DJ (2008). Mycorrhizal symbiosis. Academic Press Inc., London, UK, pp. 800.
- Smith SE, Smith, FA, Jakobsen I (2003). Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. Plant Physiology 133 (1): 16-20. - doi: [10.1104/pp.103.024380](https://doi.org/10.1104/pp.103.024380)
- Thonar C, Schnepf A, Frossard E, Roose T, Jansa J (2011). Traits related to differences in function among three arbuscular mycorrhizal fungi. Plant and Soil 339 (1-2): 231-245. - doi: [10.1007/s11104-010-0571-3](https://doi.org/10.1007/s11104-010-0571-3)
- Treseder KK (2004). A meta-analysis of mycorrhizal responses to nitrogen, phosphorus and atmospheric CO₂ in field studies. New Phytologist 164 (2): 347-355. - doi: [10.1111/j.1469-8137.2004.01159.x](https://doi.org/10.1111/j.1469-8137.2004.01159.x)
- Van der Heijden MGA, Klironomos JN, Ursic M, Moutoglis P, Streitwolf-Engel R, Boller T, Wiemken A, Sanders IR (1998). Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. Nature 396 (6706): 69-72. - doi: [10.1038/23932](https://doi.org/10.1038/23932)
- Walkley A, Black IA (1934). An examination of the Degtjareff method for determining organic carbon in soils: effect of variations in digestion conditions and of inorganic soil constituents. Soil Science 63 (4): 251-264. - doi: [10.1097/00010694-194704000-00001](https://doi.org/10.1097/00010694-194704000-00001)
- Waltert B, Wiemken V, Rusterholz H., Boller T, Baur B (2002). Disturbance of forest by trampling: effects on mycorrhizal roots of seedlings and mature trees of *Fagus sylvatica*. Plant and Soil 243 (2): 143-154. - doi: [10.1023/A:1019983625473](https://doi.org/10.1023/A:1019983625473)
- Wu Q, Zou YN, He XH (2011). Differences of hyphal and soil phosphatase activities in drought-stressed mycorrhizal trifoliolate orange (*Poncirus trifoliata*) seedlings. Scientia Horticulturae 129: 294-298. - doi: [10.1016/j.scienta.2011.03.051](https://doi.org/10.1016/j.scienta.2011.03.051)
- Xu P, Christie P, Liu Y, Zhang J, Li X (2008). The arbuscular mycorrhizal fungus *Glomus mosseae* can enhance arsenic tolerance in *Medicago truncatula* by increasing plant phosphorus status and restricting arsenate uptake. Environmental Pollution 156 (1): 215-220. - doi: [10.1016/j.envpol.2008.01.003](https://doi.org/10.1016/j.envpol.2008.01.003)
- Yong SZ, Chao ZC, Yun LZ, Gu F, Peter C, Yan CT, Lin XL (2007). Diversity and zonal distribution of arbuscular mycorrhizal fungi on the northern slopes of the Tianshan Mountains. Sci China Ser D-Earth Sci 50: 135-141.
- Zhao J, Dong Y, Xie X, Li X, Zhang X, Shen X (2011). Effect of annual variation in soil pH on available soil nutrients in pear orchards. Acta Ecologica Sinica 31 (4): 212-216. - doi: [10.1016/j.chnaes.2011.04.001](https://doi.org/10.1016/j.chnaes.2011.04.001)