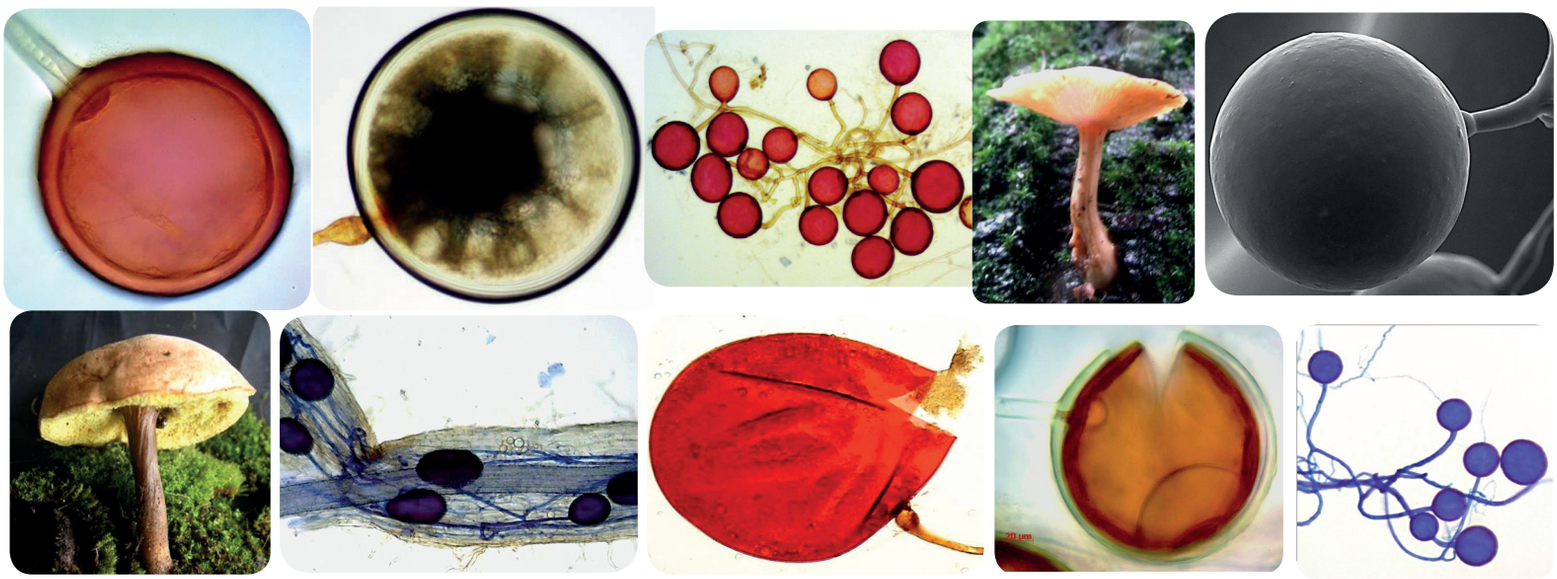
teri

MYCORRHIZA NEWS

The Quarterly Newsletter of Mycorrhiza Network

Volume 31 • Issue 2 • July 2019



About **TERI**

The Energy and Resources Institute (TERI) is a dynamic and flexible organization with a global vision and a local focus. TERI's focus is on research in the fields of energy, environment, and sustainable development, and on documentation and information dissemination. The genesis of these activities lies in TERI's firm belief that the efficient utilization of energy, sustainable use of natural resources, large-scale adoption of renewable energy technologies, and reduction of all forms of waste would move the process of development towards the goal of sustainability.

TERI's **Mycorrhiza Network**

TERI's Mycorrhiza Network is primarily responsible for establishing the Mycorrhiza Information Centre (MIC), the Centre for Mycorrhiza Culture Collection (CMCC), and publishing *Mycorrhiza News*. The Network helps scientists carry out research in mycorrhiza and promotes communication among mycorrhiza scientists.

Mycorrhiza News

The *Mycorrhiza News* provides a forum for the dissemination of scientific information on mycorrhiza research and activities; publishes state-of-the-art papers from eminent scientists; notes on important breakthroughs; brief accounts of new approaches and techniques; publishes papers complied from its RIZA database; provides information on forthcoming events on mycorrhiza and related subjects; lists important research references published during the quarter; and highlights the activities of the CMCC.

For further information, visit www.mycorrhizae.org.in

CONTENTS

Research finding papers

Seasonal Colonization of Arbuscular Mycorrhiza in *Andrographis Paniculata* (Burm.f.) Nees

Kripamoy Chakraborty[a], Jenifar Lushai[a], Aparajita Roy Das[b], Ajay Krishna Saha[b], and Panna Das[a]*

Introduction

Andrographis paniculata (Burm.f.) Nees is one of the extensively used medicinal plants and hence has the potential for export (Anandalwar and Vasantha 1989). Some of the attributes that make it such a unique herb include anticancer (Kumar, Sridevi, Kumar, *et al.* 2004), antihyperglycemic (Subramanian and Asmawi 2006), antimalarial (Misra, Guru, Katiyar, Srivastava, *et al.* 1992), antioxidant (Singh, Banerjee, and Rao 2001), antihepatitis (Sharma, Singh, Sehgal, *et al.* 1991), and anti-HIV activity (Yu, Chang, Su, *et al.* 2008).

From plant nutrition perspective, arbuscular mycorrhizal fungi (AM fungi) of Glomeromycota (Tedersoo, Sa´nchez-Ramı´rez, Ko˜ljalg, *et al.* 2018) have the ability to create a specialized niche (McArthur and Knowles 1993; Tobar, Azcón, and Barea, 1994 a, b). Such symbiotic relation has many non-nutritional benefits such as improvement of plant growth and yield (Javaid, Iqbal, and Hafeez 1994; Cavagnaro, Jackson, Six, *et al.* 2006), enhancement of tolerance to various biotic (Khaosaad, García-Garrido, Steinkellner, *et al.* 2007) and abiotic stresses (Al-Garni 2006; Takeda, Kistner, Kosuta, *et al.* 2007). AM fungal morphology can be divided into three types: (i) *Arum*, (ii) *Paris*, and (iii) Intermediate (Dickson 2004). Morphological types of AM fungi have been examined in many plant taxa (Kubato and McGonigle 2005; Yamato and Iwasaki 2002; Muthukumar, Senthilkumar, Rajangam, *et al.* 2006; Muthukumar and Prakash 2009; Das Kayang 2010; Das, Saha, and Kayang 2013; Chakraborty, Sinha , Debnath, *et al.* 2016; Chakraborty, Talapatra, Roy Das, *et al.* 2019; Chakraborty, Banik, Debnath, *et al.* 2019).

Despite a moderate literature on the AM fungal colonization in *A. paniculata*, reports concerning structural features (within the root) and seasonal colonization is lacking. In this connection, the present study, carried out in Tripura, India is focused on the analysis of AM fungal colonization and composition associated with *A. paniculata*.

Materials and Methods

Study sites

For assessing AM fungal colonization and composition, root and soil samples of *A. paniculata* were collected during the dry season (early March) and wet rainy season (August) from two study sites of Suryamaninagar and Kanchancherra, Tripura. *A. paniculata* is an annual, branched, erect herbaceous plant, commonly found in hedgerows throughout the waste ground and road sides.

Root and soil sampling

The fine root samples of five randomly selected healthy and disease-free plants, distanced approximately 20 m away from each other were collected by uprooting. Utmost care was taken during root collection process. The task of identifying A. paniculata was difficult as the desired plant was surrounded by the robust

[a*] Microbiology Laboratory, Department of Botany, Tripura University, Suryamaninagar – 799022, Tripura, India; E-mail:kripachakraborty@gmail.com

[b] Mycology and Plant Pathology Laboratory, Department of Botany, Tripura University, Suryamaninagar – 799022, Tripura, India

composition of other herbs or shrubs. Root samples were first washed gently to remove the adhering soil and treated with formalin-acetic acid (FAA) solution before introducing to the laboratory for processing. The soil adhering to the roots and adjacent to roots was collected from each of the selected individual, mixed in marked zipped polythene bags and brought to the laboratory. The soil samples were divided into two equal halves. One half was stored at 4°C to assess the spore density and composition of AM fungi. The other half of the mixed soil was shade-dried and used for the assessment of soil physicochemical properties.

Analysis of rhizospheric soil

The pH and electrical conductivity (EC) were measured by using electronic digital pH and EC meter, respectively. The moisture content (MC) of the soil was determined by following Jackson (1967). The bulk density was determined by following Anderson and Ingram (1993). Estimation of soil organic carbon was done by following Anderson and Ingram (1993) and available soil phosphorus content was determined (Allen, Grimshaw, Parkinson, *et al.* 1974).

Assessment of AM fungal colonization

The root samples were washed several times in running tap water and cut into approximately 1 cm in size and cleaned with 10% NaOH at 90°C for 2 hours. This is followed by several rounds of washing of root samples with tap water. Then 2–3 drops of 2% hydrogen peroxide (H_2O_2) were added and slightly heated for additional cleaning. After this, the root segments were again washed with tap water and stained (Roy Das Talapatra, Chakraborty *et al.* 2015). After this, the root segments were mounted on lactoglycerol and observed under compound microscope (Olympus CX21i) with camera (SLIDE 500) for various AM fungal structures. The estimation of AM fungal colonization was done by magnified intersection method (McGonigle, Miller, Evans, *et al.* 1990).

Isolation and identification of AM fungal spores

Leaf litter and larger pebbles contained in the soil brought from the field were removed carefully. AM fungal spores were isolated by wet sieving and decanting method (Gerdeman and Nicolson 1963). The spores were then mounted on glass slides in polyvinyl-lactic acid glycerol and cautiously crushed under a dissecting microscope (Koske and Tessier 1983). All intact spores, free from parasitic attack, inhabiting the rhizosphere, were taken into consideration during the enumeration of spore numbers. Extracted spores were identified on the basis of spore morphology, subcellular characters, and ornamentation in the spore wall. Spore characters were compared with the original descriptions.[1]

Data analysis

Spore density (SD) was calculated in terms of number of spores in 50 g of soil samples. Mean and standard error of mean were also calculated. Duncan test was utilized to separate the mean colonization of AM fungi and soil physico-chemical properties using the software, *Statistica* 9.0.

Results

Soil properties

The rhizospheric soil physico-chemical properties of A. *paniculata* of both dry and wet seasons are presented in Table 1. At both the sites, between two seasons, significant difference in soil pH was observed. The EC differed considerably between two seasons in the soils of Suryamaninagar. Same trend was observed for MC difference between two seasons at both the study sites. In addition, bulk density of the soils from Suryamaninagar differed significantly between seasons. Soils of both the sites had shown noteworthy difference in available phosphorus and total nitrogen between the two seasons. Out of Suryamaninagar and Kanchancherra, notable organic carbon difference between two seasons was shown by soils of Kanchancherra.

AM fungal colonization

AM fungal colonization and composition and spore density is depicted in Table 2. AM fungal structures such as intercellular hyphae (Figure 1a), vesicles in the root cortex (Figure 1b and c), *Arum* type of AM morphology (Figure 1d and e), spores attached with roots (Figure 1f). These structures are mostly found in the root segments and are responsible for confirming the presence of AM fungi in the root segments of *A. paniculata.*

There is an appreciable difference in AM fungal colonization between two seasons of both the sites. AM fungal colonization and spore density were higher in wet season. The AM fungal species extracted from the rhizosphere of *A. paniculata* is depicted in Table 3. A total of six species of AM fungal spores were recovered from the rhizospheric soil inhabited by of *A. paniculata*. Five and four species were isolated from the soils of Kanchancherra and Suryamaninagar, respectively. *Glomus multicaule, Rhizophagus clarus,* and *Rhizophagus diaphanus* were recovered from both the study sites.

[1] Details available at www.amf-phylogeny.com

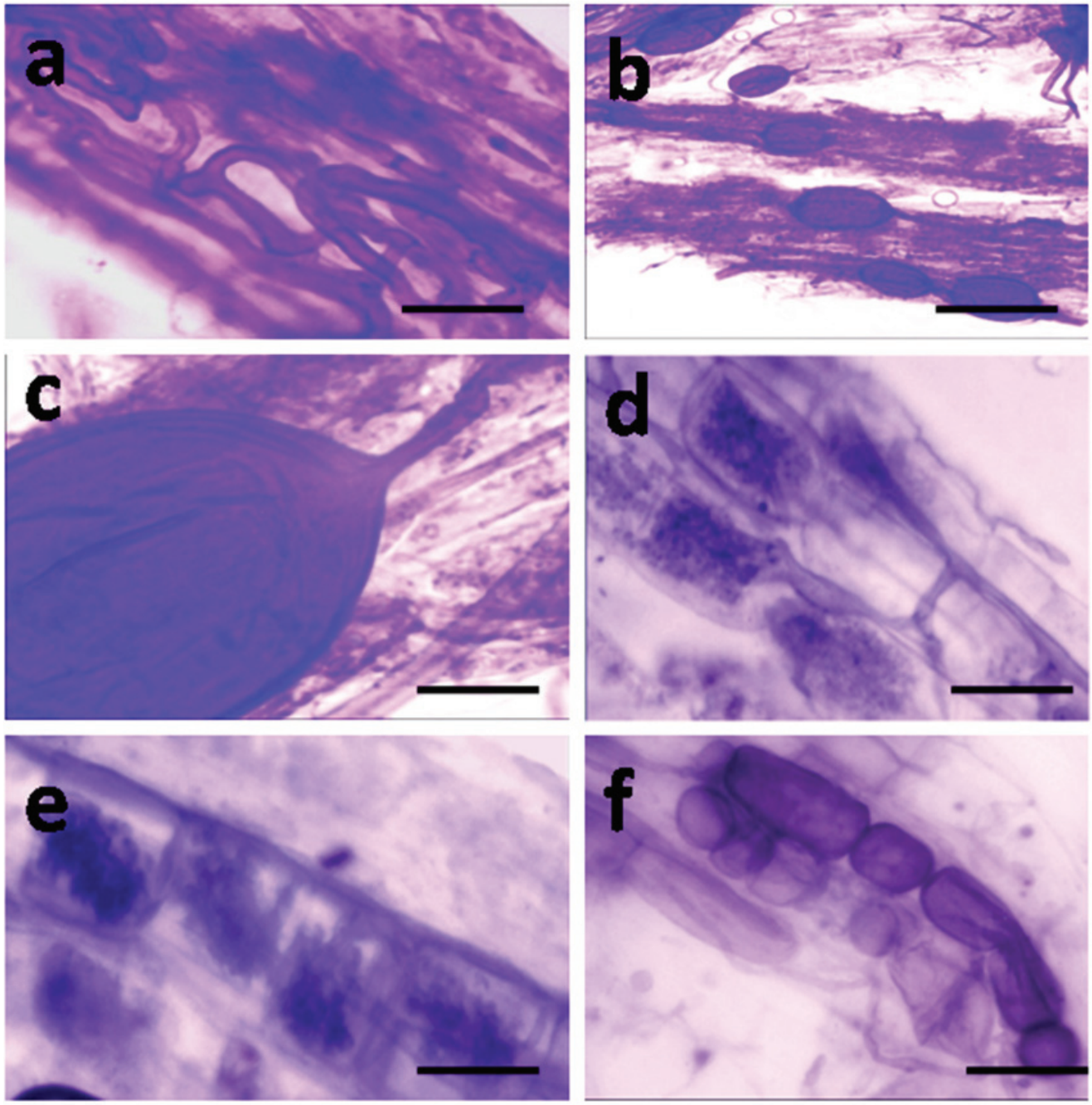


Figure 1 Light microscopic images of arbuscular mycorrhizal colonization in the roots of *Andrographis paniculata* (a): Hyphal coil in the epidermal layer of root, (b) and (c): Vesicles in the root cortex, (d) and (e): *Arum* type of AM fungal morphology in the cortical cells of root, and (f) Spores of AM fungi attached with roots. Scale bars (a, c, d, e, and f = 150µm, b = 200µm)

Discussion

On the basis of the knowledge gathered from the available resources, it can be concluded that this is the first attempt of the assessment of structural features and seasonal colonization by AM fungi associated with *A. paniculata* (Chiramel, Bagyaraj, and Patil 2006; Arpana and Bagyaraj 2007; Gupta, Chaturvedi, and Sharma 2009; Tejavathi, Anitha, Murthy, *et al.* 2011).

In the present assessment, AM fungal colonization varied significantly between the seasons. This seasonal variation in AM fungal colonization is mainly attributed to the additional nutrients' requirement for successful completion of the reproductive cycle (July–October) compared to the vegetative growth phase which is in agreement with the earlier findings (Javaid, Riaz, and Khan 2007). Literature survey

Table 1 Physico-chemical properties of rhizospheric soil of *Andrographis paniculata* from two seasons

Seasons	pH		EC (cS cm^{-1})		MC (%)		BD (g cm^{-3})		AP(mg/g)		TN(kg/h)		OC (%)	
	S	K	S	K	S	K	S	K	S	K	S	K	S	K
Dry	6.39±0.01b	5.84±0.02b	24.33±2.03b	57±3.46a	7.37±0.24b	11.80±0.17b	1.38±0.01b	1.41±0.01a	43.13±2.05b	38.87±1.41b	69.45±1.16b	61.75±1.44b	0.82±0.01a	0.79±0.04b
Wet	6.72±0.02a	6.28±0.01a	21.33±1.45a	47±2.65a	11.13±0.34a	16.93±0.34a	1.34±0.02a	1.44±0.02a	22.13±0.75a	29.40±1.85a	72.77±2.84a	50.60±1.63a	0.88±0.02a	0.64±0.03a

Note Different alphabets differ significantly at *P<0.05*
AP: available phosphorus, BD: bulk density, EC: electrical conductivity, K: Kanchancherra; MC: moisture content, OC: organic carbon, S: Suryamaninagar, TN: total nitrogen

Table 2 Arbuscular mycorrhizal colonization and spore density of *Andrographis paniculata* during two seasons

Seasons	% RLA		% RLV		% RLH		SD/50 g soil	
	S	K	S	K	S	K	S	K
Dry	8.59±1.04b	11.16±1.14b	10.76±1.28b	14.30±1.13b	33.49±1.16b	46.80±1.56b	28.67±2.73b	36.67±2.60b
Wet	11.28±1.25a	15.44±1.32a	22.10±1.50a	22.10±1.50a	56.25±2.85a	66.60±2.07a	33.33±2.33a	47.33±2.60a

Note Different alphabets differ significantly at P<0.05
% RLA: percentage of root length arbuscules/arbusculate cells; % RLHL: percentage of root length hyphae/hyphal coil, % RLV: percentage of root length vesicles, K: Kanchancherra, S: Suryamaninagar, SD: spore density

Table 3 Arbuscular mycorrhizal fungi isolated from the rhizosphere of *Andrographis paniculata*

AM fungi	Suryamaninagar		Kanchancherra	
	Dry	Wet	Dry	Wet
Acaulospora cavernata	-	-	-	+
Funneliformis sp.	+	+	-	-
Glomus macrocarpum	-	-	+	-
Glomus multicaule	+	-	-	+
Rhizophagus clarus	-	+	-	+
Rhizophagus diaphanus	+	-	+	-

Note + Presence; – Absence

concerning the role of AM fungi in plant reproduction pointed out that infection by AM fungi may result in increased reproduction in many plant species such as *Abutilon theophrasti* (Koide, Shumway, and Mabon 1994; Stanley, Koide, and Shumway1993), wild and cultivated species of *Avena* (Koide, Li, Lewis, *et al.* 1988), *Glycine max* (Vejsadova, Siblikova, Gryndler, *et al.*1993), *Triticum aestivum* (Karagiannidis and Hadjisavva-Zinoviadi 1998), and *Capsicum annuum* (Dodd, Krikun, and Haas 1983). This may be corresponding with the enhancement of potassium uptake in mycorrhizal-infected plants compared to non-mycorrhizal ones during that particular period (Dunne and Fitter 1989; McGonigle and Fitter 1988). The positive influence of AM fungi may be attributable with the increased tiller production in *Agropyron smithii* (Miller, Jarstfer, and Pillai, 1987) and tuber production in *Solanum tuberosum* (Douds, Nagahashi, Reider, *et al.* 2007), possibly by altering host hormone balance (Miller, Jarstfer, and Pillai, 1987). Bryla and Koide (1990) reported that AM fungi also promote early flowering in AM fungi inoculated plants.

Plant roots harbor more than one AM fungi (Börstler, Renker, Kahmen, *et al.* 2006) and they are the key determinant in composition of the plant species in different habitats (van der Heijden, Boller, Wiemken, *et al.* 1998). AM fungi are dependent on season, soil type, nutrients, and spatial distribution of host species (Louis and Lim 1987; Harikumar and Bagyaraj 1988). In the rhizospheric soil, adhering and near to examined root samples, six AM fungal species belonging to the *Acaulospora*, *Glomus,* and *Rhizophagus* genera were extracted. *Glomus* was one of the most commonly occurring AM fungi in the soil of Tripura

(Chakraborty, Sinha, Debnath, *et al.* 2016; Sinha, Chakraborty, and Saha, 2016; Debnath, Sinha, Talapatra, *et al.* 2017; Chakraborty, Talapatra, Roy Das, *et al.* 2019; Chakraborty, Banik, Debnath, *et al.* 2019) and from India (Muthukumar and Udaiyan 2000; Bhattacharya and Bagyaraj 2002). The affluence of *Glomus* may be due to their high adaptability to varied soil conditions (Ho 1987).

Conclusion

The incidences of AM fungal colonization differ significantly during reproductive phase compared to vegetative growth phase underpin the positive impact of AM fungal colonization in plant reproduction. However, an extensive study under experimental conditions needs to be carried out before arriving at any concrete generalization. *A. paniculata* is an annual plant, having a single-reproductive season, can be applied as a test plant for assessment of the net effect of infection by AM fungi to reveal the exact role of native AM fungi inhabiting the same rhizosphere. These indispensible rhizospheric mycobiota may be used for the enhancement of plant growth, development and yield along with the increase in the production of pharmaceutically important compounds of medicinal plants.

Acknowledgements

The authors are thankful to Head, Department of Botany, Tripura University for providing with the laboratory facilities. Kripamoy Chakraborty is grateful to Department of Science and Technology, Government of India for honouring with the INSPIRE fellowship.

References

Al-Garni S M S. 2006 Increased heavy metal tolerance of cowpea plants by dual inoculation of an arbuscular mycorrhizal fungi and nitrogen-fixer *Rhizobium*. *African J. Biotech* **5:** 133–42

Allen S E, Grimshaw M H, Parkinson J A, and Quarmby C. 1974. Chemical analysis of ecological materials. Blackwell's Scientific Publications, Oxford

Anandalwar T R and Vasantha L. 1989. Necessity of identification, cultivation, collection, preservation and promotion of medicinal plants in Karnataka. *My Forest* **25:** 67–73

Anderson J M and Ingram J S I (Eds). 1993. Tropical Soil Biology and Fertility: a handbook of methods. CAB International, Wallingford, UK

Arpana J, and Bagyaraj D J. 2007 Response of kalmegh to an arbuscular mycorrhizal fungus and a plant growth promoting rhizo microorganism at two levels of phosphorus fertilizer. *Am. Eurasian J. Agr. Environ. Sci.* **2:** 33–38

Bhattacharya S and Bagyaraj D J. 2002. Arbuscular mycorrhizal fungi associated with *Coffea Arabica. Geobios* **29:** 93–96

Börstler B, Renker C, Kahmen A, and Buscot F. 2006. Species composition of arbuscular mycorrhizal fungi in two mountain meadows with differing management types and levels of plant biodiversity. *Biol. Fert. Soils* **42**(4): 286–298

Bryla D R and Koide R T. 1990. Regulation of reproduction in wild and cultivated *Lycopersicon esculentum* Mill.by vesicular-arbuscular mycorrhizal infection. *Oecologia* **84**: 74–81

Cavagnaro T R, Jackson L E, Six J, Ferris H, Goyal S, Asami D, and Scow K M. 2006. Arbuscular mycorrhizas, microbial communities, nutrient availability and soil aggregates in organic tomato production. *Plant and Soil* **282:** 209–25

Chakraborty K, Sinha S, Debnath A, Das Roy A, Saha A K, and Das P. 2016. Arbuscular mycorrhizal fungal colonization in three different age group of rubber plantations in Tripura, Northeast India. *Pl. pathol . Quantine* **6**(2): 122–131

Chakraborty K, Talapatra K, Roy Das A, Saha A K, and Das P. 2019. Mycorrhizal colonization in *Drosera burmannii* Vahl, a carnivorous Plant: observation using light and fluorescence microscopy. *Ambient Sci.* DOI:10.21276/ambi.2019.06.1.ra02

Chakraborty K, Banik S, Debnath A, Das Roy A, Saha A K, and Das P. 2019. Arbuscular mycorrhiza and dark septate endophyte fungal associations of *Oryza sativa* L. under field condition: colonization features and their occurrence. *Pl. Sci. Today* **6**(1): 63–70

Chiramel T, Bagyaraj D J, and Patil C S P. 2006. Response of *Andrographis paniculata* to different arbuscular mycorrhizal fungi**.** *J Agri. Techno.* **2**(2): 221–228

Das P, and Kayang H. 2010. Mycorrhizal colonization and distribution of arbuscular mycorrhizal fungi associated with *Michelia champaca* L. under plantation system in northeast India. *J Forestry Res.* **21:**137–142

Das P, Saha A K, and Kayang H. 2013. Arbuscular mycorrhizal fungal morphology in *Michelia champaca* L. *J. Mycopathol Res* **51**(1):177–179

Debnath A, Sinha S, Talapatra K, Chakraborty K, Saha A, and Das P. 2017 Comparison of arbuscular mycorrhizal colonization and diversity of two different rubber plantations of Tripura, northeast India. *Trends. Front. Pl. Sci. Res.*, pp. 239–247

Dickson S. 2004. The *Arum–Paris* continuum of mycorrhizal symbioses. *New Phytol.* **163:** 187–200

Dodd J, Krikun J, and Haas J. 1983. Relative effectiveness of indigenous populations of vesiculararbuscular mycorrhizal fungi from four sites in the Negev. *Israel J. Bot.* **32:** 10–21

Douds D D, Nagahashi G, Reider C, and Hepperly P R. 2007. Inoculation with arbuscular mycorrhizal fungi increases the yield of potatoes in a high P soil. *Biol. Agric. Hort.* **25:**67–78

Dunne M J and Fitter A H. 1989. The phosphorus budget of a field-grown strawberry (*Fragaria x ananassa* cv. Hapil) crop: evidence for a mycorrhizal contribution. *Ann. Appl. Biol.* **114:**185–193

Gerdemann J W and Nicolson T W. 1963 Spores of mycorrhizal endogone species extracted from soil by wet-sieving and decanting method. *Transac. Brit. Myco. Soc.* **46**: 235–245

Gupta A K, Chaturvedi S, and Sharma A K. 2009 Arbuscular mycorrhizal fungal diversity in some medicinal plants. *Mycorrhiza News* **20**: 10–13

Harikumar K M and Bagyaraj D J. 1988. Effect of crop rotation on native vesicular arbuscular mycorrhizal propagules in soil. *Plant and Soil* **110**(1): 77–80

Ho I. 1987. Vesicular arbuscular mycorrhizae of halophytic grasses in the Alvard desert of Oregon. *Northwest Sci.* **61:** 148–151

Jackson M L. 1967. *Soil Chemical Analysis.* Prentice Hall, New Delhi, India

Javaid A, Iqbal S H, and Hafeez F Y. 1994. Effect of different strains of Bradyrhizobium and two types of vesicular arbuscular mycorrhizae (VAM) on biomass and nitrogen fixation in *Vigna radiata* (L.) Wilczek var. NM 20–21. *Sci. Int.* **6:** 265–267

Javaid A, Riaz T, and Khan S N. 2007 Mycorrhizal status of *Narcissus papyraceus* Ker-Gawl. co-cultivated with *Cynodon dactylon* Pers. *Int. J. Agric. Biol.* **9:** 901–904

Karagiannidis N and Hadjisavva-Zinoviadi S. 1998 The mycorrhizal fungus *Glomus mosseae* enhances growth, yield and chemical composition of a durum wheat variety in 10 different soils. *Nutr. Cycl. Agroecosyst.* **52:**1–7

Khaosaad T, García-Garrido J M, Steinkellner S, Vierheilig H. 2007 Take-all disease is systemically reduced in roots of mycorrhizal barley plants. *Soil Biol. Biochem.* **39**: 727–34

Koide R T, Li M, Lewis J, and Irby C. 1988. Role of mycorrhizal infection in the growth and reproduction of wild vs. cultivated plants. I. Wild vs. cultivated oats. *Oecologia* **77**: 537–543

Koide R T, Shumway D L, and Mabon S A. 1994. Mycorrhizal fungi and reproduction of field populations of *Abutilon theophrasti* Medic. (Malvaceae). *New Phytol.* **126:**123–130

Koske R E and Tessier B. 1983 A convenient, permanent slide mounting medium. *Myco. Soc. Am. Newsletter* **34:** 59

Kubato M, McGonigle T P, and Hyakumachi M. 2005. Co-occurrence of *Arum*- and *Paris*-type morphologies of arbuscular mycorrhizae in cucumber and tomato. *Mycorrhiza* **15:** 73–77

Kumar R A, Sridevi K, Kumar N V, Nanduri S, and Rajagopal S. 2004. Anticancer and immunostimulatory compounds from *Andrographis paniculata*. *J Ethno. Pharmacol.* **92** (2–3): 291–295

Louis I and Lim G. 1987. Spore density and root colonization of vesicular-arbuscular mycorrhizas in tropical soil *Transac. Brit. Mycolog. Soc.* **88**: 207–212

McArthur D A J and Knowles N R. 1992. Resistance responses of potato to vesicular-arbuscular mycorrhizal fungi under varying abiotic phosphorus levels. *Plant Physiol.* **100:** 341–351

McGonigle T P and Fitter A H. 1990. Ecological specificity of vesiculararbuscular mycorrhizal associations. *Mycol. Res.* **94:** 120–122

McGonigle T P, Miller M H, Evans D G, Fairchild G L, and Swan J A. 1990. A method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorrhizal fungi. *New Phytol.* **115:** 495–501

Miller R M, Jarstfer A G, and Pillai J K. 1987. Biomass allocation in an *Agropyron smithii – Glomus* symbiosis. *Am. J. Bot.* **74:** 114–122

Misra P, Pal N L, Guru P Y, Katiyar J C, Srivastava V, and Tandon J S. 1992 Antimalarial activity of *Andrographis paniculata* (Kalmegh) against *Plasmodium berghei* NK 65 in Mastomysnatalensis. *Int. J. Pharmacog.* **30**(4): 263–274

Muthukumar T and Prakash S. 2009. Arbuscular mycorrhizal morphology in crops and associated weeds in tropical agroecosystems. *Mycoscience* **50:** 233–239

Muthukumar T, Senthilkumar M, Rajangam M and Udaiyan K. 2006. Arbuscular mycorrhizal morphology and dark septate fungal associations in medicinal and aromatic plants of Western Ghats, Southern India. *Mycorrhiza* **17:**11–24.

Muthukumar T and Udaiyan K. 2000. Arbuscular mycorrhizas of plants growing in the Western Ghats region, Southern India. *Mycorrhiza* **9:** 297–313

Roy Das A, Talapatra K, Chakraborty K, Saha A K, and Das P. 2015. A commercially available fabric whitener serves as a stain for detection of arbuscular mycorrhizal fungi in roots. *Mycorrhiza News* **27**(3): 2–4

Sharma A, Singh R T, Sehgal V, and Handa S S. 1991. Anti-hepatotoxic activity of some plants used in herbal formulations. *Fitoterapia* **62**(2): 131–138

Singh R P, Banerjee S, and Rao A R. 2001. Modulatory influence of *Andrographis paniculata* on mouse hepatic and extra hepatic carcinogen metabolizing enzymes and antioxidant status. *Phyto. Ther. Res.* **15**(5): 382–390

Sinha S, Chakraborty K, Saha A K, and Das P. 2016. Mycorrhizal colonization in plants from selected home garden of Tripura. *J. Mycopathol. Res.* **54**(3): 349–353

Stanley M R, Koide R T, and Shumway D L. 1993. Mycorrhizal symbiosis increases growth, reproduction and recruitment of *Abutilon theophrasti* Medic. in the field. *Oecologia* **94:** 30–35

Subramanian R and Asmawi M Z. 2006. Inhibition of α-glucosidase by *Andrographis paniculata* ethanol extract in rats. *Pharmac. Bio.* **44**(8): 600–606

Takeda N, Kistner C, Kosuta S, Winzer T, Pitzschke A, Groth M, Sato M, Kaneko T, Tabata S, and Parniske M. 2007. Proteases in plant root symbiosis. *Phytochem.* **68:** 111–21

Tedersoo L, Sa´nchez-Ramı´rez S, Ko˜ljalg U, Bahram M, Do¨ring M, Schigel D, May T, Ryberg M, and Abarenkov K. 2018. High-level classification of the Fungi and a tool for evolutionary ecological analyse**.** *Fungal Divers.* Details available at https://doi.org/10.1007/s13225-018-0401-0

Tejavathi D H, Anitha P, Murthy S M, and Nijagunaiah R. 2011. Effect of AM fungal association with normal and micropropagated plants of *Andrographis paniculata* Nees on biomass, primary and secondary metabolites**.** *Int. Res. J Pl. Sci.* **2**(12): 338-348

Tobar R, Azcón R, and Barea J M. 1994a. Improved nitrogen uptake and transport from 15N-labelled nitrate by external hyphae of arbuscular mycorrhiza under water-stressed conditions. *New Phytol.* **126:** 119–122

Tobar R, Azcón R, and Barea J M. 1994b. The improvement of plant N acquisition from an ammonium-treated, drought-stressed soil by the fungal symbiont in arbuscular mycorrhiza. *Mycorrhiza* **4:** 105–108

van der Heijden M G A, Boller T, Wiemken A, and Sanders I R. 1998. Different arbuscular mycorrhizal fungal species are potential determinants of plant community structure. *Ecolog.* **79:** 2082–2091

Vejsadova H, Siblikova D, Gryndler M, Simon T, and Miksik I. 1993. Influence of inoculation with *Bradyrhizobium japonicum* and *Glomus claroideum* on seed yield of soybean under greenhouse and field conditions. *J. Plant Nutr.* **16:** 619–629

Yamato M and Iwasaki M. 2002. Morphological types of arbuscular mycorrhizal fungi in roots of understorey plants in Japanese deciduous broadleaved forests. *Mycorrhiza* **12:** 291–296

Yu B C, Chang C K, Su CF, and Cheng J T. 2008. Mediation of β-endorphin in andrographolide-induced plasma glucose lowering action in type I diabetes-like animals Naunyn Schmiedebergs. *Arch Pharmacol* **377**(4–6): 529–540

High-throughput Image-based Phenotyping for Studying Plant Responses to Arbuscular Mycorrhizal Fungi

Akshaya S[*] and Manoharachary C[*]

Arbuscular mycorrhizal fungi (AMF), as plant bio-stimulants, have been gaining prominence in agriculture because of their potential in improving nutrient uptake efficiency, tolerance to various stressors, and crop growth (Rouphael, Spichal, Panzarova, *et al.* 2018). Multiple benefits to plants by AMF include uptake of phosphorus and other poorly mobile nutrients (for example, N, S, K, Ca, Fe, Cu, Zn), increased soil aggregation and carbon sequestration, and stimulation of other organismal growth in the rhizosphere (Ingraffia, Amato, Frenda, *et al.* 2019; Battini, Grønlund, Agnolucci, *et al.* 2017). Responses to the mycorrhizal colonization may vary widely, depending on the host plant as well as the fungus. The aforementioned responses are positive for plant's growth, but there are a few negative responses exhibited by plants when exposed to AMF, for example, mycorrhizal growth depressions. These negative responses are gaining popularity amongst researchers/scientists engaged in AMF development. These responses can be observed in the form of phenotypic changes in plants. Plants respond to AMF and are colonized by them at different times and intensities. A better understanding of plant growth response to mycorrhizae can be achieved by collecting time series data of the plant phenotype. Such data sets can be laborious and costly to generate, as they usually rely on multiple harvests (Watts-Williams, Jewell, Brien, *et al.* 2019). An emerging advancement in obtaining such data is the use of image capture technology and open source analysis tools (Fahlgren, Gehan, and Baxter 2015). Plant phenotyping is an important tool in addressing and understanding plant environment interaction and its translation into application in crop management practices and effects of biostimulants (Pieruschka and Schurr 2019). Plant phenomics employs high-throughput image-based phenotyping of above-ground plant tissues (Marko, Brigila, Summerer, *et al.* 2018; Fahlgren, Gehan, and Baxter 2015). 'High-throughput' is a technological classification term that is relative to the effort associated with measurement (Fahlgren, Gehan, and Baxter 2015). Improvements in the specificity and throughput of phenotypic assessment at different biological levels such as phenomics, metabolomics, and genomics, are the main objectives of modern phenotyping (Sytar, Zivcak, Olsovska, *et al.* 2018). Modern phenotyping comprehensively assesses complex plant traits such as growth, development, tolerance, resistance to biotic and abiotic stresses, architecture, physiology and yield, through automated processes (Marko, Brigila, Summerer, *et al.* 2018; Fahlgren, Gehan, and Baxter 2015). Recent advances in this technology have enabled rapid worldwide development of high-throughput automated and semi-automated field and laboratory phenotyping platforms. The newly developed plant phenotyping platforms produce relatively large quantity of data than the initial platforms; hence need special systems for data management, access and storage, and also new statistical tools for deriving biologically significant signals from both experimental and environmental noise (Sytar, Zivcak, Olsovska, *et al.* 2018).

High-throughput phenotyping platforms (HTPPs) are capable of accurate and non-destructive capturing of plant traits, both qualitatively and quantitatively, by imaging hundreds of plants per day (Marko, Brigila, Summerer, *et al.* 2018). This advancement permits time-series measurements that are necessary to follow the progression of growth and stress on individual plants. Phenotyping of whole shoots, as opposed to excised organs, allows for examination of architecture-dependent traits, such as tillering and flowering and architecture-independent traits such as biomass and colour. Also, eliminating destructive measurements increases the experimental capacity for genotypes, treatments, and biological replicates by reducing the required replicate sampling sets (Fahlgren, Gehan, and Baxter 2015). Examples of high-throughput platforms (HTPs) currently being used are growth chamber platforms (small-scale screening), greenhouse platforms (medium-scale screening), and field platforms (large-scale screening) (Rouphael, Spichal, Panzarova, *et al.* 2018). Greenhouse-based and growth-chamber phenotyping platforms have the advantage of increased experimental cycling and environmental control, but they are often defined by pot growth and a spectrum of environmental conditions that can be measured. Controlled environmental conditions are also well suited for the investigation of root phenotypes (Sytar, Zivcak, Olsovska, *et al.* 2018). For

[*] Compiled from TERI Riza database
(TERI, Darbari Seth Block, India Habitat Centre, Lodhi Road, New Delhi – 110003, India)

targeting the scope of field experiments, unmanned aerial systems (UAS) offer a flexible alternative to ground-based phenotyping platforms, particularly for large-breeding nurseries and genetic studies with thousands of plots (Singh, Wang, Kumar *et al.* 2019). High-parameterized platforms that have been installed for phenotyping include semi-automatic evaluation of morphometric parameters using red–green–blue (RGB) image analysis, chlorophyll and fluorescence kinetic imaging and hyper spectral, thermal and infrared light imaging, positron emission tomography (PET), magnetic resonance imaging (MRI), computerized tomography (CT), and three-dimensional (3D) imaging. Photosynthetic parameters such as plant morphometry (using RGB systems), stomatal conductance (using IR thermal cameras), metabolomics of experimental plants at different stages of growth (using hyper-spectral imaging or HSI systems) can be evaluated as well (Sytar, Zivcak, Olsovska, *et al.* 2018). A variety of cameras are available to capture signals from the visible and infrared spectrum of light. The use of diverse camera systems in HTTPs results in images that require plant-centric trait extraction tools (for instance, tools available in Plant Image Analysis database). VIS (visible) cameras detect light in the visible range, from nearly 400 nm to 700 nm, and image-processing algorithms identify pixels that are plant derived and hence measure the morphological (shape, structure), geometric (length, area), and colour properties of the plants. It has been demonstrated that plant pixel area from a single-image stack can be used to calculate an approximate plant volume or total leaf area value that can accurately model fresh and dry weight, as well as above ground plant biomass. In addition, VIS imaging has also been used to measure dynamic processes like plant growth rates. The interaction of infrared light with plant tissue has several properties that make infrared analysis potentially useful for phenotyping. Infrared cameras that detect near-infrared (NIR) light are used for night imaging while those that detect short-wave infrared (SWIR) light are used for leaf water content. Thermal infrared (TIR) cameras detect long-wave infrared (LWIR) light which is emitted by leaves in a temperature-dependent intensity (Fahlgren, Gehan, and Baxter 2015). A disadvantage of VIS and NIR cameras is that specific wavelength information is lost in the output image. In contrast to this, state-of-the-art hyper spectral cameras detect hundreds of spectral bands with nanometer-level resolution between 350 nm and 2500 nm and thus are more suitable to detect plant stress (Fahlgren, Gehan, and Baxter 2015; Sytar, Zivcak, Olsovska, *et al.* 2018). These systems are composed of controlled watering and nutrient regimes regulated by automatic weighing systems and environmental controls in the imaging cabinet (in laboratory platforms) thereby ensuring precision. The control and programming of platform systems and data analysis is performed with sophisticated and user friendly software packages. Mass spectrometry-based imaging techniques (MALDI-MSI, DESI-MSI, MALDI-TOF, ESI-TOF) are also used as a part of HSI to provide knowledge of proteins and other metabolites in plant tissues (Sytar, Zivcak, Olsovska, *et al.* 2018).

Watts-Williams, Jewell, Brien, *et al.* (2019) used HTTP to explore growth responses (growth depression, in particular) of tomato, barley, and Medicago truncatula to Rhizophagus irregularis and zinc, thereby exploring the complexity of mycorrhizal responses. Another example involving the use of HTP facility is to analyse transgenic tomato plants, overexpressing *arginine decarboxylase* 2 gene (a gene involved in polyamine biosynthetic pathway), for tolerance to abiotic stress and differences in water content as well as their ability to recover after drought stress (Marko, Brigila, Summerer, *et al.* 2018). Previous experiments utilizing HTP proved valuable for studies in variation of traits in chickpea, barley, wheat, and rice (Watts-Williams, Jewell, Brien, *et al.* 2019). *Arabidopsis thaliana*, a classical model plant in biology, has been studied using this technology. Currently, HTP technologies are gaining attention because of being able to accomplish many purposes such as for product screening, and development as efficient means to automated, non-destructive online monitoring of multiple morpho-physiological plant traits; of necessary time-series measurements for following the progression of growth, plant performance and stress responses of individual plants, at high resolution; for reduced cost, labour and time for analyses through automatization, remote sensing, improved data integration and experimental design (Rouphael, Spichal, Panzarova, *et al.* 2018). Further advancement of plant phenotyping could be made possible through developments in disciplines such as remote sensing, robotics, computer vision and artificial intelligence, to shorten processing time and enable real-time HSI monitoring. Also improvements in HSI methodology would meet important theoretical needs of plant physiology (for example, a standard spectrum database for the identification of biological compounds) (Sytar, Zivcak, Olsovska, *et al.* 2018; Pieruschka and Schurr, 2019). It is, therefore, evident that such advanced techniques could help in the establishment of efficient protocols to study plant–fungal associations and can be further improved through experimentation.

References

Battini F, Grønlund M, Agnolucci M, Giovannetti M, and Jakobsen I. 2017. Facilitation of phosphorus uptake in maize plants by mycorrhizosphere bacteria. Scientific Reports 7 (4686). DOI: 10.1038/s41598-017-04959-0

Fahlgren N, Gehan M A, and Baxter I. 2015. Lights, camera, action: high-throughput plant phenotyping is ready for a close-up. Current Opinion in Plant Biology **24**: 93–99

Ingraffia R, Amato G, Frenda A S, and Giambalvo D. 2019. Impacts of arbuscular mycorrhizal fungi on nutrient uptake, N2 fixation, N transfer and growth in a wheat/faba bean intercropping system. PLOS ONE. DOI: 10.1371/journal.pone.0213672

Marko D, Brigila N, Summerer S, Petrozza A, Cellini F, and Iannacone R. 2018. High-throughput Phenotyping in Plant Stress Response Methods and Potential Applications to Polyamine field. Methods in Molecular Biology, 1694. DOI: 10.1007/978-1-4939-7398-9_31

Pieruschka R and Schurr U. 2019. Plant Phenotyping: past, present, and future. Plant Phenomics. DOI: org/10.34133/2019/7507131

Rouphael Y, Spichal L, Panzarova K, Casa R, and Colla G. 2018. High-throughput Plant Phenotyping for Developing Novel Biostimulants: from lab to field or from field to lab? Frontiers in Plant Science 9: 373–388. DOI: 10.3389/fpls.2018.01197

Singh D, Wang X, Kumar U, Gao L, Noor M, Imtiaz M, Singh R P, and Poland J. 2019. High-throughput Phenotyping Enabled Genetic Dissection of Crop Lodging in Wheat. Frontiers in Plant Science 10(394). DOI: 10.3389/fpls.2019.00394

Sytar O, Zivcak M, Olsovska K, and Brestic M. 2018. Perspectives in High-throughput Phenotyping of Qualitative Traits at Whole-Plant Level, Eco-friendly Agro-biological Techniques for Enhancing Crop Productivity. Springer 213–243

Watts-Williams S J, Jewell N, Brien C, Berger B, Garnett T, and Cavagnaro T R. 2019. Using High-throughput Phenotyping to Explore Growth Responses to Mycorrhizal Fungi and Zinc in Three Plant Species. Plant Phenomics. DOI: 10.34133/2019/5893953

NEWS HIGHLIGHTS

Stowaway fungi hitch a ride with birds to be with their fungal partners

A new phytologist study says that researchers from Portugal provide first evidence that fungi hitch a ride with birds to be with their plant partners, thereby filling in a fundamental piece in understanding the global distribution of mycorrhizal fungi as well as the colonization of remote territories by plants and associated fungi.[1]

Mapping the Wood Wide Web

The age-old subterranean social network of roots, fungi, and bacteria is now known as the 'Wood Wide Web'. An international study, published in Nature, has produced the first global map of the mycorrhizal fungi networks. Using millions of direct observations of trees and their symbiotic associations on the ground, the researchers have built models from the bottom up to visualize these networks. "This study provides key information about who lives where and why", says Dr Merlin Sheldrake, a Mycorrhizal Ecologist.[2]

Simple and sophisticated

It so turns out that AM Fungi are experts when it comes to dealing with resource inequality (like patchy phosphorus supply). They take advantage of their symbionts, by following the classic trading strategy 'Buy low, sell high'. Using quantum dots to track phosphorus movements through fungal networks, the team of scientists from the Netherlands found out that resource inequality stimulated trade and the greater the disparity across its network, the more the fungus transferred phosphorus to the root.[3]

One among the reading list.....

'Underland', a delicious and absorbing work by the author Robert Macfarlane, describes the world that lies beneath our feet. The 'Wood Wide Web' is also a part of his search to illuminate the life underground.[4]

The new MycoApply Injector Endo

MycoApply Injector Endo is the latest addition to the MycoApply horticulture and turf line of products of Mycorrhizal Applications, Oregon. The concentrated powder formulation, on a soluble humic carrier, features four species of endomycorrhizal fungi: (i) Glomus (ii) intraradices, (iii) G. mosseae, and (iv) G. etunicatum. Developed for application via horticulture injection equipment, the drench can be applied to crops via boom spray, sprinkler systems, hand sprayers, etc.[5]

---

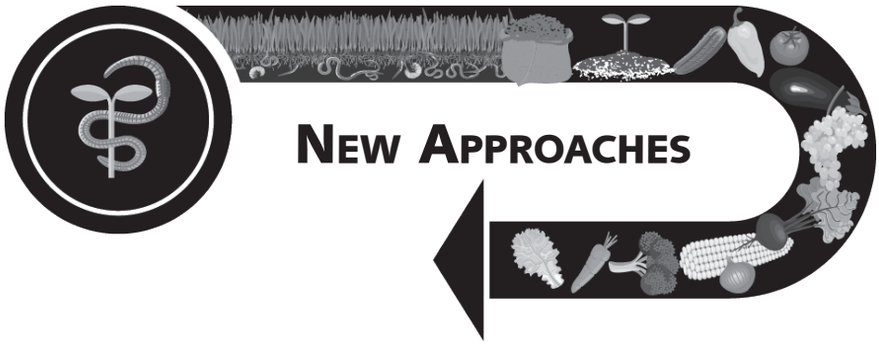
[1] Details available at www.eurekalert.org

[2] Details available at www.bbc.com

[3] Details available at www.newscientist.com

[4] Details available at www.ehn.org

[5] Details available at www.greenhousemag.com



New Approaches and Techniques

A Novel Method for Anatomical Analysis of Edaphic Organisms

Plant root interactions with soil organisms have significant impacts on plant performance and yield. Organisms such as the arbuscular mycorrhizal fungi (AMF) have been associated with over 70%–80% of terrestrial vegetation and have been an interest of research for a long time. Visualization of how these organisms colonize root tissue plays a significant role in understanding how they affect root health and development. Laser ablation tomography (LAT) is an innovative imaging technology that fulfils the requirement for rapid, three-dimensional visualization of biological samples. This technique provides full colour scans of samples at spatial scales from 0.1 mm to 1 cm with micron-level resolution, hence, addressing a gap in sample throughput and scale that is unfulfilled by conventional microscopy techniques. The LAT system uses a pulsed UV laser source, from which the beam gets directed to the beam shaping optics and becomes an oscillating beam over a linear distance, thus creating a cutting sheet. The root sample is moved into the beam path on a motorized linear stage as the camera simultaneously images the exposed anatomy ablated by the beam. LAT enables the study of root anatomy and root organisms across a wide spectrum of plant species and edaphic organisms through the contrasting composition-specific autofluorescence spectra emitted from different tissue samples (plant and fungal), arthropods, bacteria, and nematodes. The spectral differentiation between tissues in roots and the colonizing organisms highlights the varied chemical composition (which is not visible under bright field conditions). LAT improves interpretation of root-organism interactions in relatively large, opaque root segments. Due to its high-throughput imaging of root anatomy, LAT serves as an excellent tool for breeders and pathologists to conduct quantitative screens characterizing resistance to root pathogens. Deeper understanding of the relationships between root inhabiting biota can provide important insights into pest management and agricultural productivity. With significant opportunities to improve upon the present capabilities of LAT through modification of laser wavelengths, increased resolution and hyperspectral imaging technologies, many research applications remain for the employment of LAT.

Such technologies act as strengths when elaborating the mycorrhizal infection process and its establishment in the host plant. Further, they also give insight to understanding the ultra-structural details (layer-to-layer or wall-to-wall) that get be modified/ changed due to the symbiosis. Also, very little information on such technologies is found in the available literature and hence it becomes an important technology to be adopted and understood in-depth. A preliminary data has been made available by the authors (Strock, Schneider, Galindo-Castañeda, *et al.* 2019).

Reference

Strock C. F., Schneider H. M., Galindo-Castañeda, Hall B. T., Van Gansbeke B., Mether D. E., Roth M. G., Chilvers M. I., Guo X., Brown K., and Lynch B. J. 2019. Laser Ablation Tomography for Visualization of Root Colonization by Edaphic Organisms. *Journal of Experimental Botany.* DOI: 10.1093/jxb/erz271

Recent references

The latest additions to the network's database on mycorrhiza are published here for the members' information. The list consists of papers from the following journals:

- *AMB Express*
- *An International Journal of Plant Biology*
- *Applications in Plant Science*
- *Applied Soil Ecology*
- *Biotechnology Reports*
- *BMC Ecology*
- *Chemosphere*
- *Ecotoxicology and Environmental Safety*
- *Environmental Pollution*
- *Frontiers in Environmental Science*
- *Frontiers in Plant Sciences*
- *International Journal of Molecular Sciences*
- *Journal of Environmental Radioactivity*
- *Mycorrhiza*
- *Nature Communications*
- *Nature Plants*
- *Pest Management Science*
- *Planta*
- *Plant Biology (Stuttg)*
- *Plant, Cell and Environment*
- *Plant Science*
- *Scientific Reports*

Name of the author(s) and year of publication	**Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)**
Adeoyo OR*, Pletschke BI, Dames JF. 2019	**Purification and characterization of an amyloglucosidase from an ericoid mycorrhizal fungus *(Leohumicola incrustata)*** *AMB Express* **29**: 8(1): 154 [*Department of Biochemistry and Microbiology, Rhodes University, PO Box 94, Grahamstown, 6140, South Africa]
Bogar L*, Peay K, Kornfeld A, Huggins J, Hortal S, Anderson I, Kennedy P. 2019	**Plant-mediated partner discrimination in ectomycorrhizal mutualisms** *Mycorrhiza* **29**(2): 97–111 [*Department of Biology, Stanford University, 371 Serra Mall, Stanford, CA, 94305, USA. lbogar@stanford.edu.]
Debeljak M*, van Elteren JT, Špruk A, Izmer A, Vanhaecke F, Vogel-Mikuš K. 2018	**The role of arbuscular mycorrhiza in mercury and mineral nutrient uptake in maize** *Chemosphere* **212**: 1076–1084 [*Department of Analytical Chemistry, National Institute of Chemistry, Hajdrihova 19, SI-1000 Ljubljana, Slovenia]
Erik A Lilleskov, Thomas W Kuyper, Martin I.Bidartondo, Erik A Hobbie. 2019	**Atmospheric nitrogen deposition impacts on the structure and function of forest mycorrhizal communities: a review** *Environmental Pollution* **246**: 148–162 [*Forestry Sciences Laboratory, USDA Forest Service, Northern Research Station, 410 MacInnes Dr, Houghton, MI, 49931, USA]
Fan X*, Chang W, Feng F, Song F. 2019	**Responses of photosynthesis-related parameters and chloroplast ultrastructure to atrazine in alfalfa (*Medicago sativa L.*) inoculated with arbuscular mycorrhizal fungi** *Ecotoxicology and Environmental Safety* **166**: 102–108 [*Northeast Forestry University, Harbin 150040, China]
Heikham Evelin, Thokchom Sarda Devi, Samta Gupta, Rupam Kapoor*. 2019	**Mitigation of Salinity stress in plants by arbuscular mycorrhizal symbiosis: current understanding and new challenges** *Frontiers in Plant Sciences* **10**: 470 [*Department of Botany, Rajiv Gandhi University, Itanagar, India]

Name of the author(s) and year of publication	Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)
J Mason Heberling*, David J Burke. 2019	**Utilizing herbarium specimens to quantify historical mycorrhizal communities** *Applications in Plant Science* **7**(4): e01223 [*Section of Botany, Carnegie Museum of Natural History, 4400 Forbes Avenue, Pittsburgh, Pennsylvania, 15213, USA,]
Karin Hage-Ahmed*, Kathrin Rosner, Siegrid Steinkellner. 2019	**Arbuscular mycorrhizal fungi and their response to pesticides** *Pest Management Science* **75**(3): 583–590 [*Division of Plant Protection, Department of Crop Sciences, University of Natural Resources and Life Sciences Vienna, Tulln, Austria]
Kothamasi D*, Wannijn J, Van Hees M, Nauts R, Van Gompel A, Vanhoudt N, Vandenhove H. 2019	**Exposure to ionizing radiation affects the growth of ectomycorrhizal fungi and induces increased melanin production and increased capacities of reactive oxygen species scavenging enzymes** *Journal of Environmental Radioactivity* **197**: 16–22 [*Biosphere Impact Studies Unit, Belgian Nuclear Research Center (SCK•CEN), Boeretang 200, 2400, Mol, Belgium; Laboratory of Soil Biology and Microbial Ecology, Department of Environmental Studies, University of Delhi, Delhi, 110 007, India. Electronic address: dkothamasi@es.du.ac.in.]
Matteo Chialva*, Jonatan U Fangel, Mara Novero, Inès Zouari, Alessandra Salvioli di Fossalunga, William G T Willats, Paola Bonfante, Raffaella Balestrini*	**Understanding changes in tomato cell walls in roots and fruits: the contribution of arbuscular mycorrhizal colonization** *International Journal of Molecular Science* **20**(2): 415 [*Department of Life Sciences and Systems Biology, University of Torino, Viale P.A. Mattioli 25, I-10125 Torino, Italy]
Mohamed I*, Eid KE, Abbas MHH, Salem AA, Ahmed N, Ali M, Shah GM, Fang C. 2019	**Use of plant growth promoting Rhizobacteria (PGPR) and mycorrhizae to improve the growth and nutrient utilization of common bean in a soil infected with white rot fungi** *Ecotoxicology and Environmental Safety* 171: 539–548 [*Key Laboratory of Aquatic Botany and Watershed Ecology, Wuhan Botanical Garden, Chinese Academy of Science, Wuhan 430074, China; Soil and Water Sciences Department, Faculty of Agriculture, Benha University, Egypt; China Program of International Plant Nutrition Institute, Wuhan 430074, China. Electronic address: Ibrahim.ali@fagr.bu.edu.eg.]
Mucha J, Gabała E, Zadworny M. 2019	**The effects of structurally different siderophores on the organelles of Pinus sylvestris root cells** *Planta* **249**(6): 1747–1760 [*Institute of Dendrology, Polish Academy of Science, Parkowa 5, 62-035, Kórnik, Poland. jmucha@man.poznan.pl.]
Nuria Ferrol*, Concepción Azcón-Aguilar, Jacob Pérez-Tienda. 2019	**Arbuscular mycorrhizas as key players in sustainable plant phosphorus acquisition: an overview on the mechanisms involved** *Plant Science* **280**: 441–447 [*Departamento de Microbiología del Suelo y Sistemas Simbióticos, Estación Experimental del Zaidín, CSIC, C. Profesor Albareda 1, 18008, Granada, Spain]

Name of the author(s) and year of publication	Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)
Peter N McGuiness*, James B Reid, Eloise Foo. 2019	**The role of Gibberellins and Brassinosteroids in nodulation and arbuscular mycorrhizal associations** *Frontiers in Plant Sciences* **10**(269) 15 March 2019 [*School of Natural Sciences, University of Tasmania, Hobart, TAS, Australia]
Piotr Piszczek*, Karolina Kuszewska,Janusz Błaszkowski, Anna Sochacka-Obruśnik, Anna Stojakowska, Szymon Zubek. 2019	**Associations between root-inhabiting fungi and 40 species of medicinal plants with potential applications in the pharmaceutical and biotechnological industries** *Applied Soil Ecology* **137**: 69–77 [*Jagiellonian University, Faculty of Biology, Institute of Botany, 30-387 Kraków, Gronostajowa street 3, Poland]
Rico M Hartmann*, Sieke Schaepe, Daniel Nübel, Arne C Petersen, Martina Bertolini, Jana Vasilev, Helge Küster, Natalija Hohnjec. 2019	**Insights into the complex role of GRAS transcription factors in the arbuscular mycorrhiza symbiosis** *Scientific Reports* **9**: 3360 [*Unit IV-Plant Genomics, Institute of Plant Genetics, Leibniz Universität Hannover, Herrenhäuser Str. 2, D-30419, Hannover, Germany]
Ronelle Roth*, Stefan Hillmer, Charlotta Funaya, Marco Chiapello, Karin Schumacher, Libera Lo Presti, Regine Kahmann, Uta Paszkowski. 2019	**Arbuscular cell invasion coincides with extracellular vesicles and membrane tubules** *Nature Plants* **5**: 204–211 (2019) [*Department of Plant Sciences, University of Cambridge, Cambridge, UK]
Roth R*, Chiapello M, Montero H, Gehrig P, Grossmann J, O'Holleran K, Hartken D, Walters F, Yang SY, Hillmer S, Schumacher K, Bowden S, Craze M, Wallington EJ, Miyao A, Sawers R, Martinoia E, Paszkowski U. 2019	**A rice serine/threonine receptor-like kinase regulates arbuscular mycorrhizal symbiosis at the peri-arbuscular membrane** *Nature Communications* 8; **9**(1): 4677 [*Department of Plant Sciences, University of Cambridge, Cambridge, CB2 3EA, UK. rr472@cam.ac.uk.]
Sarah L Bluhm*, Anton M Potapov, Julia Shrubovych, Silke Ammerschubert, Andrea Polle and Stefan Scheu	**Protura are unique: first evidence of specialized feeding on ectomycorrhizal fungi in soil invertebrates** *BMC Ecology* **19**: 10 [*J F Blumenbach Institute of Zoology and Anthropology, Animal Ecology, University of Göttingen, Untere Karspüle 2, 37073 Göttingen, Germany]
Shivani Srivastava, David M Cahill, Alok Adholeya. 2019	**Optimal method selection for biocompatible extraction of rosmarinic acid from mycorrhizal hairy roots of Ocimum basilicum** *Biotechnology Reports* 23, September 2019 [TERI–Deakin Nanobiotechnology Centre, TERI Gram, The Energy and Resources Institute (TERI), Gwal Pahari, Gurugram, Haryana, 122002, India]
Varga S*, Soulsbury CD. 2019	**Arbuscular mycorrhizal fungi change host plant DNA methylation systemically** *Plant Biology (Stuttg)* **21**(2): 278–283 [*School of Life Sciences, Joseph Banks Laboratories, University of Lincoln, Lincoln, UK]

Name of the author(s) and year of publication	Title of the article, name of the journal, volume number, issue number, page numbers (address of the first author or of the corresponding author, marked with an asterisk)
Wenguang Shi*, Yuhong Zhang, Shaoliang Chen, Andrea Polle, Heinz Rennenberg, Zhi-Bin Luo. 2019	**Physiological and molecular mechanisms of heavy metal accumulation in non-mycorrhizal versus mycorrhizal plants** *Plant Cell and Environment* **42**(4): 1087–1103 [*State Key Laboratory of Tree Genetics and Breeding, Key Laboratory of Silviculture of the State Forestry Administration, Research Institute of Forestry, Chinese Academy of Forestry, Beijing, 100091, China]
Yang N*, Butenschoen O, Rana R, Köhler L, Hertel D, Leuschner C, Scheu S, Polle A, Pena R. 2019	**Leaf litter species identity influences biochemical composition of ectomycorrhizal fungi** *Mycorrhiza* **29**(2): 85–96 [*Forest Botany and Tree Physiology, University of Goettingen, Buesgenweg 2, 37077, Goettingen, Germany]
Yoshihiro Kobae*. 2019	**Dynamic Phosphate Uptake in Arbuscular Mycorrhizal roots under field conditions** *Frontiers in Environmental Science* **6**: 9 January 2019 [*Laboratory of Crop Nutrition, Department of Sustainable Agriculture, Rakuno Gakuen University, Ebetsu, Japan]
Yunjian Xu*, Suwen Zhu, Fang Liu, Wei Wang, Xuewen Wang, Guomin Han, *Beijiu Cheng*. 2019	**Identification of Arbuscular Mycorrhiza Fungi Responsive microRNAs and Their Regulatory Network in Maize** *International Journal of Molecular Sciences* **19**(10): 3201 [*School of Life Sciences, Anhui Agricultural University, Hefei 230036, China]
Zakaria M. Solaiman*, Lynette K Abbott, Daniel V Murphy. 2019	**Biochar phosphorus concentration dictates mycorrhizal colonisation, plant growth and soil phosphorus cycling** *Scientific Reports* **9**, Article number: 5062 (2019) [*SoilsWest, UWA School of Agriculture and Environment, and the UWA Institute of Agriculture, The University of Western Australia, Perth, WA, 6009, Australia]
Zhang XF*, Hu ZH, Yan TX, Lu RR, Peng CL, Li SS, Jing YX. 2019	**Arbuscular mycorrhizal fungi alleviate Cd phytotoxicity by altering Cd subcellular distribution and chemical forms in Zea mays** *Ecotoxicology and Environmental Safety* **171**: 352–360 [*Guangzhou Key Laboratory of Subtropical Biodiversity and Biomonitoring, Key Laboratory of Ecology and Environmental Science in Guangdong Higher Education, Guangdong Provincial Engineering Technology Research Center for Drug and Food Biological Resources Processing and Comprehensive Utilization, College of Life Sciences, South China Normal University, Guangzhou 510631, China]

About Mycorrhiza News

The Mycorrhiza News provides a forum for dissemination of scientific information on mycorrhiza research and activities; publishes state-of-the-art papers from eminent scientists; notes on important breakthroughs; brief accounts of new approaches and techniques; publishes papers complied from its RIZA database; provides information on forthcoming events on mycorrhiza and related subjects; lists important research references published during the quarter; and highlights the activities of the CMCC.

ORDER FORM

Mycorrhiza News Quarterly (ISSN 0970-695-X) - Print + Online

Year	Print* (₹)	Print* ($)	
1	300 ☐	50 ☐	**Online Free*

Name (IN BLOCK LETTERS): .....

.....

Designation: .....

Organization: .....

Address: .....

City: ..... State: .....Country.....

Pin: ..... Tel.: ..... Fax: .....

Email: .....

Enclosed is a demand draft/cheque (payable at, New Delhi) no. ..... for Rs.....

Dated ..... / ..... / ..... payable to TERI, New Delhi

Payment Procedure

Send your order along with payment directly to us by demand draft or cheque in favour of **TERI**, payable at New Delhi. Outstation cheques are not accepted. OR purchase through onlinebookstore at *<http://bookstore.teri.res.in>*.

Send your payment along with your name, designation, institution/company, address, phone number, and email details to

The Energy and Resources Institute
Attn: TERI Press
Darbari Seth Block
IHC Complex, Lodhi Road
New Delhi – 110 003, India

Tel. 2468 2100 or 4150 4900
Fax: 2468 2144 or 2468 2145
India +91 Delhi (0)11
Email: teripress@teri.res.in
Web: http://bookstore.teri.res.in

Forthcoming events
conferences, congresses, seminars, symposiums, and workshops

Osaka, **Japan**
July 15–16, 2019

Mycology Congress: 4th World Mycology & Mushroom Congress

E-mail: mycologycongress@insightsummits.com
Website: https://www.asianmeetings.net/conferences/mycology

Vienna, **Austria**
August 19–20, 2019

14th International Conference on Microbial Interactions & Microbial Ecology

E-mail: microbialinteractions@brainstormingmeetings.com
Website: https://microbialinteractions.expertconferences.org

Tokyo, **Japan**
August 19–20, 2019

Global Summit on Agriculture & Organic Farming
Theme: A Sustainable Eco-friendly Agricultural Approach to Crop Improvement

E-mail: agriculture@conferenceint.com
Website: https://agriculture.agriconferences.com/organizing-committee.php

Singapore
August 21–22, 2019

7th World Congress on Earth & Environmental Science
Theme: An Insight into the Recent Advancements in Earth and Environmental Science

E-mail: earthscience@conferencesseries.org
Website: https://geology.earthscienceconferences.com

Bangkok, **Thailand**
August 22–23, 2019

6th International Conference on Agriculture 2019 – (AGRICO 2019)

E-mail: info@agroconference.com
Website: https://agroconference.com

Warsaw and Białowieża, **Poland**
September 16–21, 2019

XVIII Congress of European Mycologists

E-mail: polskietowarzystwomykologiczne@gmail.com
Website: https://xviiicem.pl/

Madrid, **Spain**
October 7–8, 2019

7th Global Summit on Plant Science

Email: agriculture@conferenceint.com
Website: https://agriculture.agriconferences.com

Madrid, **Spain**
October 7–8, 2019

6th International Conference on Mycology and Fungal Infections

E-mail: infections@pulsusmeet.net
Website: https://fungalinfections.cmesociety.com

Tsu, **Japan**
October 1–4, 2019

Asian Mycological Congress 2019

E-mail: amc2019officer@mycology-jp.org
Website: http://amcfungi2019.com/index.html

Milan, **Italy**
October 18–19, 2019

2nd European Plant Science Conference
Theme: Transforming Future of Plant Science

E-mail: plantscience@insightsummits.com
Website: https://www.meetingsint.com/agri-aqua-conferences/plant-science

Puducherry, **India**
November 7–9, 2019

National Conference on 'Recent Advances in Biodiversity, Biology and Biotechnology of Fungi' and 46th Annual Meeting of Mycological Society of India (MSI)

E-mail: sarmavv@yahoo.com; msi2019pu@gmail.com
Website http://fungiindia.co.in/images/2019/2019.pdf

Editor Alok Adholeya • **Associate Editor** T P Sankar • **Assistant Editor** Sachin Bhardwaj

Printed and published by Dr Ajay Mathur on behalf of The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110003, and *printed at* Multiplexus (India), C-440, DSIDC, Narela Industrial Park, Narela, Delhi – 110040