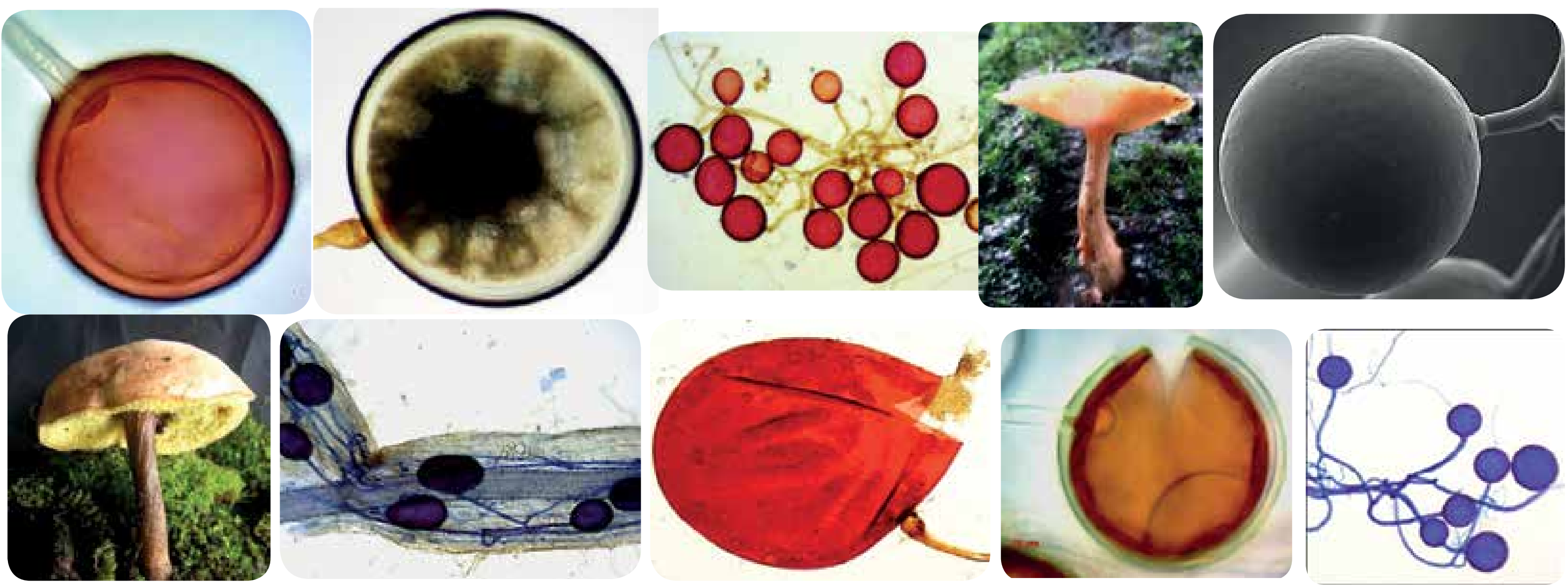
MYCORRHIZA NEWS

The Quarterly Newsletter of Mycorrhiza Network

Volume 32 • Issue 1 • April 2020



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

Research finding paper

Effects of Vesicular-arbuscular Mycorrhiza Colonization on Biomass Production of Economically Important Crop Plants Grown Directly over Industrial Sludge

A. Tripathi[1] *and N. K. Srivastava*[2]

Introduction

In India, more than 53% of the land area is degraded. This is mainly attributed to rapid industrialization and land disturbance due to effluent discharge. Mycorrhizal fungi are known to improve the revegetation of such disturbed areas (Draft and Nicolson 1974; Draft and Hasckaylo 1976; Khan 1981).

Bioremediation is a technology that has gained great popularity and is currently attracting attention as a remedial measure where microorganisms are used to detoxify wastes. Some industrial set-ups engaged in manufacturing distilleries and chemicals produce huge quantities of alcohol and thereby generate spent wash as well as sludge (two major pollutants) in mammoth proportions. There are several reports on increased plant growth even under various environmental stresses, when infected with vesicular-arbuscular mycorrhizal (VAM) fungi (Fitler 1985; Jeffries 1987; Azcon, Atrach, and Barea 1988). The present study— Effects of Vesicular-arbuscular Mycorrhiza Colonization on Biomass Production of Economically Important Crop Plants Grown Directly over the Sludge—was conducted to explore the impact of VAM colonization on economically important crop plants grown in industrial sludge.

Materials and Methods

The sludge used in the present study was collected directly from the industrial area of Satharia, Jaunpur, powdered and mixed thoroughly. Viable seeds of *Vigna mungo* (Urad bean), *Vigna radiata* (Mung bean), *Vigna catijung* (Cow pea), *Cajanus cajan* (Pigeon pea), *Sorghum vulgare* (Indian millet), and *Pennisetum typhoides* (Pearl millet) were selected and sown in earthen pots containing only the sludge. Seedlings grown in sludge-free soil were treated as control. After 50 days, the plants were uprooted and their aerial parts and roots were collected (Draft and Nicolson 1974). Substrates were collected from the control (sludge-free soil) and treated (sludge) pots, and the VAM spores were isolated by wet sieving and decanting method and then identified. Elemental analysis of the 50 days old crop plants was carried out using a flame photometer (Systronics, India). Analysis of total biomass was carried out in 90-day old *Vigna mungo, Vigna radiata, Vigna catijung,* and 120-day old *Sorghum vulgare*, *Pennisetum typhoides* and their harvest indices were calculated.

Results, Discussion, and Conclusion

The present study critically analyses the effect of sludge on VAM infection, plant biomass, and crop productivity. Physicochemical properties of the sludge indicated that its water-holding capacity was 122% while that of the garden soil was about 19%. Among the chemical parameters, pH was found to be very high in the sludge (9.82) while the electrical conductivity (EC) value was found to be 8.63 mS/cm, thereby indicating extreme salinity. The sludge

[1] Department of Botany, Shibli National Postgraduate College, Azamgarh, Uttar Pradesh – 276001
E-mail: aloktripathi5151@gmail.com

[2] Department of Botany, Sri Durga Ji Post Graduate College, Chandeshwhar, Azamgarh, Uttar Pradesh – 276128
(corresponding author)
E-mail: naveen.srivastava15@yahoo.com

was found to contain various organics like sugars, phenols, sucrose, starch, nitrogen, and proteins as well as elements such as N, P, K, and Ca. The percentage of germination and seedling vigour index were not affected even when the sludge (alone) was used for raising the plants. Chemical properties like pH have been reported to have a definite influence on VAM diversity, spore population, and spore germination (El-Kherbawy, Angle, Heggo, *et al.* 1989). As given in Table 1, the percentage of VAM infection was more in the 50-day old plants grown directly in the sludge (21%–80%) when compared to the control. Maximum infection was noted in *Vigna catijung* (90%) whereas in control it was only 50%. The pH and EC values of the sludge did not affect the VAM spore occurrence, germination and root colonization.

It has been well established that mycorrhizal colonization can enhance the efficiency of nutrient uptake (in addition to P) (Eivazi and Weir 1989; Harrison and Dixon 1994). Therefore, elements such as N, P, K, and Ca in the roots of 50-day old plants were analysed to find out if the mycorrhizal symbiosis could improve the efficiency of nutrient uptake in plants. The studied elements (mg/g Dry Weight (DW)) were found to be higher in the plants grown directly in the sludge. The phosphorus uptake was more, followed by nitrogen, calcium, and potassium. Table 2 clearly indicates that mycorrhizal symbiosis is one of the mechanisms by which nutrient uptake in plants could be improved. The improved N, P, K, and Ca uptake by VAM plants could be due to the increased amounts of unidentified organic acids (Fabig, Veilhauer, Moawad, *et al.* 1989), chelating compounds (Jayachandran, Kshwab, and Hetrick 1989) or CO_2 (a result of the symbiosis) (Knight, Allen, Jurinak, *et al.* 1989).

After studying the elemental composition of the roots, interest was to find out if the increased uptake and mycorrhizal effectiveness could improve plant growth and productivity and hence, their biomass and harvest indices were calculated (Table 3).

Table 1 VAM colonization in 50 days old plants (grown directly in sludge)

Crop plants	Infection (in %)	
	Control	Sludge
Vigna radiata	66	80 (121)
Vigna mungo	53	73 (138)
Vigna catijung	50	90 (180)
Cajanus cajan	53	65 (123)
Sorghum vulgare	66	86 (130)
Pennisetum typhoides	60	86 (143)

Table 2 Elemental analyses of 50 days old plant roots, grown in sludge

Element (in mg/g DW)							
Nitrogen (N)		Phosphorus (P)		Potassium (K)		Calcium (Ca)	
Control	Sludge	Control	Sludge	Control	Sludge	Control	Sludge
122	180 (148)	33	68 (206)	11	16 (145)	3	5 (167)
109	200 (183)	34	75 (220)	11	14 (127)	4	7 (175)
119	228 (192)	48	74 (154)	9	13 (144)	3	5 (167)
95	165 (174)	43	85 (198)	10	15 (150)	3	5 (167)
89	116 (130)	14	28 (200)	8	12 (150)	3	7 (233)
86	129 (150)	22	35 (159)	8	10 (125)	2	4 (200)

Table 3 Total biomass and harvest indices of 90 days old *Vigna radiata*, *Vigna mungo*, *Vigna catijung,* and 120 days old *Sorghum vulgare* and *Pennisetum typhoides* grown sludge

Crop plants	Biomass (in g)		Harvest index (in %)	
	Control	Sludge	Control	Sludge
Vigna radiata	11.20	14.54 (130)	40	54 (145)
Vigna mungo	11.28	15.04 (133)	42	58 (138)
Vigna catijung	26.07	44.89 (173)	59	84 (142)
Cajanus cajan	35.27	59.27 (168)	48	64 (133)
Sorghum vulgare	18.05	25.96 (144)	41	54 (132)
Pennisetum typhoides	16.29	22.42 (138)	42	53 (126)

Total biomass increased significantly in sludge plants (30%–73%) and the harvest index was also found to be higher (26%–45%) over the control. There is a lot of literature evidence to indicate VAM inoculation significantly increases the dry weight of different plants (Tanner and Clayton 1985; Sharma and Srivastava 1991).

Through the study 'Effects of Vesicular-arbuscular Mycorrhiza Colonization on Biomass Production of Economically Important Crop Plants Grown Directly over the Sludge', it can be concluded that application of industrial sludge is not harmful to plants and it was also found that the increased level of pH and EC did not affect VAM spore populations, spore germination, root colonization or mycorrhizal effectiveness. The study further supports the occurrence of mycorrhiza, VAM in particular, in disturbed environments.

Acknowledgements

The authors would like to thank the Principals of Sri Durga Ji Post Graduate College, Chandeshwar, Azamgarh and Shibli National Post Graduate College, Azamgarh, Uttar Pradesh, for their invaluable encouragement and extending the necessary facilities.

References

Azcon, R., El-Atrach, F., and Barea, J. M. 1988. Influence of mycorrhiza versus soluble phosphate on growth, nodulation and N_2 fixation (^{15}N) in alfalfa under different levels of water potential. *Biology and fertility of Soils* 7: 28–21

Daft, M. J. and Hacskaylo, E. 1976. Arbuscular mycorrhizas in the anthracite and bituminous coal wastes of Pennsylvania. *Journal of Applied Ecology* **13**: 523–531

Daft, M. J. and Nicolson, T. H. 1974. Arbuscular Mycorrhiza in plants colonizing coal wastes in Scotland. *New Phytologist* **73**: 1129–1138

Eivazi, F. and Weir, C.C. 1989. Phosphorus and mycorrhizal interaction on uptake of P and trace elements by maize. *Fertilizer Research* **21**: 19–22

El-Kherbawy, M., Angle, J. S., Heggo, A., and Chaney R. L. 1989. Soil pH, rhizobia and vesicular-arbuscular mycorrhizae inoculation effects on growth and heavy metal uptake of alfalfa (*Medicago sativa* L.) *Biology and Fertility of Soils* **8**: 61–65

Fabig, B. F., Veilhauer, K., Moawad, A. M., and Achtnich, W., 1989. Gas chromatographic separation of organic acids and electrophoretic determination of phosphates from VAM roots. *Z. pflanzenernaebr bodenk* **152**: 261–265

Fitler, A. H. 1985. Functioning of VAM's under field conditions. New Phytologist **99**: 257–265

Harrison, M. J. and Dixon, R. A. 1994. Spatial patterns of expression of flavonoid isoflavonoid pathway genes during interactions between roots of *Medicago truncatula* and the mycorrhizal fungus *Glomus versiforme*. *The Plant Journal* **6** (1): 9–20

Jagpal, R., Sharma, P. D., and Mukerji, K. G. 1988. Distribution of VAM fungi in relation to pollution. *Proceedings of the First Asian Conference on Mycorrhiza*, pp. 109–225. Chennai: University of Madras

Jayachandran, K., Kshwab, A. P., and Hetrick, B. A. D. 1989. Mycorrhizal mediation of phosphorus availability: synthetic iron chelate effects on phosphorus solubilization. *Soil Science Society of American Journal* **53**: 1701–1706

Jeffries, P. 1987. Use of mycorrhizae in agriculture. *Critical Review in Biotechnology* **5**: 319–357

Khan, A. G. 1981. Growth of endomycorrhizal onions in unsterilized coal waste. *The New Phytologist* **87**: 363–370

Knight, W. G., Allen, M. F., Jurinak, J. J., and Dudley, L. M. 1989. Elevated carbon dioxide and solution phosphorus in soil with vesicular-arbuscular mycorrhizal western wheat grass. *Soil Science Society of American Journal* **53**: 1075–1082

Nicolson, T. H. 1967. Vesicular-arbuscular mycorrhiza a universal plant symbiosis. *Science Progress Oxford* **55**: 561–581

Sharma, A. K. and Srivastava, P. C. 1991. Effect of vesicular-arbuscular mycorrhizae and zinc application on dry matter and zinc uptake of green gram (*Vigna radiata* L. Wilczek). *Biology and Fertility of Soils* **11**: 52–56

Tanner, C. C. and Clayton, J. S. 1985. Effect of vesicular-arbuscular mycorrhiza in growth and nutrition of a submerged aquatic plant. *Aquatic Botany* **22**: 377–386

Arbuscular Mycorrhizal Fungi- Mediated Phytoremediation of Heavy Metal-Contaminated Sites

Akshaya S.[1]

Owing to our increasing needs and demands, the past few decades have seen a dramatic acceleration in activities which have been contributing to biosphere pollution (Varma, Prasad, and Tuteja 2017). One of the needs of the hour being abatement of pollution, several measures with the aim of achieving this in a cost-effective, durable, and environment-friendly way have been adopted by communities across the globe. Bioremediation (one such measure) is a biotechnological method that uses biological processes or activities of organisms to transform contaminants into inert substances (Pandey, Larroche, and Soccol 2018; Kaur, Mavi, and Raghav 2019). This method is currently being used for the treatment of various wastes and the remediation of contaminated air, water, and soil, and has been found to be more efficient when compared to conventional physico-chemical methods (for example, soil flushing, soil leaching, electro-chemical methods, soil washing) which cause significant changes to the physical, chemical, and biological characteristics of the treated resource (Varma, Prasad, and Tuteja 2017; Jin, Luan, Ning, *et al.* 2018; Pandey, Larroche, and Soccol 2018). When plants are used for the ecological rehabilitation/reclamation of the contaminated site, the technique is termed as phytoremediation, an alternative *in-situ* phytorestorative (bioremediation) technology which exploits plants and their rhizosphere to remove the contaminants or lower (through accumulation) their bioavailability in soil and water (Muthukumar and Bagyaraj 2010; Atanagana, Khasa, Chang, *et al.* 2014; Dal Corso, Fasani, Manara, *et al.* 2019). Plants require various chemical elements for their life processes and have developed a number of adaptations for acquiring these elements under a wide range of environmental conditions (Dal Corso, Fasani, Manara, *et al.* 2019). Among these elements are heavy metals (HMs) which naturally occur in the Earth's crust. While HMs such as iron (Fe), zinc (Zn), copper (Cu), nickel (Ni), cobalt (Co), molybdenum (Mo) (micronutrients essential for plant biochemistry) become toxic to the plants only when in excess, others such as cadmium (Cd), mercury (Hg), silver (Ag), lead (Pb), chromium (Cr) cause toxicity even at low concentrations (Gaur and Adholeya 2004; Dal Corso, Fasani, Manara, *et al.* 2019). Geologic (processes) and anthropogenic activities (for example, use of agrochemicals and long-term application of urban sewage sludge, industrial waste disposal, waste incineration, vehicle exhausts) increase HM concentration to levels that are harmful to many living forms. Their transport in the form of leachates and gases and in particulate phases has led to their rapid accumulation in soil, water, and living systems (Gaur and Adholeya 2004; Ferrol, Tamayo, and Vargas 2016; Mishra, Singh, and Arora 2017). Uptake, translocation, sequestration, and detoxification are the key processes in plants for HM homeostasis (Shi, Zhang, Chen, *et al.* 2019; Dal Corso, Fasani, Manara, *et al.* 2019). Although plants possess several defence strategies to avoid or tolerate HM intoxication, that is, for HM homeostasis, these mechanisms do fail and jeopardize the plants when their threshold is crossed (Ferrol, Tamayo, and Vargas 2016; Mishra, Singh, and Arora 2017).

In-loco strategies/mechanisms employed by plants and their rhizosphere for soil reclamation (HM decontamination) include phytoextraction—accumulation of pollutants in harvestable biomass; phytovolatilization—conversion of pollutants to volatile form and their subsequent release to the atmosphere; phyto(rhizo) stabilization—limiting the mobility and bioavailability of pollutants in soil by plant roots (Joner and Leyval, 2003; Ali, Khan, and Sajad 2013; Dal Corso, Fasani, Manara, *et al.* 2019). In spite of many exemplary properties possessed by plants, often, physico-chemical properties of the waste or the contaminated site prevent plant establishment because of the absence of/limited nutrients and microbial activities. In cases such as these, the employment of microbial symbionts such as bacteria (for example, *Rhizobium*) and fungi (for example, AMF, mushrooms) is an alternative strategy for safe and efficient management of the contaminated site (Varma, Prasad, and Tuteja 2017). Mycorrhizae, one of the world's ancient symbioses that exist between plants and fungi, are important from the perspective of plant growth, nutrition, diversity, nutrient cycling and ecosystem functioning. Arbuscular mycorrhizal fungi (AMF) are important soil microorganisms, obligate biotrophs that establish mutualistic symbiotic associations with many plant species and are known to benefit plants under various environmental stress conditions (Varma, Prasad, and Tuteja 2017; Shah, Venkatramanan, and Prasad 2019). They improve the antioxidative status of the host plant and can trigger differential expression of genes involved in HM accumulation in both partners (Shi, Zhang, Chen, *et al.* 2019). Mycorrhizal fungi have been found to be inherently more capable in dealing with metals, when

[1] *Project Associate, Mycorrhiza Information and Resources, The Energy and Resources Institute*

compared to vascular plants, owing to their diversity in metal-contaminated soils (Coninx, Martinova, and Rineau 2017). *Funneliformis mosseae, Rhizophagus irregularis, Glomus intraradices, G. versiforme,* and *Scutellospora reticulate* are some examples of AMF that are capable of thriving in HM-contaminated soils (Alori and Fawole 2012; Lingua, Bona, Todeschini, *et al.* 2012; Ferrol, Tamayo, and Vargas 2016). They expand the interface between plants and soil through an extensive network of extraradical hyphae, thereby contributing to the plants' uptake of macronutrients as well as micronutrients (or HMs) beyond the depletion zone that develops around roots and thus provide a new pathway. Inside the roots, they develop arbuscules to facilitate nutrient exchange between the symbionts. AMF also improve the soil structure and act as filters, blocking xenobiotics within their mycelium. They have gained prominence all over the world in treating various kinds of HM-contaminated soils (Ferrol, Tamayo, and Vargas 2016; Varma, Prasad, and Tuteja 2017; Shah, Venkatramanan, and Prasad 2019). The use of mycorrhizal plants in phytoremediation of contaminated sites has been described as mycorrhizoremediation (Abdul 2006; Giasson, Jaouich, Cayer, *et al.* 2006; Channabasava, Lakshman, and Muthukumar 2015) and as mycorrhiza-assisted remediation (MAR) as well (Chibuike 2013). It has also been reported that combinations of AMF and plant growth-promoting rhizobacteria (PGPR) (for example, *Rhizobium*) and, AMF interaction with other soil fungi (for example, *Fusarium concolor, Trichoderma koningii),* earthworms, and so on facilitate the growth of plants and phytoremediation in metal-contaminated soils (Malekzadeh, Alikhani, Savaghebi-Firoozabadi, *et al.* 2011; Chibuike 2013).

The AMF provide an attractive system to advance plant-based environmental clean-up (Varma, Prasad, and Tuteja 2017). AMF-mediated phytoremediation takes place in two processes—phytostabilization (also known as phytoimmobilization) and phytoextraction (also known as phytoaccumulation, phytoabsorption or phytosequestration) (Ali, Khan, and Sajad 2013; Shah, Venkatramanan, and Prasad 2019). Their key elements are chelation and sequestration, which result in inactivation and removal of toxic HMs from sensitive sites, and metal transport systems, which control HM acquisition and efflux. Over the years, genome sequencing and transcriptomic analyses of various AMF have resulted in the identification of a number of genes encoding putative transport proteins (for example, CTR family of Cu transporters—RiCTR1 and RiCTR3, iron permease—RiFTR1) that mediate the uptake of HMs from polluted soils. AMF handle metal pollutants through phytostabilization—a mechanism in which HMs are immobilized/sequestered within the soil. AMF-mediated HM immobilization in the soil takes place as illustrated in Figure 1(B). The mechanisms include extracellular chelation by excreted ligands (such as glomalin, a glycoprotein produced by hyphae), biosorption of metals to the fungal cell wall, enhanced efflux via transporters located at the plasma membrane, reduced uptake via transporters located at the plasma membrane, intracellular chelation, subcellular compartmentation and vacuolar compartmentation. Since free HMs in the cytosol could represent a serious threat, the two symbionts have developed mechanisms to sequester and deliver them in bound forms (for example, chaperones, apo-metalloproteins, metallothioneins, organic acids). In the vacuoles, HMs are stabilized with polyP (polyphosphate) granules and some of these vacuoles are translocated to the fungal spores. Most of the metals taken up by the fungi are utilized for their own metabolism while the surplus metal is translocated to the aerial parts (Ferrol, Tamayo, and Vargas 2016; Coninx, Martinova, and Rineau 2017; Shah, Venkatramanan, and Prasad 2019). AMF also immobilize metal ions by adsorbing them through their cell wall components such as chitin and extracellular slime and function as biological barriers for HM entry into host plants (Ali, Khan, and Sajad 2013; Shi, Zhang, Chen, *et al.* 2019).

The AMF can colonize the roots extensively in metal-contaminated soils and it has been seen that mycorrhizal plants produce considerably more biomass and grow faster when compared to the non-mycorrhizal ones because, because of the enhanced phosphate, water and micronutrient uptake. Apart from this, the AMF hyphae also take up HMs and transport them to the plants. This second process by which HMs are extracted by the above ground plant tissues—with the aid of AMF—is known as phytoextraction (Figure 1(A)) (Abbaslou and Bakhtiari 2017; Shah, Venkatramanan, and Prasad 2019). It has been observed that effective phytoextraction of HM-contaminated soils could be achieved by employing hyperaccumulators (for example, *Brassica juncea*, *Helianthus annuus*, *Arundo donax*, *Eichhornia crassipes*), that is plants which show the ability to accumulate extraordinarily high amounts of metals and organic pollutants in aboveground tissues without suffering phytotoxic effects. Hyperaccumulators are also easy to cultivate and harvest, have a high-growth rate, produce more above-ground biomass, are widely distributed and have highly branched root system, show faster root-to-shoot translocation, are resistant to diseases and infestation by pests, and can repel herbivores to avoid food chain contamination (Rascio and Navari-Izzo 2011; Ali, Khan, and Sajad 2013; Atanagana, Khasa, Chang, *et al.* 2014; Shah, Venkatramanan, and Prasad 2019; Dal Corso, Fasani, Manara, *et al.* 2019). For achieving the desired reduction in soil HM concentration, it is necessary to select and cultivate hyperaccumulators for several cycles (including harvest and removal of the HM-enriched biomass). Indigenous plant species are preferred because of their adaptations to the native environmental conditions and reduced need for management (Shah, Venkatramanan, and Prasad 2019). Proper integration of hyperaccumulating plants and AM fungi could be a key solution to the issue of HM pollution (Miransari 2011). The mycorrhizal pathway of phytoextraction of HM involves acquisition by high-affinity metal transporters located in the extraradical mycelium, followed by metal translocation along the hyphae to intracellular structures, and then transfer to the root at the symbiotic interface. Once the HMs reach the intraradical mycelium, release from the fungus in the apoplast of the symbiotic interface is facilitated by ion-specific carriers, pumps or channels. Metals released by the fungus at the interface are then taken up by the specific plant.

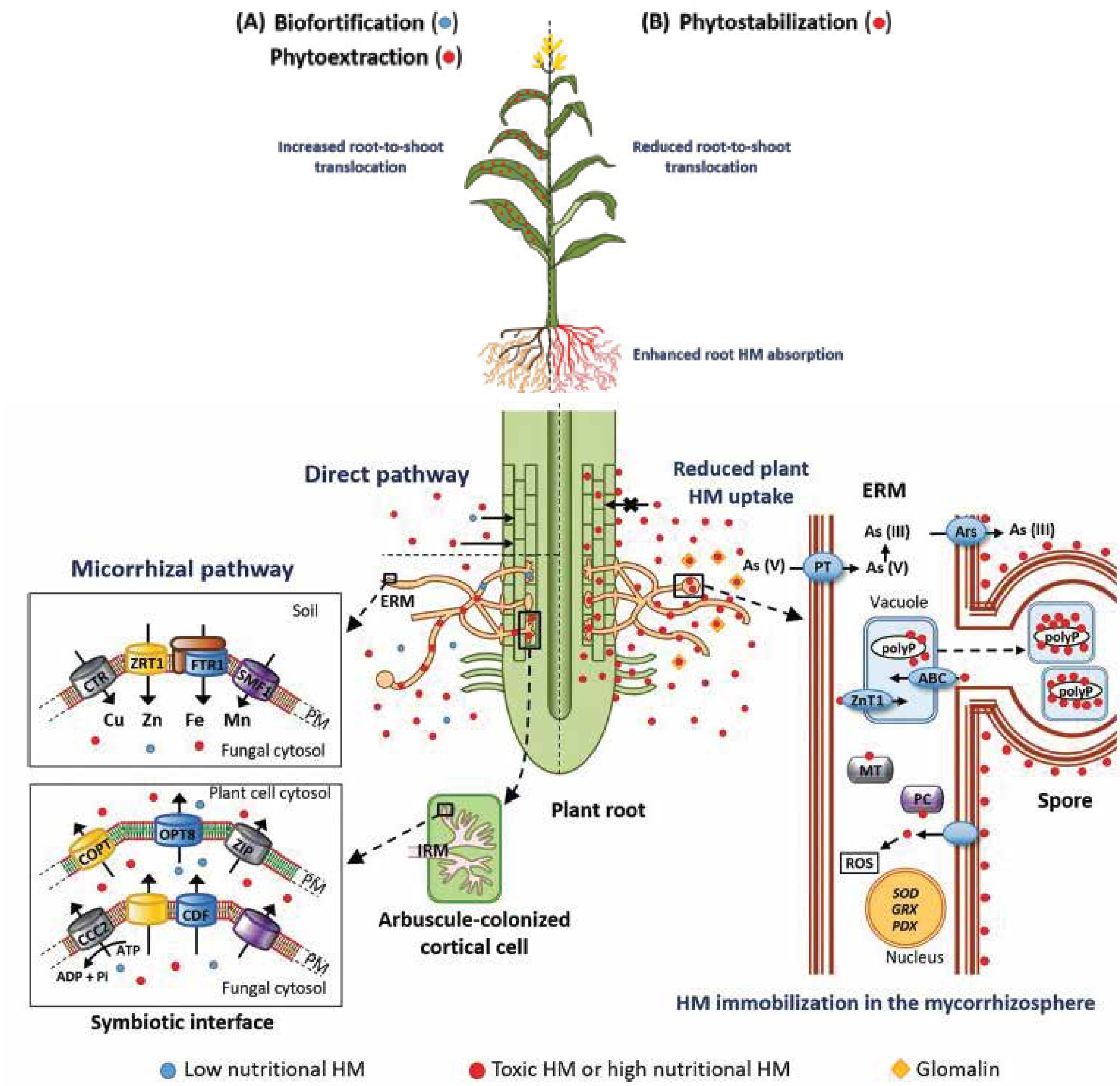


Figure 1 AMF-mediated HM uptake

A: Phytoextraction CTR (fungal Cu transporter), CCC2 (Cu-ATPase), CDF (cation diffusion facilitator), COPT (plant Cu transporter), FTR1 (Fe permesase), OPT (oligopeptide transporter), SMF1 (Mn transporter). ZRT1 (Zn transporter), ZIP (Zn–Fe permease);
B: Phytostabilization ABC (ABC transporter), Ars (arsenite pump), GRX (glutaredoxin), MT (metallothionein), PC (phytochelatin), PDX (pyridoxine synthase), PT (P transporter), ROS (reactive oxygen species), SOD (superoxide dismutase), ZnT1 (Zn transporter)

Source Ferrol, Tamayo, and Vargas (2016)

Transporters expressed in the periarbuscular membrane (Ferrol, Tamayo, and Vargas 2016). Sequestration sites in plant cells mainly include cell walls, vacuoles, and the Golgi apparatus. HM ions are known to bind to the functional groups of cell wall components (cellulose, hemicellulose, lignin, pectin). Some plants have been found to even enhance their lignin biosynthesis in response to HM exposure (Shi, Zhang, Chen, *et al.* 2019). It has also been shown that the use of chelating agents such as ethylenediaminetetraacetic acid (EDTA) and ethylenediamine dissuccinate (EDDS) as soil amends, in combination with AMF, enhances the bioavailability of HMs, hence, improving the phytoextraction process (Wang, Pan, Shah, *et al.* 2018; Shah, Venkatramanan, and Prasad 2019). Mycorrhizal fungi also enhance HM accumulation in host plants by enhancing their defence systems and by inducing transcriptional overexpression of host genes involved in HM transport, detoxification, and sequestration (Shi, Zhang, Chen, *et al.* 2019).

Selection of the appropriate mycorrhizal fungi can enhance the accumulation of HMs in host plants and increase the efficiency of phytoremediation, however, some mycorrhizal fungi do lead to less HM accumulation (Shi, Zhang, Chen, *et al.* 2019). Hence, the outcome of the symbiosis established with metallophytes depends on the fungal isolate as well as the plant species and some other factors (biotic factors like mutation, interaction and abiotic factors like nutrients, temperature, pH) (Ferrol, Tamayo, and Vargas 2016; Abatenh, Gizaw, Tsegaye, *et al* 2017; Shi, Zhang, Chen, *et al.* 2019). To be able to exert a beneficial effect on the process, the mycorrhizal fungi must first be able to establish the symbiosis and therefore, the ability of the fungi to survive in the metal-contaminated area is an important prerequisite for its use (Coninx, Martinova, and Rineau 2017). An important aspect to be considered during phytoremediation is the disposal of the contaminated biomass. Appropriate storage or disposal of the hazardous biomass is absolutely essential to ensure that it does not pose any risk to the environment. Main constituents of the biomass (such as lignin, hemicellulose, cellulose, mineral matter) vary with the species involved. Post-phytoremediation harvest management techniques include composting and compaction, combustion and gasification, phytomining and pyrolysis. Among these, phytomining (defined as the natural uptake and pre-concentration of bioavailable metal species from the environment into the plant biomass) has been found to be a less expensive and environment-friendly method for recovery of dispersed metals from soils (Mohanty 2016). While advantages of MAR are simplicity, cost effectiveness, and safety (in terms of topsoil protection, secondary pollution, waste generation), the major disadvantage is that it is a relatively slow process (Chibuike 2013; Jin, Luan, Ning, *et al.* 2018). Although, the importance of AMF in improving plant nutrition and in alleviating HM toxicity has been well established, many questions regarding various mechanisms of HM homeostasis in AM still remain unanswered. Understanding them would be extremely useful in enhancing the efficiency of MAR. Apart from this compatibility between various AM fungal isolates and plant varieties and their possible use for the remediation of HMs still needs exploration. More efforts are required towards accomplishment of tasks like planting, maintenance of the remediation site, and fruitful conversion of the harvested biomass, for completely harnessing the benefits of this method of soil remediation (Chibuike 2013; Zadehbagheri, Azarpanah, and Javanmardi 2014; Dal Corso, Fasani, Manara, *et al*. 2019).

References

Abatenh, E., Gizaw, B., Tsegaye, Z., and Wassie, M. 2017. Application of microorganisms in bioremediation: a review. *Journal of Environmental Microbiology* **1** (1): 2–9

Abbaslou, H. and Bakhtiari, S. 2017. Phytoremediation potential of heavy metals by two native pasture plants (*Eucalyptus grandis* and *Ailanthus altissima*) assisted with AMF and fibrous minerals in contaminated mining regions. *Pollution* **3** (3): 471–486

Abdul, K. G. 2006. Mycorrhizoremediation – an enhanced form of phytoremediation. *Journal of Zhejiang University* **7** (7): 503–514

Ali, H., Khan, E., and Sajad, M. A. 2013. Phytoremediation of heavy metals: concepts and applications. *Chemosphere* **91**: 869–881

Alori, E. and Fawole, O. 2012. Phytoremediation of soils contaminated with aluminium and manganese by two arbuscular mycorrhizal fungi. *Journal of Agricultural Science* **4** (8)

Atanagana, A., Khasa, D., Chang, S., and Degrande, A. 2014. *Tropical Agroforestry*, pp. 343–352. Springer

Channabasava, A., Lakshman, H. C., and Muthukumar, T. 2015. Fly ash mycorrhizoremediation through *Paspalum scrobiculatum* L., inoculated with *Rhizophagus irregularis*. *Comptes Rendus Biologies* **338**: 29–39

Chibuike, G. U. 2013. Use of mycorrhiza in soil remediation: a review. *Scientific Research and Essays* **8** (35): 1679–1687

Coninx, L., Martinova, V., and Rineau, F. 2017. Chapter Four: Mycorrhiza-assisted Phytoremediation. *Advances in Botanical Research* **83**: 127–188

Dal Corso, G., Fasani, E., Manara, A., Visioli, G., and

Furini, A. 2019. Heavy metal pollutions: state of the art and innovation in phytoremediation. *International Journal of Molecular Sciences* **20** (3412)

Ferrol, N., Tamayo, E., and Vargas, P. 2016. The heavy metal paradox in arbuscular mycorrhizas: from mechanisms to biotechnological applications. *Journal of Experimental Botany* **67** (220): 6253–6265

Gaur, A. and Adholeya, A. 2004. Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. *Current Science* **86** (4): 528–534

Giasson, P., Jaouich, A., Cayer, P., Gagné, S., Moutoglis, P., and Massicotte, L. 2006. Enhanced phytoremediation: a study of mycorrhizoremediation of heavy metal-contaminated soil. *Remediation Journal* **17** (1)

Jin, Y., Luan, Y., Ning, Y., and Wang, L. 2018. Effects and mechanisms of microbial remediation of heavy metals in soil: a critical review. *Applied Sciences* **8** (1336)

Joner, E. J. and Leyval, C. 2003. Phytoremediation of organic pollutants using mycorrhizal plants: a new aspect of rhizosphere interactions. *Agronomie* **23**: 495–502

Kaur, R., Mavi, G. K., and Raghav, S. 2019. Bioremediation of sludge using *Pseuomonas aeruginosa*. *International Journal of Current Microbiology and Applied Sciences* **8** (4): 69–79

Lingua, G., Bona, E., Todeschini, V., Cattaneo, C., Marsano, F., Berta, G., and Cavaletto, M. 2012. Effects of heavy metals and arbuscular mycorrhiza on the leaf proteome of a selected poplar clone: a time course analysis. *PLoS ONE* 7 (6): e38662

Malekzadeh, E., Alikhani, H. A., Savaghebi-Firoozabadi, G. R., and Zarei, M. 2011. Influence of arbuscular mycorrhizal fungi and an improving growth bacterium on Cd uptake and maize growth in Cd-polluted soils. *Spanish Journal of Agricultural Research* **9** (4): 1213–1223

Miransari, M. 2011. Hyperaccumulators, arbuscular mycorrhizal fungi and stress of heavy metals. *Biotechnology Advances* **29** (6): 645–653

Mishra, J., Singh, R., and Arora, N. K. 2017. Alleviation of heavy metal stress in plants and remediation of soil by rhizosphere microorganisms. *Frontiers in Microbiology* **8** (1706)

Mohanty, M. 2016. Post-harvest management of phytoremediation technology. *Journal of Environmental & Analytical Toxicology* **6** (5)

Muthukumar, T. and Bagyaraj, D. J. 2010. Use of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils. *Proceedings of the National Academy of Sciences, India – Section B: Biological Sciences* **80**: 103–121

Pandey, A., Larroche, C., and Soccol, C. R. (eds). 2018. *Current Developments in Biotechnology and Bioengineering: current advances in solid-state fermentation,* pp. 285–318. Elsevier

Rascio, N. and Navari-Izzo, F. 2011. Heavy metal hyperaccumulating plants: how and why do they do it? And what makes them so interesting? *Plant Science* **180** (2): 169–181

Shah, S., Venkatramanan, V., and Prasad, R. (eds). 2019. *Sustainable Green Technologies for Environmental Management,* pp. 67–85. Springer

Shi, W., Zhang, Y., Chen, S., Polle, A., Rennenberg, H., and Luo, Z. B. 2019. Physiological and molecular mechanisms of heavy metal accumulation in nonmycorrhizal versus mycorrhizal plants. *Plant Cell & Environment* **42** (4): 1087–1103

Varma, A., Prasad, R., and Tuteja, N. (eds). 2017. *Mycorrhiza – Nutrient Uptake, Biocontrol, Ecorestoration*, fourth edition, pp. 271–286. Cham: Springer

Wang, S., Pan, S., Shah, G. M., Zhang, Z., Yang, L., and Yang, S. 2018. Enhancement in arsenic remediation by maize (*Zea mays* L.) using EDTA in combination with arbuscular mycorrhizal fungi. *Applied Ecology and Environmental Research* **16** (5): 5987–5999

Zadehbagheri, M., Azarpanah, A., and Javanmardi, S. 2014. Perspective of arbuscular mycorrhizal fungi phytoremediation on contamination and remediation of heavy metal soil in sustainable Agriculture. *American-Eurasian Journal of Agriculture and Environment* **14** (4): 379–386

NEWS HIGHLIGHTS

Controlling mycorrhizal colonization

According to a study published in *Theoretical and Applied Genetics*, certain genes control the chemical signals and pathways that call the specific mycorrhizal fungi towards the roots. They allow the plant to recognize the specific fungus as a 'good guy', and help build arbuscules. Such information could be crucial in developing cultivars with a higher affinity for the fungus, reduce the overuse of fertilizers and pesticides, and so on.[1]

From the thawing permafrost

A study, that could have implications for researchers and computer models that predict nitrogen pathways at both regional and global levels, has been conducted by a team of scientists from the Center for Ecoss at NAU. Ericoid mycorrhizal and ectomycorrhizal were found to be involved in their respective plant partner's nitrogen uptake (from the permafrost).[2]

Fossil fungi

A new research that backs up previous findings of the symbiotic relationship between fungi and the first plants has been brought to light. The discovery of the new fungus would aid in filling the gaps in fossil records and completing the timeline for the emergence of terrestrial multicellular life.[3]

An alarming loss

Disappearance of *Theocostele alata* from its ecosystem in Bangladesh (Chittagong region) along with 31 other native orchids has left researchers worried about their future. Experts say that if orchid habitat is destroyed, we could potentially also see the extinction of the unique resident fungi. And the truth is that not much is known about these fungi as some of them have never been described at the species level.[4]

Mitti ke doctor

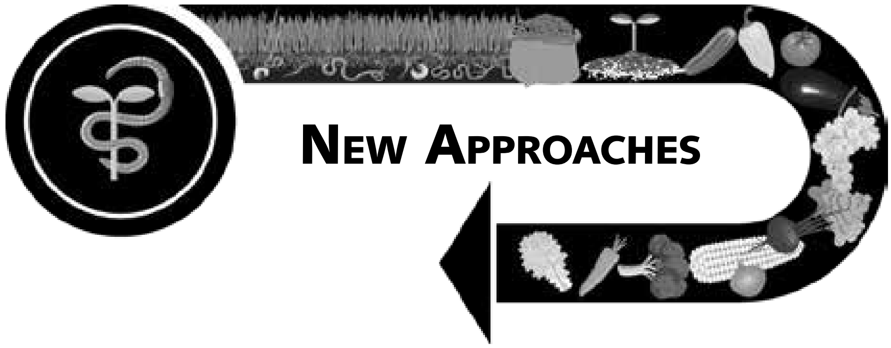
The Soil Health Cards (SHC) programme, implemented in 2015, assesses soil fertility in terms of availability of key nutrients and physical parameters. The receptivity of farmers to the programme has led to the emergence of soil health specialists who encourage the farmers to switch to balanced fertilizer (for example, bio-fertilizers and pesticide application for sustainable agriculture without compromising productivity.[5]

Recognition and accommodation of beneficial organisms

A study published in *Nature Plants* describes the discovery of a common genetic basis for all the symbioses observed in nature. It was discovered that three genes are shared exclusively by the plants that form intracellular symbiosis and lost in plants unable to form this type of beneficial relationship.[6]

[1] Details available at https://phys.org
[2] Details available at www.sciencedaily.com
[3] Details available at www.sciencealert.com

[4] Details available at https://blogs.scientificamerican.*com*
[5] Details available at https://indianexpress.com
[6] Details available at www.sciencedaily.com



New Approaches and Techniques

Digitizing Microscopic Observations of Arbuscular Mycorrhizal Fungal Colonization

Since the mid-twentieth century, a number of methods have been proposed to assess the presence of mycorrhizal fungal structures and the level of mycorrhizal colonization in plants' root cortexes. When tracking the temporal development of colonization, researchers are forced to choose and adapt a particular method, which often reduces or makes harder the possibility of comparing it with similar studies. The harmonization of methodologies for the assessment of radicular endophytic colonization is a current necessity as the functionality of mycorrhizal symbionts for plants can be described only by indicators obtained based on microscopic analysis. The MycoPatt model is an objective system that has been proposed for assessing mycorrhization. The model takes into account the linear segmentation of root samples where each root fragment that is considered for microscopic evaluation corresponds to a number of 15 microscopic fields at 400×. Each structure is encoded in a data collection table in a 10×10 matrix and, the evaluation and coding can be done directly at the microscope (by applying the eyepiece micrometer grid) or by applying 10×10 grids to the images captured. The penetration of hyphae into intracellular spaces as well as occurrence of arbuscules, vesicles, intraradical spores, and auxiliary cells can be observed. The model could also be adapted for thicker roots and used without any changes, at different microscopic magnification. Collected data is transferred to an Excel data table which automatically converts each microscopic field into a coloured mycorrhizal map (for each 1 cm fragment) and this is assembled into a complex model that follows the pattern of mycorrhizal development throughout the root system (Figure 1). It is also possible to correlate the obtained data with root architecture and plant dependence to mycorrhiza. The background formulae are adaptable and the coding can be changed with minimal effort, depending on the user's needs. The coloured map developed for arbuscular mycorrhizal (AM) aids in microscopic evaluation. This could also be adapted for dark septate or fine root endophytes. The main advantage of MycoPatt is that it tracks the establishment and development of symbiosis with AM fungi along the root length, highlighting the entry areas in the cortex and branches. MycoPatt evaluates the expansion of AM in detail where each indicator is calculated separately (horizontally and vertically) for each microscopic field and in this way, the objectively made final data report presents the actual level of structural extension in the roots. Another result is the achievement of a clear separation between mycorrhized and non-mycorrhized areas. Up to date, it is the only method that allows the evaluation of all AM structures at once and, their exact position in plant roots. The efficiency of the model is attributed to increased resolution of observation, speed of analysis, and fidelity of produced data. Examples of fields where the model could be used include bioproduct production, agronomy, plant breeding, phytosociology research, and so on.

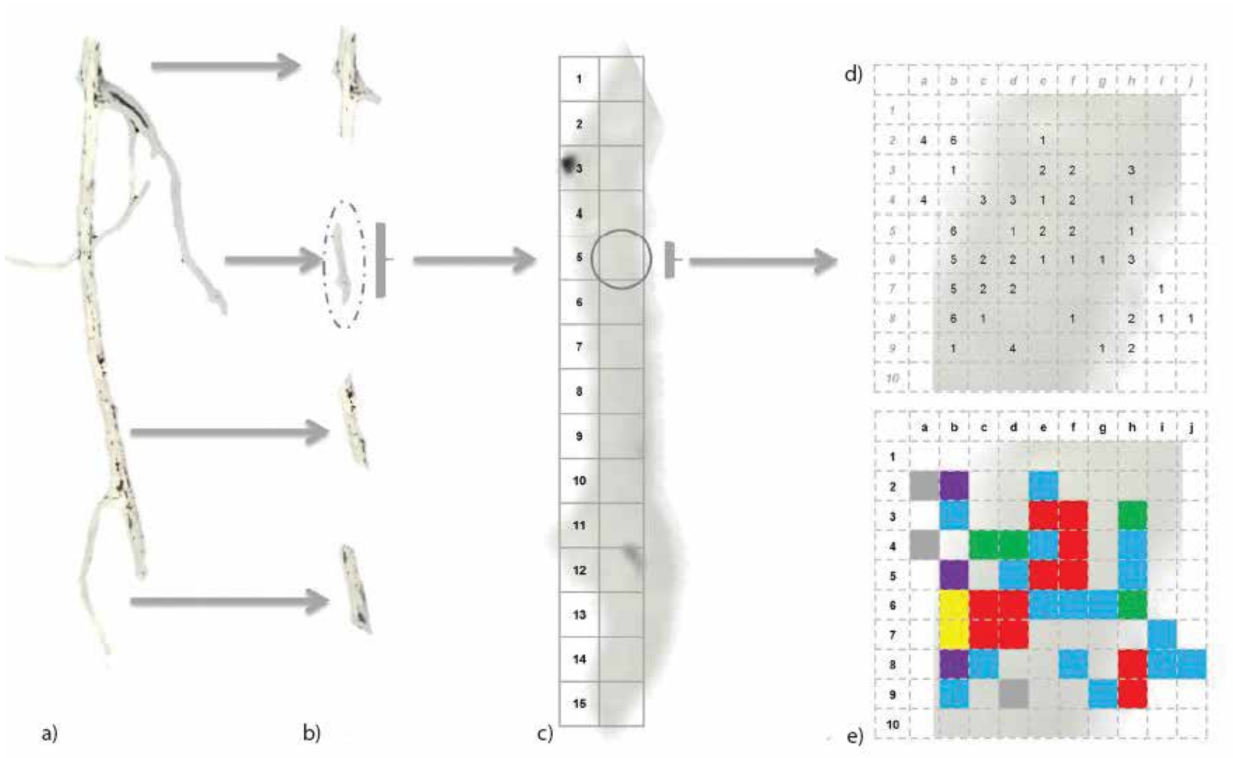


Figure 1 Schematic framework of MycoPatt model: **(a)** Root system; **(b)** Selection of 1 cm segments; **(c)** Segment analysis flow: 15 microscopic fields/segment; **(d) MycoPatt** grid overlay on each microscopic field with the assignment of values for mycorrhizal structures: (1) hyphae, (2) arbuscules, (3) vesicles, (4) spores, (5) auxiliary cells, (6) entry points; **(e)** Conversion of values into colours for development of mycorrhizal map: (1) blue, (2) red, (3) green, (4) gray, (5) yellow, (6) purple

Harmonization of mycorrhiza studies based on MycoPatt methodology could lead to the creation of a unitary system of data collection and therefore increase the flexibility of research and applications. Numeric expression of colonization patterns along with the creation of new sets of indicators (adapted for a realistic description of symbiotic mechanisms) could open a new stage in mycorrhizology. Evolution of this methodology could lead to digitization of AM systems which might also allow the creation of databases that supplement the existing ones (Stoian, Vidican, Crişan, *et al.* 2019).

Reference

Stoian, V., Vidican, R., Crişan, I., Puia, C., Şandor, M., Stoian, V. A., Păcurar, F., and Vaids, I. 2019. Sensitive Approach and Future Perspectives in Microscopic Patterns of Mycorrhizal Roots. *Scientific Reports* **9**: 10233

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:

- *Agroforestry Systems*
- *Agronomy*
- *Annals of Botany*
- *Botanical Studies*
- *Environmental Microbiology*
- *Frontiers in Microbiology*
- *Frontiers in Plant Science*
- *Fungal Biology*
- *Fungal Ecology*
- *Genes*
- *Journal of Soils and Sediments*
- *Mycorrhiza*
- *Mycoscience*
- *New Phytologist*
- *Oecologia*
- *Plant and Soil*
- *Plants*
- *Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences*
- *Science of the Total Environment*
- *Scientific Reports*
- *Soil and Tillage Research*
- *Sustainability*
- *Symbiosis*

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)
Banasiak, J.*, Borghi, L., Stec, N., Martinoia, E., and Jasiński, M. 2020	**The full-size ABCG transporter of *Medicago truncatula* is involved in strigolactone secretion, affecting arbuscular mycorrhiza** *Frontiers in Plant Science* **11** (18) [*Department of Plant Molecular Physiology, Institute of Bioorganic Chemistry, Polish Academy of Sciences, Poznan, Poland]
Buta, M.*, Blaga, G., Paulette, L., Păcurar, I., Rosca S., Borsai O., Grecu F., Sînziana, P. E., and Negrușier, C. 2019	**Soil reclamation of abandoned mine lands by revegetation in northwestern part of Transylvania: a 40-year retrospective study** *Sustainability* **11** (12): 3393 [*Department of Soil Sciences, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Calea Mănăstur 3–5, 400372 Cluj-Napoca, Romania]
Cottet, A. C.* and Messuti, M. I. 2019	**New evidence about the interactions between liverworts in the genus *Symphyogyna* (Pallavicinizaceae) and arbuscular mycorrhizal fungi** *Symbiosis* **79**: 117–121 [*Instituto de Investigaciones en Biodiversidad y Medioambiente (INIBIOMA); Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Universidad Nacional del Comahue (UNComahue), Quintral 1250, CP 8400, San Carlos de Bariloche, Río Negro, Argentina]
Crisan, I.*, Vidican, R., Olar, L., Stoian, V., Morea, A. and Ștefan, R. 2019	**Screening for changes on *Iris germanica* L. rhizomes following inoculation with arbuscular mycorrhiza using Fourier transform-infrared spectroscopy** *Agronomy* **9** (12): 815 5 [*Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine, Manastur Street No. 3–5, 400372 Cluj-Napoca, Romania]
Deja-Sikora, E.*, Kowalczyk, A., Trejgell, A., Szmidt-Jaworska, A., Baum, C., Mercy, L., and Hrynkiewicz, K. 2020	**Arbuscular mycorrhiza changes the impact of potato virus Y on growth and stress tolerance of *Solanum tuberosum* L. *in vitro*** *Frontiers in Microbiology* **10** (2971) [*Department of Microbiology, Faculty of Biological and Veterinary Sciences, Nicolaus Copernicus University, Toruń, Poland]

Contd…

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)
Golubkina, N. *, Krivenkov, L., Sekara, A., Vasileva, V., Tallarita, A., and Caruso, G. 2020	**Prospects of arbuscular mycorrhizal fungi utilization in production of *Allium* plants** *Plants (Basel, Switzerland)* **9** (2) [*Federal Scientific Center of Vegetable Production, Selectsionnaya 14 VNIISSOK, 143072 Moscow, Odintsovo, Russia]
Gu, S.*, Wu, S., Guan, Y., Zhai, C., Zhang, Z., Bello, A., Guo, X., and Yang, W. 2020	**Arbuscular mycorrhizal fungal community was affected by tillage practices rather than residue management in black soil of northeast China** *Soil and Tillage Research* **198** (10452) [*College of Resources and Environment, Northeast Agricultural University, Harbin, China]
Lee, S. J.*, Morse, D., and Hijri, M. 2019	**Holobiont chronobiology: mycorrhiza may be a key to linking aboveground and underground rhythms** *Mycorrhiza* **29** (5): 403–412 [*Present address: Department of Ecology and Evolution, University of Lausanne, 1015, Lausanne, Switzerland]
Leonardi, P.*, Murat, C., Puliga, F., Lotti, M., and Zambonelli, A. 2020	**Ascoma genotyping and mating type analyses of mycorrhizas and soil mycelia of *Tuber borchii* in a truffle orchard established by mycelial inoculated plants** *Environmental Microbiology* **22** (3): 964–975 [*Department of Agricultural and Food Sciences, University of Bologna, Viale Fanin 44, 40127, Bologna, Italy]
Li, X.*, Han, S., Luo, X., Chen, W., and Huang, Q. 2020	**Arbuscular mycorrhizal-like fungi and glomalin-related soil protein drive the distributions of carbon and nitrogen in a large scale** *Journal of Soils and Sediments* **20**: 963–972 [*State Key Laboratory of Agricultural Microbiology, Huazhong Agricultural University, Wuhan, 430010, China]
Li, Y. Y.*, Guo, S. X., and Lee, Y. I. 2020	**Ultrastructural changes during the symbiotic seed germination of *Gastrodia elata* with fungi, with emphasis on the fungal colonization region** *Botanical studies* **61**: 4 [*College of Plant Protection/Beijing Key Laboratory of Seed Disease Testing and Control, China Agricultural University, Beijing, 100193, China]
Miyamoto, Y.*, Maximov, T. C., Sugimoto, A., and Nara, K. 2019	**Discovery of *Rhizopogon* associated with *Larix* from northeastern Siberia: insights into host shift of ectomycorrhizal fungi** *Mycoscience* **60** (5): 274–280 [*Arctic Research Center, Hokkaido University, Kita 21 Nishi 11, Kita-ku, Sapporo, Hokkaido 011-0021, Japan]
Mujic, A. B.*, Huang, B., Chen, M. J., Wang, P. H., Gernandt, D. S., Hosaka, K., and Spatafora, J. W. 2019	**Out of western North America: evolution of the *Rhizopogon-Pseudostuga* symbiosis inferred by genome-scale sequence typing** *Fungal Ecology* **39**: 12–25 [*Department of Botany and Plant Pathology, Oregon State University, Corvallis, OR, USA]

Contd...

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)
Murphy, C. L.*, Youssef, N. H., Hartson, S., and Elshahed, M. 2020	**The extraradical proteins of *Rhizophagus irregularis*: a shotgun proteomics approach** *Fungal Biology* **124** (2): 91–101 [*Department of Microbiology and Molecular Genetics, Oklahoma State University, Stillwater, OK, USA]
Pickles, B. J.*, Truong, C., Watts-Williams, S. J., and Bueno, C. G. 2020	**Mycorrhizas for a sustainable world** *New Phytologist* **225** (3): 1065–1069 [*School of Biological Sciences, University of Reading, Whiteknights, Harborne Building, Reading, RG6 6AS, UK]
Plouznikoff, K.*, Asins, M. J., Dupré de Boulois, H., Carbonell, E. A., and Declerrck, S. 2019	**Genetic analysis of tomato root colonization by arbuscular mycorrhizal fungi** *Annals of Botany* **124** (6): 933–946 [*Université catholique de Louvain, Earth and Life Institute, Mycology, Louvain-la-Neuve, Belgium]
Quezada, E. H.*, García, G. X., Arthikala, M. K., Melappa, G., Lara, M., and Nanjareddy, K. 2019	**Cysteine-rich receptor-like kinase gene family identification in the *Phaseolus* genome and comparative analysis of their expression profiles specific to mycorrhizal and rhizobial symbiosis** *Genes* **10**: 59 [*Ciencias Agrogenómicas, Escuela Nacional de Estudios Superiores Unidad León—Universidad Nacional Autónoma de México (UNAM), C.P. 37684 León, Mexico]
Salto, C. S.*, Sagadin, M. B., Luna, C. M., Oberschelp, G. P. J., Harrand, L., and Cabello, M. N. 2020	**Interactions between mineral fertilization and arbuscular mycorrhizal fungi improve nursery growth and drought tolerance of *Prosopis alba* seedlings** *Agroforestry Systems* **94**: 103–111 [*Estación Experimental Agropecuaria Concordia, Instituto Nacional de Tecnología Agropecuaria (INTA), Casilla de Correo 34, CP 3200, Concordia, Entre Ríos, Argentina]
Seb, J.* and Ajungla, T. 2019	**Influence of soil moisture on ectomycorrhizal formation of *Prunus cerasoides* BUCH.-HAM. EX D. DON** *Research Journal of Life Sciences, Bioinformatics, Pharmaceutical and Chemical Sciences* **5** (1): 75–80 [*Department of Botany, Nagaland University, Lumami, Nagaland, India]
Song, Z.*, Bi, Y., Zhang, J., Gong, Y., and Yang, H. 2020	**Arbuscular mycorrhizal fungi promote the growth of plants in the mining associated clay** *Scientific Reports* **10**: 2663 [*State Key Laboratory of Coal Resources and Safe Mining, College of Geoscience and Surveying Engineering, China University of Mining and Technology (Beijing), Beijing, 100083, China]

Contd…

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)
Thomas, P.* and Büntgen, U. 2019	**A risk assessment of Europe's black truffle sector under predicted climate change** *Science of the Total Environment* **655**: 27–34 [*University of Stirling, Stirling FK9 4LA, UK]
Tran, B. T. T.*, Cavagnaro, T. R., and Watts-Williams, S. J. 2019	**Arbuscular mycorrhizal fungal inoculation and soil zinc fertilization affect the productivity and the bioavailabilty of zinc and iron in durum wheat** *Mycorrhiza* **29**: 445–457 [*The School of Agriculture, Food and Wine, and the Waite Research Institute, The University of Adelaide, Waite Campus, PMB1, Glen Osmond, SA, 5064, Australia]
Vieira, L. C.*, Alves da Silva, D. K., Escobar, I. E. C, Maria da Silva, J., Andrêssa de Moura, I., Oehl, F., and Alves da Silva, G. 2020	**Changes in an arbuscular mycorrhizal fungi community along an environmental gradient** *Plants* **9** (1): 52 [*Programa de Pós-Graduação em Biologia de Fungos, Departamento de Micologia, Universidade Federal de Pernambuco. Avenida da Engenharia, s/n, Recife 50740-600, PE, Brazil]
Wang, Y. L.*, Gao, C., Chen, L., Ji, N. N., Wu, B. W., Lü, P. P., Li, X. C., Qian, X., Maitra, P, Babalola, B. J, Zheng, Y., and Guo, L. D. 2020	**Community assembly of endophytic fungi in ectomycorrhizae of betulaceae plants at a regional scale** *Frontiers in Microbiology* **10**: 3105 [*State Key Laboratory of Mycology, Institute of Microbiology, Chinese Academy of Sciences, Beijing, China]
Wulantuya*, Masaka, K., Bayandala, Fukasawa Y., Matsukura, K., and Seiwa, K. 2020	**Gap creation alters the mode of conspecific distance-dependent seedling establishment via changes in the relative influence of pathogens and mycorrhizae** *Oecologia* **192**(2): 449–462 [*Graduate School of Agricultural Science, Tohoku University, Naruko-onsen, Osaki, Miyagi, 989-6711, Japan]
Xie, W.*, Hao, Z., Yu, M., Wu, Z., Zhao, A., Li, J., Zhang, X., and Chen, B. 2019	**Improved phosphorus nutrition by arbuscular mycorrhizal symbiosis as a key factor facilitating glycyrrhizin and liquirtin accumulation in *Glycyrrhiza uralensis*** *Plant and Soil* **439**: 243–257 [*State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, 18 Shuangqinglu, Haidian District, Beijing, 100085, China]
Zhang, Y.*, Li, Y. Y., Chen, X. M., Guo, S. X., and Lee, Y. I. 2020	**Effect of different mycobionts on symbiotic germination and seedling growth of *Dendrobium officinale*, an important medicinal orchid** *Botanical Studies* **61** (1): 2 [*Institute of Medicinal Plant Development, Chinese Academy of Medical Sciences and Peking Union Medical College, Beijing, 100193, China]

MYCORRHIZA NEWS

The Quarterly Newsletter of Mycorrhiza network

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

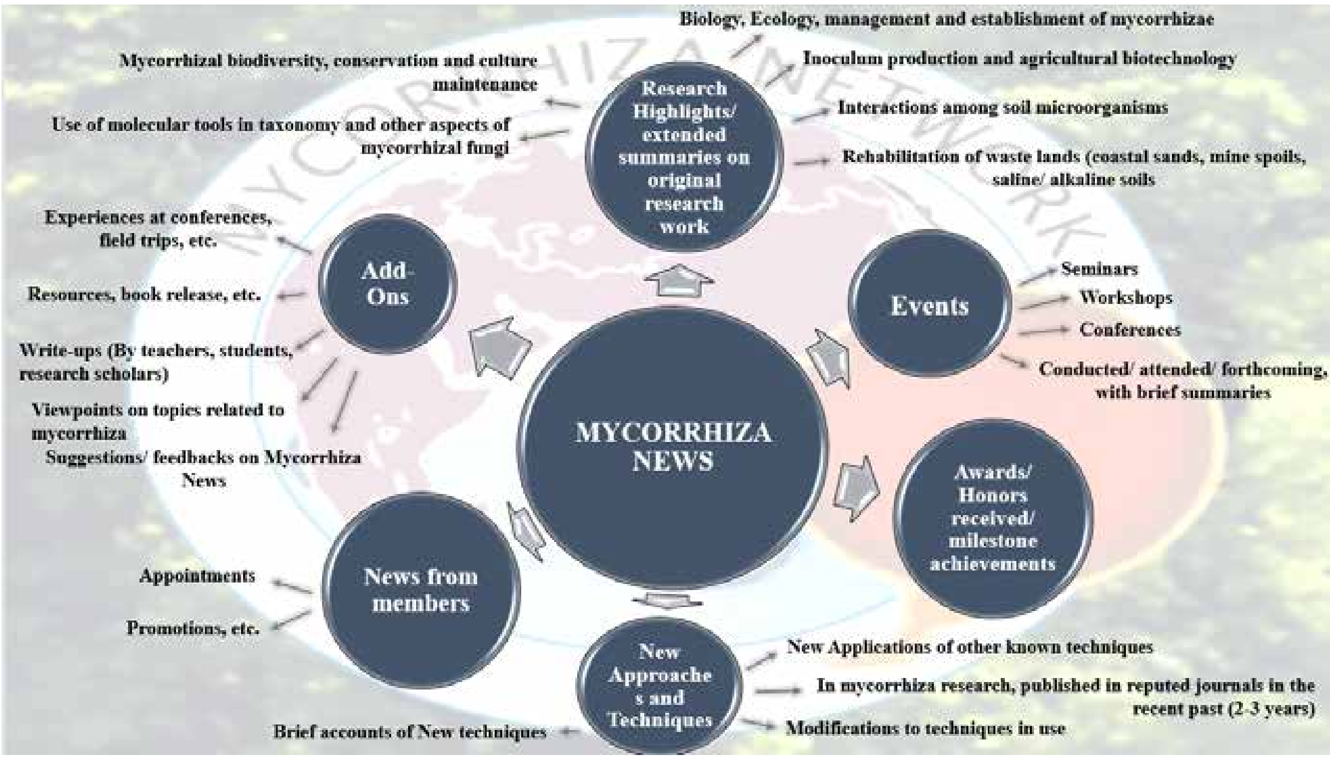
Send your order along with payment directly to us by demand draft or cheque in favour of **TERI**, payable at New Delhi. Outstation cheques are not accepted. OR purchase through onlinebookstore at *<http://bookstore.teri.res.in>*.

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

Contributors have always been an invaluable asset to *Mycorrhiza News*. It is their efforts which make it an interesting and authentic read. Contribution to the periodical can be made through the following channels



E-mail: c_akshaya.s@teri.res.in

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

Published by Dr Ajay Mathur on behalf of The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003.