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SHORT NOTE

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Effect of forest fire on number, viability and post-fire re-establishment of arbuscular mycorrhizae

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Abstract Forest fire can affect arbuscular mycorrhizal (AM) fungi by changing the soil conditions and by directly altering AM proliferation. We studied the effects of a severe forest fire at Margalla Hills near Islamabad on the number and viability of AM fungal propagules in the burnt soil and their role in the re-establishment of post-fire infection in colonized plants. Compared with a nearby control area, the burnt site had a similar number of total spores but a lower number of viable AM fungal propagules. The roots of the two most frequent species at the burnt site, *Dodonaea viscosa* and *Aristida adscensionis*, showed a gradual increase in percentage root length colonized by AM fungi in general and hyphal infection in particular. Our results indicate resumption of mycorrhizal activity following the fire, probably from AM hyphae in the roots of these dominant shrubs.

Key words Arbuscular mycorrhiza · Forest fire · Revegetation · MPN

Introduction

The importance of mycorrhiza, especially arbuscular mycorrhiza (AM) caused by Glomalean fungi, in the rehabilitation of severely disturbed ecosystems is well recognized (Miller 1979; Reeves et al. 1979; Khan 1981; Trappe 1987). The reduction and/or loss of infectivity of AM fungi as a result of natural or man-induced disturbance of ecosystems has been reported by various researchers (Allen and Allen 1980; Powell 1980; Allen et al. 1984).

Annual forest fires are a typical feature of Margalla Hills near Islamabad, Pakistan. The role of fire in changing vegetation structure and soil characteristics has been the subject of a number of studies (Naveh 1973, 1975; Trabaud 1984, 1987; Johnson 1992; Kutiel and Shaviv 1993). Fire can dramatically change surface-soil characteristics and erosion rates (Anderson 1974; Amaranthus and McNabb 1984; Amaranthus 1989). Although several workers have reported significant effects of fire on soil microorganisms in general (Algren and Algren 1960; Perry et al. 1987), few studies have examined the effect of burning on AM fungi. The degradation of soil causes changes in the AM fungal population, reflected by a decrease in the number of AM fungal propagules (Allen et al. 1984; Day et al. 1987; Khan 1978) and hence a low inoculum potential (Khan 1988). Vilarino and Arines (1991) found that burning of vegetation had serious effects on both the spore population and the infection potential of AM fungi.

Our objectives were to determine the effects of forest fire on the number and viability of AM fungal propagules in affected areas of Margalla Hills, including post-fire re-establishment of AMF infection in the dominant shrubs of the burnt sites.

Materials and methods

The study was conducted on the south-facing slopes of Margalla Hills which constitutes the northwest boundary of Islamabad, Pakistan. The area of 12 605 ha is scrub type vegetation and the summer maximum temperature reaches 44 °C (Hoeflaken 1988). The vegetation on the burnt and the nearby control sites was identical before the fire and the sites experienced the same climatic conditions. In fact the demarcation of the sites was only possible after the fire. *Dodonaea viscosa* and*Artisia adscensionis* were among the dominant shrubs of both areas, covering 11.6 and 9.2%, respectively, of the control site and 2.3 and 4.3% of the burnt site.

Fire broke out at the end of July 1994 and plant and soil samples were collected in December 1994 and April 1995. At each

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collection date, soil (sandy loam) samples, plants and their mycorrhizospheres were collected. Five uniformly spaced soil cores (4 cm wide × 10 cm deep) were taken from each site on each occasion and pooled to give two composite samples for extraction of AM fungal spores by wet sieving and decanting (Gerdemann and Nicolson 1963). The composite soil samples were sieved with a 2-mm sieve to remove coarse debris and oven-dried (80 °C overnight). Ca. 100 gm of dried soil sample was then thoroughly wetted for 1 h before sieving and decanting for AM fungal spore extraction.

The numbers of viable AM fungal propagules (spores, mycelium, infected root pieces) per 100 g of dried soil sample were determined by the most probable number (MPN) technique (Porter 1979, as modified by Woomer 1994), using pre-germinated red clover seedlings as the test plant. A tenfold dilution series of each mycorrhizosphere sample with acid-washed sand as dilutent was planted with 6-day-old pre-germinated red clover seedlings in 50-ml vials with 1 seedling per vial and 5 replicates per dilution. The vials were maintained at field capacity by frequent watering to a constant weight and were randomized in trays in a glasshouse (temperature range 13–25 °C and photoperiod 14 h). After 6 weeks, clover seedlings were harvested and their roots removed, washed and fixed in FAA (formalin, acetic acid, ethanol 5:5:90) and stored at 4 °C. The MPN of AM fungal propagules for each inoculum were calculated according to Alexander (1965).

Roots of *Dodonaea viscosa* and*Aristida adscensionis* were collected by excavating the whole root systems of five plants per species. The roots were carefully washed to remove soil debris, cut into 1-cm pieces, fixed in FAA, and cleared (2.5% KOH) and stained (acid glycerol aniline blue) according to Koske and Gemma (1989).

The data was subjected to one-way ANOVAR and χ^2 test.

Results and discussion

Our results indicate adverse effects of fire on the viability of AM fungal propagules (Table 1). The MPN method revealed a significantly lower number of viable AM fungal propagules at the burnt site than at the control site, suggesting that burning of the vegetation and subsequent loss of top soil by erosion reduced infectivity of AM fungal propagules. Moreover, direct effects of burning may have resulted in heat injury causing low viability and/or dormancy of AM fungal spores; the MPN bioassay may fail to detect such dormant spores. Dead AM fungal spores degrade slowly and the proportion of vital spores is often about half that of total spores (An et al.1990). Similarly, the presence of propagules of AM fungi such as *Glomus intraradices,* which produces spores inside roots and are not recovered in wet sieving, will be revealed in the MPN bioassay plants but are unlikely to be isolated by the wet-sieving technique (An et al. 1990). Reduced AM fungal spore viability at the burnt site in the present study may also be attributed to toxic substances released from organic matter as a result of fire (Raison 1979).

The total number of spores at the burnt site, viable or not, was not significantly different from the control-site 5 months after the fire (Table 1). These results are consistent with those of other workers (Vilarino and Arines 1991). At 10 months after the fire, rhizosphere soil from the control site did not contain a higher number of total AM fungal spores than at the burnt site. This contrasts with results of Dhillion et al. (1988), who recorded an increase in spore production with the reduced growth of little blustem subjected to a prairie fire in the USA. No speciation differences in the AM fungal spore populations were noted (Table 2). In general the number of spores of *Glomus* sp. was greater than *Gigaspora gigantea* and *Gigaspora margarita* at both sites.

Examination of the roots of *Dodonaea viscosa* and *Aristida adscensionis* from the burnt site showed the gradual re-establishment of AM associations (Table 3). In December 1994, 4 months after the fire, the percentage root length colonized by AM fungi was significantly higher ($P<0.05$) at the control site for all samples than at the burnt site for both plants studied. A significant increase in root length colonized by AM fungal hyphae in plants growing at the burnt site was found in April 1995, 10 months after the fire. It has been demonstrated by various workers that hyphal regrowth from root segments occurs more frequently and more rapidly than from spores, where infection is delayed by the time required for spores to germinate and pass through a highly branched phase before becoming infective (Powell 1976; Hayman and Stovold 1979; Hall 1988). Zakha et al. (1995) studied the mycorrhizal inoculum potentials in sugar maple forests and suggested that colonized root pieces and hyphal fragments are more likely to be propagules for infection than spores. Other researchers (Powell 1976; Abbott and Robson 1981) suggested that

Table 1 Number of viable arbuscular mycorrhizal (AM) propagules and spores in burnt and control forest sites as determined by MNP and wet-sieving techniques on two sampling dates. Mean values in columns within a sampling followed by different letters are significantly different at $P<0.05$ ($n=2$)

Method	Site	December 1994	April 1995
MPN			
	Burnt	93[a]	105[a]
	Control	156[b]	203[b]
Wet-sieving technique			
	Burnt	311[a]	322[a]
	Control	298[a]	382[a]

Table 2 Numbers of spores of AM fungal species recovered per 100 g soil from burnt and control sites by wet sieving and decanting ($n=10$). The data are mean results from 10 plants ± SD

Species	December 1994		April 1995	
	Control	Burnt	Control	Burnt
Glomus sp.	49 ± 13	37 ± 21	89 ± 17	71 ± 12
Glomus fasciculatum	60 ± 25	84 ± 32	67 ± 16	45 ± 19
Glomus mosseae	101 ± 26	98 ± 28	110 ± 31	94 ± 30
Gigaspora gigantea	50 ± 11	41 ± 19	83 ± 9	55 ± 21
Gigaspora margarita	9 ± 3	22 ± 12	12 ± 2	34 ± 8
Acaulospora sp.	18 ± 5	24 ± 7	7 ± 2	14 ± 3
Unknown	11 ± 7	5 ± 1	14 ± 1	9 ± 1
Total	298 ± 77	311 ± 54	382 ± 41	322 ± 38

Table 3 Mean ± SD percentage root length colonization by AM fungi of plants from burnt and the control sites. Mean values in a line, within a sampling, followed by different letters are significantly different at $P < 0.05$ ($n = 10$)

Host	Form of infection	December 1994		April 1995	
		Control	Burnt	Control	Burnt
Dodonaea viscosa	Total	$57^{b} \pm 8$	$23^{a} \pm 3$	$99^{b} \pm 13$	$47^{a} \pm 3$
	Hyphal	$35^{b} \pm 11$	$14^{a} \pm 3$	$61^{b} \pm 19$	$26^{a} \pm 7$
	Vesicular	$14^{a} \pm 6$	$8^{a} \pm 2$	$26^{b} \pm 9$	$16^{a} \pm 8$
	Arbuscular	$8^{b} \pm 2$	$1^{a} \pm 2$	$11^{b} \pm 4$	$5^{a} \pm 3$
Artisia adscensionis	Total	$43^{b} \pm 3$	$20.7^{a} \pm 2$	$45^{b} \pm 6$	$29^{a} \pm 5$
	Hyphal	$28^{b} \pm 5$	$15^{a} \pm 2$	$31^{b} \pm 6$	$14^{a} \pm 3$
	Vesicular	$12^{b} \pm 2$	$5^{a} \pm 2$	$11^{a} \pm 3$	$13^{a} \pm 2$
	Arbuscular	$3^{b} \pm 1$	$0^{a} \pm 1$	$3^{a} \pm 1$	$2^{a} \pm 1$

infectivity of AM is probably related to the amount of nutrient reserves in fungal structures in roots, and hypothesized that intra-radical vesicles contribute greatly to inoculum potential. Mosse (1988) and Burggraff and Beringer (1989) also reported that vesicles separated from roots retain their infectivity, and suggested that mycorrhizal root pieces are preferable to germinating spores.

To establish the relationships of mycorrhizal activity, time following fire and soil edaphic factors, both the dynamics of succession of vegetation and associated AM fungal populations on the Margalla Hills need to be examined further (Janos 1980). Mycorrhizal dependence and AM fungal propagule availability are prime determinants of early stages of community development and affect long-term plant dominance (Allen and Allen 1990; Molina et al. 1992).

References

Abbott LK, Robson AD (1981) Infectivity and effectiveness of vesicular-arbuscular mycorrhizal fungi: effects of inoculum type. Aust J Agric Res 32:631–639

Alexander M (1965) Most probable number method for microbial population. In: Black CA (ed) Methods of soil analysis, part 2. Chemical and microbiological properties. American Society Agronomy, Madison, Wisc, pp 1467–1472

Algren IF, Algren CE (1960) Ecological effects of forest fires. Bot Rev 26:483–533

Allen EB, Allen MF (1980) Natural re-establishment of vesicular arbuscular mycorhizae following strip-mine reclamation in Wyoming. J Appl Ecol 17:139–147

Allen MF, Allen EB (1990) Carbon source of VA mycorrhizal fungi associated with Chenopodiaceae from semiarid shrub-steppe. Ecology 71:2019–2021

Allen MF, MacMahon JA, Anderson DC (1984) Re-establishment of Endogonaceae on Mount St. Helens: survival of residues. Mycologia 76:1031–1038

Amaranthus MP (1989) Effect of grass seedling and fertilizing on surface erosion on intensely burned sites in southwestern Oregon. USDA Forest Service Technical Report PSW-109:147–149

Amaranthus MP, McNabb DH (1984) Bare soil exposure following logging and prescribed burning in southwest Oregon. In: New forests for a changing world. Proceedings of the Society of American Foresters National Convention, 16–20 October, Portland, Ore, pp 235–237

An Z-Q, Hendrix JW, Henson GT (1990) Evaluation on the "most probable number" (MPN) and wet-sieving methods for determining soil-born populations of endogonaceous mycorrhizal fungi. Mycologia 82:576–581

Anderson HW (1974) Sediment deposition in reservoirs associated with rural roads, forest fires and catchment attributes. In: Proceedings of the Symposium on Man's Effect on Erosion and Sedimentation. Paris, pp 87–95

Burggraff AJP, Beringer JE (1989) Absence of nuclear DNA synthesis in vesicular-arbuscular mycorrhizal fungi during in vitro development. New Phytol 111:25–33

Day LD, Sylvia DM, Collins ME (1987) Interactions among vesicular-arbuscular mycorrhizae, soil and landscape position. Soil Sci Soc Am J 51:635–639

Dhillion SS, Andersen RC, Liberta AE (1988) Effect of fire on the mycorrhizal ecology of little blustem (*Schizachyrium scoparium*). Can J Bot 66:706–713

Gerdemann JW, Nicolson TH (1963) Spores of mycorhizal *Endogone* extracted from soil by wet sieving and decanting. Trans Br Mycol Soc 46:235–244

Hall IR (1988) Response of *Coprosoma robusta* to different forms of endomycorrhizal inoculum. Trans Brit Mycol Soc 67:409–411

Hayman DS, Stovold GE (1979) Spore populations and infectivity of vesicular-arbuscular mycorrhizal fungi in New South Wales. Aust J Bot27:227–233

Hoeflaken HV (1988) Hiking around Islamabad. Asian Study Group, Islamabad

Janos D (1980) Mycorrhizae influence tropical succession. Biotropica 12:56–64

Johnson EA (1992) Fire and vegetation dynamics: studies from the North American boral forest. Cambridge University Press, London

Khan AG (1978) Vesicular-arbuscular mycorrhizas in plants colonizing black wastes from bituminous coal mining in the Illawarra region of New South Wales. New Phytol 81:53–63

Khan AG (1981) Growth responses of endomycorrhizal onion in unsterilized coal waste. New Phytol 87:363–370

Khan AG (1988) Inoculum density of *Glomus mosseae* and growth of onion plants in unsterilized bituminous coal spoil. Soil Biol Biochem 20:749–753

Koske RE, Gemma JN (1989) A modified procedure of staining roots to detect VA mycorrhizas. Mycol Res 92:486–505

Kuteil P, Shaviv A (1993) Effects of soil types, plant composition and leaching of soil nutrients following a simulated forest fire. For Ecol Manage 53:329–343

Miller RM (1979) Some occurrences of vesicular-arbuscular mycorrhizae in natural and disturbed ecosystems of the Red Desert. Can J Bot 57:619–623

Molina R, Massicotte H, Trappe JM (1992) Specificity phenomena in mycorrhizal symbiosis: community-ecological consequences and practical implications. In: Allen MF (ed) Mycorrhizal functioning – an integrative plant fungal process. Chapman & Hall, New York, pp 357–423

Mosse B (1988) Some studies relating to "indigenous" growth of vesicular-arbuscular endophytes. Can J Bot 66:2533–2540

Naveh Z (1973) The ecology of fire in Israel. Proceedings of the Annual Tall Timbers Fire Ecology Conference, March 22–23, 1973, Tall Timbers Research Station Tallahassee, Fla, pp 131–170

Naveh Z (1975) The evolutionary significance of fire in the Mediterranean region. Vegetatio 29:199–208

Perry DA, Molina R, Amaranthus MP (1987) Mycorrhizae, mycorrhizospheres, and reforestation: current knowledge and research needs. Can J For Res 17:929–940

Porter WM (1979) The "most probable number" method for enumerating infective propagules of vesicular-arbuscular mycorrhizal fungi in soil. Aust J Soil Res 17:515–519

Powell CLi (1980) Mycorrhizal infectivity of eroded soils. Soil Biol Biochem 12:247–250

Powell CLi (1976) Developmental of mycorrhizal infection from *Endogone* spores and infected root segments. Trans Br Mycol Soc 66:439–445

Raison RJ (1979) Modification of soil environment by vegetation fires, with particular reference to nitrogen transformations: a review. Plant Soil 51:73–108

Reeves FB, Wagner D, Moorman T, Kiel J (1979) The role of endomycorrhizae in revegetation practices in the semi-arid west. I. A comparison of incidence of mycorrhizae in severely disturbed versus natural environments. Am J Bot 66:6–13

Trabaud L (1984) Fire adaptation strategies of plants in the French Mediterranean area. In: Margaris NS, Arianoutsou-Farragitaki M, Oechel WC (eds) Tasks for vegetation science. Junk, The Hague

Trabaud L (1987) The role of fire in ecological systems. SPB, The Hague

Trappe JM (1987) Phylogenetics and ecological aspects of mycotrophy in the angiosperms from an evolutionary standpoint. In: Safir GR (ed) Ecophysiology of VA mycorrhizal plants. CRC Press, Boca Ratan, Fla, pp 2–25

Vilarino A, Arines J (1991) Number and viability of vesicular arbuscular fungal propagules in field soil samples after wildfire. Soil Biol Biochem 23:1083–1087

Woomer PL (1994) Most probable number counts. In: Weaver RW, Angle S, Bottomley P, Bezdicek D, Smith S, Tabatai A, Wollum A (eds) Methods of soil analysis. Part 2. Microbiological and Biochemical properties. No. 5 in the Soil Science Society of America Book Series, Soil Science Society of America, Madison, USA, pp 59–79

Zakha GA, Baggett KL, Wong BL (1995) Inoculum potential and other VAM fungi parameters in four sugar maple forests with different levels of stand dieback. For Ecol Manage 75:123–134