Forest Ecology and Management 260 (2010) 2160–2169

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Arbuscular mycorrhizal associations in *Boswellia papyrifera* (frankincense-tree) dominated dry deciduous woodlands of Northern Ethiopia

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ARTICLE INFO

Article history:
Received 22 June 2010
Received in revised form 3 September 2010
Accepted 6 September 2010

Key words:
AM fungi
Glomus
Dry tropical woodland
Exclosure
Management

ABSTRACT

This study assessed the arbuscular mycorrhizal (AM) status of *Boswellia papyrifera* (frankincense-tree) dominated dry deciduous woodlands in relation to season, management and soil depth in Ethiopia. We studied 43 woody species in 52 plots in three areas. All woody species were colonized by AM fungi, with average root colonization being relatively low (16.6% – ranging from 0% to 95%). Mean spore abundance ranged from 8 to 69 spores 100 g^{-1} of dry soil. *Glomus* was the dominant genus in all study sites. Season had a strong effect on root colonization and spore abundance. While spore abundance was higher ($P < 0.001$) in the dry season in all three study sites, root colonization showed a more variable response. Root colonization was reduced in the dry season in the site that was least subject to stress, but increased in the dry season in the harshest sites. Management in the form of exclosures (that exclude grazing) had a positive effect on spore abundance in one of the two sites considered. Spore abundance did not significantly differ ($P = 0.17$) between the two soil depths. Our results show that in this arid region all trees are mycorrhizal. This has profound consequences for rehabilitation efforts of such dry deciduous woodlands: underground processes are vital for understanding species adaptation to pulsed resource availability and deserve increasing attention.

1. Introduction

More than one-third of the earth's land surface is arid or semi-arid, supporting more than 1.2 billion people (Wickens, 1998). In these areas where conditions for agriculture are harsh and unpredictable, trees and shrubs are vital assets of non-wood forest products for farmers (Sunninchan et al., 2005) and for the conservation of dryland biological diversity (Ogbazghi et al., 2006). Low moisture availability is a major stress for the establishment, survival and growth of woody species in dry areas. One of the mechanisms that enable plants to survive these conditions is their ability to form a mutualistic association with fungi (Caravaca et al., 2003; Yamato et al., 2009).

Arbuscular mycorrhiza (AM) is the most widespread and common root-fungus association in land plants (Wang and Qiu, 2006; Brundrett, 2009). Brundrett (2009) estimated that out of 280,000 plant species, over 200,000 form AM. AM associations occur in many stressful environments and enhance water and nutrient uptake in dry conditions (Nobel and Cui, 1992; Michelsen, 1993; Augé, 2001). Most of the tropical woody species form AM (Onguene and Kuyper, 2001; Wang and Qiu, 2006; Brundrett, 2009), both in the humid and semi-arid tropics. In these dryland ecosystems, levels of colonization by and spore density of AM fungi (AMF) show distinct seasonal patterns (Abbott and Robson, 1991). Soil properties (soil depth, pH, organic matter levels) and management also generate variability in these parameters. Spore abundance is high during the dry season, which is related to plant phenology (Jasper et al., 1989; Guadarrama and Alvarez-Sanchez, 1999; Moreira-Souza et al., 2003). Most plants are not or less photosynthetically active as a result of leaf fall or stomata closure during the dry season, and the combination of an interrupted carbon flow to the roots with drying out of soils induces spore formation (Cardoso et al., 2003). In the dry period AMF mostly occur as soil spore banks.

AMF spore abundance can be affected by management (Alarcon and Cuenca, 2005; Silva et al., 2005). Among management regimes, exclosures are effective in increasing herbaceous cover and decreasing surface erosion, which in turn could increase spore density. Vegetation with a higher degree of cover showed higher propagule densities than degraded bushland and cultivated areas (Michelsen and Rosendahl, 1989; Carpenter et al., 2001). Hence we also compared spore density between exclosures and open area.

The distribution and density of AMF spores differs with depth (Dalpé et al., 2000). Generally, spore density like root length den-

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doi:10.1016/j.foreco.2010.09.010

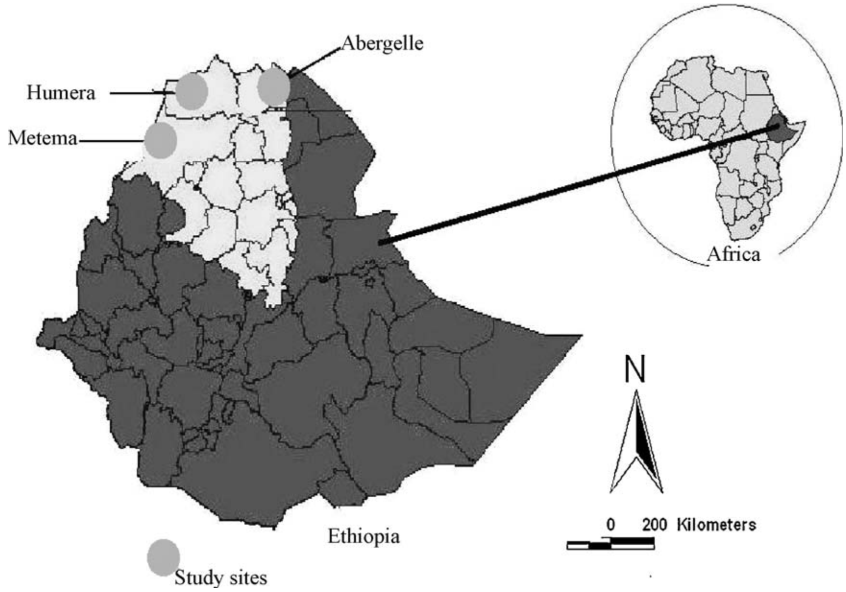

Fig. 1. Map showing the three study sites in Northern Ethiopia.

sity, declines with soil depth. Other factors that determine the distribution of moisture and soil nutrients over the profile also play a role in the distribution and density of AMF spores (Cardoso et al., 2003). Several studies noted spores at deeper soil layers (below 40 cm) because some woody plants extended their roots deep into the soil (Ingleby et al., 1997; Powers et al., 2005). Inferences based only on surface soil and root examination may then lead to incorrect generalizations about root symbionts when deeper layers support more AMF (Virginia et al., 1986). In areas where intensive grazing is coupled with erosion and shallow soil, it is likely that more spores will occur in the deeper layers as a result of loss of top soil and deeper distribution of roots.

This paper investigates the AM status of trees and shrubs in dry deciduous woodlands of Ethiopia that are dominated by the economically important frankincense tree (*Boswellia papyrifera*). Considering the strong seasonality in the area, we hypothesized higher spore density during the dry season but higher root colonization during the rainy season. The installment of exclosures as a management system to increase herbaceous cover led to the hypothesis of higher spore density in exclosures than in open areas. Finally we hypothesized a significant difference in spore density and levels of colonization between the upper and lower soil layers. To test these hypotheses we analyzed the effect of season, management and soil depth on the density of AMF spores and levels of root colonization in three different dry deciduous woodlands of Ethiopia.

2. Materials and methods

2.1. Description of the study sites

The study was conducted in Abergelle, Humera and Metema (Fig. 1 and Table 1), three *Boswellia*-dominated dry deciduous forest areas of northern Ethiopia. These sites are the main areas in the country where gum and incense are collected. The main species for incense production is *Boswellia papyrifera*, while *Acacia senegal* and *A. seyal* are used for gum production.

Abergelle, which is the driest site, has erratic rainfall, most of which occurs between mid June and August (Fig. 2). The topography is flat, surrounded by hills and mountains. The soils are shallow and have a high degree of stoniness, which limits the water-holding capacity and root space. The vegetation of *Abergelle* is categorized as *Combretum-Terminalia* and *Acacia-Commiphora* woodland (NBSAP, 2005), dry forest dominated by *Boswellia papyrifera*, *Acacia etbaica*, *Terminalia brownii* and *Lannea fruticosa*. They are also categorized as Ethiopian undifferentiated woodland under Sudanian regional centre of endemism (Gebrehiwot, 2003). Humera has a slightly less harsh climate with a dry season that lasts 8 months; rainfall is concentrated between June and September (Fig. 2). The study area has a rugged topography with flat plains surrounded by mountain tops. The vegetation cover is categorized as *Combretum-Terminalia* woodland, *Acacia-Commiphora* woodland, and *Acacia-Boswellia* woodland (NBSAP, 2005). Metema receives

Table 1
Location, elevation, soil types and characteristics of the study sites.

Locality	Abergelle	Humera	Metema
Region	Tigray	Tigray	Amhara
Specific area	Serabite/Jijike and Siye	Adigoshu/Tekeze	Lemlem Terara and Masho Terara
Area of specific site (ha)	51	295	64
Location	13°14′ to 13°42′N, 38°38′ to 39°02′E	13°42′ to 14°28′N, 36°20′ to 37°31′E	12°30′N to 12°48′N, 36°17′ to 36°55′E
Altitude (m)	1500–1640	537–913	549–600
Geology	Limestone; mixture of schist and limestone with quartz	Metamorphic terraine, phyllite and quartizite	Pre-cambrian; chlorite schists; quartizites
Soil types	Cambic Arenosols, Chromic Cambisols and Leptosols	Vertisols, Leptosols, Eutric cambisols, Vertic Luvisols	Haplic Luvisols, Humic Nitisols, Eutric Vertisols
Slope position	Middle	Middle	Middle
Disturbance	High	Medium	Medium
Erosion type	Sheet and rill	Gully	Rill