Arbuscular Mycorrhizal Colonization and Agricultural Land Use History

by Irnanda A.f. Djuuna

Chapter 17
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Irnanda A.F. Djuuna

17.1 Introduction

Most plant species form symbiotic associations with mycorrhizal fungi (Newman and Reddell 1987) and arbuscular mycorrhizal (AM) fungi are widespread in natural and agricultural ecosystems (Brundrett 1991). AM fungi can contribute to plant growth by enhancing water and nutrient uptake, especially phosphorus (P) (Ortas 1996; Jacobson 1997; Watts-Williams et al. 2014). Although AM fungi colonize roots of most plant species (Harley and Harley 1987; Smith and Read 2008), plants differ in their growth response to mycorrhizal colonization. Furthermore, plant species can influence the population of AM fungi (Crush 1978; Hiiesalu et al. 2014). AM fungi may also contribute to soil fertility by enhancing soil structure and protecting crops from root pathogens (Douds and Johnson 2003; Sharma et al. 2013). The soil environment, particularly those factors that control mineral fertility, strongly influences mycorrhizal function (Abbott and Robson 1982; Sikes et al. 2014).

In agricultural fields, the status of AM fungi is influenced by soil conditions and management practices (Jansa et al. 2014). The diversity of AM fungi species can be lower in agricultural systems than in nearby natural fields (Helgason et al. 1998; Sieverding 1991) or forested areas (Boerner et al. 1996). However, factors such as crop and rotation history can also influence the abundance of AM fungi in agricultural soil (Douds and Johnson 2003; Helgason et al. 2014).

I.A.F. Djuuna (✉)
Faculty of Agriculture and Agriculture Technology, University of Papua, Gunung Salju St. Kampus UNIPA Amban, Manokwari, Papua Barat 98314, Indonesia
e-mail: irnanda_afd@yahoo.com

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17.2 AM Fungi in Agricultural Systems

The impact of farming practices on AM fungi has been studied extensively (Abbott and Robson 1994; Gavito and Miller 1998; Thompson 1994; Barber et al. 2013). Agricultural practices such as tillage, crop rotation, and use of chemical pesticides and fertilizers (Helgason et al. 2014; Kurle and Pfleger 1994; Ortas et al. 2013) as well as clean fallowing, topsoil removal, fires, and waterlogging (Thompson 1994) have all been shown to influence the abundance of AM fungi, often reducing the level of colonization. Rotation and fertilizer practices are major factors that affect the abundance of AM fungi, especially in Mediterranean agriculture (e.g., Abbott et al. 1995). Difference may not be so marked in soils with high P (e.g., Franke-Snyder et al. 2001). However, geography and other landscape characteristics may override effects of land management on AM fungal communities (Jansa et al. 2014).

Crop rotation is a very important factor in managing nutrient supply. In general, preceding crops can affect the growth and yield of subsequent crops (Karlen et al. 1994; Brito et al. 2012). The choice of crop and crop rotation history can influence the community of AM fungi in agricultural soil because plants differ in their susceptibility to colonization. A study of 27 species of plants demonstrated that AM fungi were present in most legumes whereas Poaceae were poor hosts (Eschen et al. 2013). However, the length of root colonized by AM fungi can be higher in some grasses than in non-grasses grown in the same soil. The Leguminosae can be superior in terms of concentration of fungal hyphae per unit weight or length of root, but in terms of total length of mycorrhizal root available to exploit a given soil volume and in terms of the likely residual population of mycorrhizal propagules, the Gramineae would be superior (Thompson and Wildermuth 1989). Plants with less dense roots (fewer and coarse roots) can have high mycorrhizal colonization (Hetrick 1991) and plants with poorly developed root hairs can be highly dependent on mycorrhizas (Baylis 1970). The growth of highly mycorrhizal-dependent crops like linseed can leave a high level of mycorrhizal inoculum for subsequent crops (Thompson 1994). In addition, other factors that need to be considered when managing crop rotations to obtain maximum benefits from AM fungi include (1) whether AM fungal inoculum in the soil is low after practices such as clean fallowing, (2) whether a nonhost crop has been grown, (3) whether rice has been grown under waterlogged conditions, or (4) whether crops with low mycorrhizal dependency have been grown. If a crop with high dependency is grown for other reasons (e.g., disease control), then a high P fertilizer rate and possibly Zn fertilizer might need to be used to compensate for lower levels of mycorrhizal development if management practices have reduced their infectivity (Thompson 1994).

For soils with naturally high P fertility and high use of P fertilizer, colonization by AM fungi would not be expected to make a contribution to plant growth (Galvez et al. 2001; Kahiluoto et al. 2001). However, this is not always the case as it may depend on the soil type. P applications to field soils may be accompanied by a

decrease in the proportion of root length colonized by AM fungi (Abbott and Robson 1984; Clarke and Mosse 1981; Liu et al. 2000) but this is not always the case (Gryndler et al. 1990). The application of phosphate fertilizer to soil can delay in mycorrhiza formation as well as a decrease in the proportion of the root system colonized (Solaiman and Abbott 2008; De Miranda et al. 1989). In contrast, the addition of P fertilizer to soil with extremely low available phosphorus can increase the colonization, possibly through a direct effect on AM fungi (Bolan et al. 1984). Some studies have reported that farms which use alternative (e.g., low input) practices have higher levels of AM colonization than nearby conventional farms because of a lower available soil P associated with reduced applications of soluble P fertilizer (Mäder et al. 2000; Ryan 1999; Ryan and Ash 1999; Kahiluoto et al. 2012).

Nitrogen fertilizer may affect the infectivity of AM fungi but this is less marked than effects of P (Hodge and Storer 2014). Application of high doses of nitrogen fertilizer can reduce colonization by AM fungi (Hayman 1975; Johnson et al. 2003, 2010). Application of ammonium to soil prevented colonization by indigenous AM fungi and nitrate application resulted in a low (6 %) level of root colonization (Ortas and Rowell 2004). AM fungi can also be involved in the decomposition of complex organic material in soil and increase nitrogen capture by plants (Hodge et al. 2001).

Tillage practices can alter AM fungal populations and species composition, reduce root colonization and P uptake (Kurle and Pfleger 1994; McGonigle and Miller 2000; Brito et al. 2012), and disrupt the hyphal network (Jasper et al. 1989; Evans and Miller 1990). The physical disruption of fungal mycelia may change physicochemical properties and influence soil aggregation (Duchicela et al. 2013). Excessive secondary tillage and traffic increased soil bulk density and decreased root growth, mycorrhizal colonization, and top growth of *Phaseolus vulgaris* (Mulligan et al. 1985). On the other hand, reduced tillage intensity can favor higher colonization by AM fungi (Yocum et al. 1985; Mulligan et al. 1985; Brito et al. 2012). Soils in low-input agricultural systems can have higher populations and more propagules of AM fungi than soils under conventional management (Douds et al. 1993, 1995; Galvez et al. 1995; Kahiluoto et al. 2012). An investigation of a 7-year crop rotation and tillage scheme practice showed root length colonized by AM fungi was up to 60 % higher in plants grown in soils from low-input farming systems than in those grown in conventionally fertilized soils (Mäder et al. 2000). Similarly, AM fungal hyphal density was greater in no-till than in reduced tillage systems and lowest in a conventional tillage system (Kabir et al. 1997).

Fallowing land for an extended period without a crop is common practice in some agricultural systems. However, long fallow periods without plant cover may be detrimental to contributions by AM fungi (Douds and Johnson 2003). In some farming systems, weeds are allowed to grow and fallows are grazed by livestock. In other dry-land agricultural systems, fallows are used to accumulate soil water and nitrate and so are kept weed-free. However, longer fallows can result in reduced numbers of spores of AM fungi and lower levels of root colonization (Thompson 1991). Clean fallowing can reduce inoculum levels and colonization by AM fungi

in the following crop (Black and Tinker 1979; Thompson 1987). The reduction in abundance of AM fungi in soil during periods of fallow can be substantial, and Harinikumar and Bagyaraj (1988) reported a reduction in AM fungi colonization by 40 % associated with a long fallow period.

The application of pesticides to agricultural soils throughout the production cycle may have a range of effects on AM fungi. Some pesticides may be toxic to AM fungi (Abd-Alla et al. 2000; Jalali and Sharma 1993). Methyl bromide can kill AM propagules deep in the soil profile because it is denser than air (Menge 1982). The use of herbicides can have indirect effects on AM fungi by changing the relative abundance of plant species associated with the length of roots of species that differ in mycorrhizal dependency in the soil.

Grazing livestock can influence AM fungi through influences on root growth, changes in soil structure, and removal and return of nutrients (Harrier and Watson 1997; Davinic et al. 2013). Moderate and intense grazing resulted in increased root colonization and changes in AM fungal species composition of tall grass prairie (Eom et al. 2001). However, grazing can alter root biomass and structure, especially when compounded with other management practices such as N application (Yan et al. 2013) which can further influence communities of AM fungi. However, studies of the effect of grazing (e.g., by domestic animals) on AM fungi in agricultural fields have been inconsistent. In some situations, little effect of grazing on AM fungi has been observed (Torres et al. 2011), but grazing has been shown to have a negative effect on AM fungi in other situations (Saravesi et al. 2013). Furthermore, where domestic animal grazing influences soil structure, there are likely to be associated changes in the abundance and diversity of AM fungi in soil.

17.3 A Conceptual Model of AM Fungi in Soil

A conceptual model of factors influencing the status of AM fungi in agricultural soil is presented in Fig. 17.1. The distribution and abundance of AM fungi in soil can be influenced by a range of factors (e.g., climate, soil properties, management practices, and socioeconomic factors related to the farming enterprise). The dominance of particular influences would be site specific and include soil and geography (Jansa et al. 2014).

Field surveys have shown correlations between the distribution of AM fungi and soil pH. The distribution of some AM fungi can be restricted in either acid or alkaline conditions, while others have been found in both types of soil (Abbott and Robson 1991). For example, in a range of agricultural soils in southwestern Australia, *Acaulospora laevis* spores occurred only in more acid soils (pH in 1/5 0.01 M $CaCl_2$ less than 5.3), and *Glomus monosporum* spores occurred only in soil with pH greater than 4.85 (Abbott and Robson 1977). There was no correlation between the abundance of different spore types and soil pH. The level of root colonization was only slightly affected by pH over a range of soils at pH 4.5–7.5

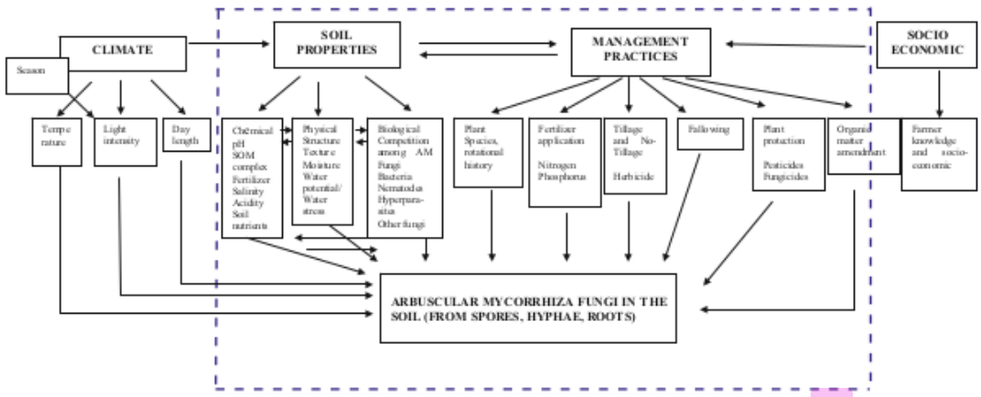

Fig. 17.1 A theoretical model of the factors which could affect the status of AM fungi in agricultural soil

(Wang et al. 1993) or at pH 4.7–7.7 (Porter et al. 1987) but different AM fungi were present at the pH extremes.

Increases in soil salinity in agricultural soils may influence the growth and activity of mycorrhiza fungi. Under saline conditions, AM fungi may have the ability to protect plants from salt stress (Rosendahl and Rosendahl 1991). Salinity can reduce the growth of AM fungi and root colonization in various ecosystems (Juniper and Abbott 1993; McMillen et al. 1998; Carvalho et al. 2003), but this is not always the case (Ruiz-Lozano et al. 1996).

Colonization by AM fungi in pot experiments is commonly reduced by low temperatures (e.g., Baon et al. 1994; Ruotsalainen and Kytöviita 2004) and increased by higher temperatures (e.g., Domisch et al. 2002) when measured as proportion of root length colonized. In the latter case, length of root colonized increased more than did the length of new roots and similar effects could influence the dynamics of mycorrhiza formation under field conditions.

17.4 Conclusion

The infectivity of AM fungi can be influenced by soil factors (chemical, physical, and biological) and agricultural practices, including plant components of agricultural systems. These factors vary across landscapes and geostatistical methods are available for quantifying them. Spatial and temporal variability in infectivity of AM fungi is expected to vary among sites and for different environmental conditions, depending on soil type and soil management. Some soil properties and agricultural practices can enhance the formation of mycorrhizas, but others can apparently be detrimental. Furthermore, as different methods have been used to measure infectivity of AM fungi, this should be considered when interpreting the effects of soil, plant, and environmental factors in these fungi. The conceptual model outlined here

for the development of AM could be used to predict the status of AM fungi in agricultural field even though this is not quantitative.

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