Chapter 2
Assessing Economic Benefits of Arbuscular Mycorrhizal Fungi as a Potential Indicator of Soil Health

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2.1 Introduction to Soil Health Indicators

Arbuscular mycorrhizal (AM) fungi have the potential to influence the economic benefits of agricultural systems through both direct and indirect processes related to plant nutrition (e.g. Smith and Smith 2012), access to moisture in water-limiting situations (e.g. Manoharan et al. 2010), building soil structure (e.g. Rillig and Mummey 2006), protection of soil carbon in aggregates (e.g. Jastrow et al. 1998) and strengthening plant resilience to disease (e.g. Azćon-Aguilar and Barea 1996). In some situations, AM fungi may have negative influences, particularly in relation to carbon transfer (Smith and Smith 2012). However, despite the demonstrated potential for AM fungi to contribute to soil physical, chemical and biological processes under controlled conditions, their contributions can be overridden in farming systems by management decisions that do not take them into account.

Although contributions of mycorrhizas are well documented (Smith and Read 2008), it is generally difficult to quantify their economic benefits (Miller et al. 1994). This is because there has been little work done either to identify systematically all such benefits or to identify how variables that influence mycorrhizal function might interact with each other to influence overall benefits. To complicate matters further, it is possible that the nature and magnitude of such benefits might be site specific, requiring all possible mycorrhizal impacts for defined rotations in a specific location to be considered. The emphasis in this overview is to determine the relevance of AM fungi in '*normal agricultural field*

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conditions', including field inoculation with AM fungi where this is demonstrated to be commercially practical.

Factors known to affect the magnitude of mycorrhizal influence under field conditions (both positive and negative) include the availability of soil phosphorus in relation to the requirements of the plant, the diversity and abundance of the AM fungi present, the plant host species growing in the farming system (either within rotations or in continuous planting of one crop or communities of pasture species), the size of the plant and its stage of development, and the levels of soil carbon and nitrogen. Other issues likely to influence mycorrhizal colonisation include plant stressors such as disease (Azćon-Aguilar and Barea 1996), soil constraints such as salinity or acidity (Evelyn et al. 2009; Juniper and Abbott 1993; Sano et al. 2002), heat and water limitation (Manoharan et al. 2010), and the presence of other soil organisms which interact directly with mycorrhizal hyphae such as soil mesofauna (Endlweber and Scheu 2007). In addition, the various factors that influence AM fungi may interact with one another, leading to negative, synergistic or additive effects (Pearson et al. 1993, 1994; Thonar et al. 2014).

2.2 Introduction to Economic Evaluation of Environmental Contributions

Arbuscular mycorrhizas are but one element of soil biodiversity, which strongly influences soil health. As well as being influenced by the presence of other soil biota, such as saprophytic fungi (Albrechtova et al. 2012), the abundance and role of AM fungi are in turn influenced by soil treatments such as tillage and soil amendments (Brito et al. 2012; Lehmann and Joseph 2009). While their complete range of impacts on agricultural and natural ecosystems is yet to be fully appreciated, their potential for beneficial effects in all types of ecosystems has been acknowledged (Chaurasia 2004). However, the need for inoculation is controversial (Schwartz et al. 2006) and cannot be determined without clear understanding of the benefits of AM fungi present in the soil and the suitability of inoculants (Abbott et al. 1992).

A problem with valuing any aspect of biodiversity is that it is generally held to be an economic intangible, that is, it has no market price (Baker and Ruting 2014; Bishop 2013; Pearce 1995). In common with many other environmental goods and services that have vast overall intangible benefits to society, biodiversity itself cannot be bought and sold, making its value very difficult to quantify (Martinez-Alier 1987). This is unlike goods and services for which a market, and therefore a price, exists (Baker and Ruting 2014). Environmental and ecological economists have long attempted to develop methodologies for valuing intangibles because without some measure of their economic benefit, these valuable resources tend to be ignored or neglected in a world where the market and its attendant prices are treated with an almost religious reverence (Dobell 1995; Loy 1997; Pearce 2002;

Lumley 2013). Thus, it is difficult to make financial comparisons of their worth in comparison with resources like minerals and timber which have tangible values. This reverence strongly influences policy globally, and decision makers have come to rely on comparative financial values to prioritise budget allocations and other important determinations (Bishop 2013; Lumley 2013).

Various attempts have been made to quantify biodiversity value because its benefits are known amongst biologists and other scientists to be far-reaching and because biodiversity loss can have long-term, sometimes catastrophic, consequences for the human economy. Pimental et al. (1997) conducted an economic analysis of the benefits of biodiversity in which they concluded that they were worth $300 billion annually to the US economy alone. In their article, the authors disaggregated various biodiversity services into 21 activities while trying to place a financial value on each activity. One of the activities they identified was 'soil formation' about which they stated (Pimental et al. 1997, p. 748): 'Diverse soil biota facilitate soil formation and improve it for crop production'. They estimated the biodiversity value of soil formation to be worth $5 billion to the US economy and $25 billion to the world economy annually. Given that this estimate was in 1997 US dollars, it will now be substantially higher. Arbuscular mycorrhizas constitute a significant subset of soil fungi, and while it is not possible to extrapolate the value of mycorrhizas alone from the figures for soil biota estimated by Pimental et al., it is likely that their economic benefits are globally significant. Schulz (2001, p. 111) while investigating the effect of arbuscular mycorrhizas on the development of micropropagated oil palms noted that: 'While the economic benefits of arbuscular mycorrhizas per se have not been calculated, it has long been recognised that they do indeed have substantial worth and overall significance to soil health. In recent years the interest in mycorrhizas has increased, partly due to economic benefits because most of the economically important plants in agriculture, horticulture and forestry have been found to be mycorrhizal'. Delian et al. (2011) claimed that the presence of mycorrhizas in soil can increase economic profitability and it is widely recorded that mycorrhizas influence crop productivity (e.g. Smith and Read 2008; Gazey et al. 2004), although Ryan and Kirkegaard (2012) question their benefits. In a modelling study of the apparent diversity of mycorrhizal effects, Veresoglou and Malley (2012) claimed that potentially beneficial versus damaging relationships between plants and mycorrhizal fungi depended upon the number and nature of mycorrhizal species that colonised the plant. In response to a suggestion that mycorrhizal colonisation might be damaging in some Australian cropping situations, Smith and Smith (2011, p. 73) state 'We know of no convincing evidence for deleterious effects in the field that can confidently be ascribed to AM symbiosis'.

The potential breadth of contributions of AM fungi to important aspects of plant health and soil quality, underlying the notion that they might be used as an indicator of soil health, 'have received less emphasis than increases in production, probably because the economic benefits are less easily quantified or appreciated' (Smith and Read 1996, p. 454). Smith and Read (1996, ibid) also state that 'The possible economic benefits of managing mycorrhizal populations in agriculture and horticulture need to be critically assessed in the context of the ecology of the systems, not simply in the growth of the crops'. Acknowledging the difficulties inherent in such an analysis, we propose a framework as a means of assessing the economic benefits of arbuscular mycorrhizas in the context of agro-ecosystems (e.g. Smith and Smith 2011) while recognising their broader ecological and global context (e.g. Chaurasia 2004). Furthermore, the same roles that are exhibited in agricultural soils extend into diverse natural ecosystems, and some of these environmental resources indirectly benefit agricultural ecosystems (Ryan and Kirkegaard 2012). Indeed, as Ryan and Kirkegaard (2012, p. 50) state, 'the role of AMF in restoration of native plants and ecosystems on agricultural lands in Australia may merit investigation. Plants in Australian native ecosystems are colonised by AMF; although there may be a significant nonmycorrhizal component in some instances'.

In order to estimate economic values of mycorrhizas at either paddock or farm level, factors affecting the life cycle of AM fungi, especially the colonisation of roots by communities of these fungi, need to be quantified. However, there are risks to making such estimates if they are based on (1) inaccurate measurement of mycorrhizal hyphae in soil and in roots including discrepancies associated with measurement of root density and/or root architecture (see Gutjahr and Paszkowski 2013); (2) misunderstanding of the behaviour and measurement of colonisation of roots by AM fungi according to the method of identification of species, 'strain' or morphotype (see Shi et al. 2012); (3) inaccurate measurement of mycorrhizal function, including estimation of variation in contributions of different AM fungi throughout stages of the plant growth cycle (see Mickan et al. submitted); (4) inaccurate assessment of benefits and disbenefits due to failure to account for mycorrhizal variation within crop rotations (see Koide and Peoples 2012); (5) not recognising the discreet effects of C and N cycles on mycorrhizas and their interactions with P cycles through plant uptake and use (see Johnson 2010); (6) lack of recognition of effects of other soil organisms which may be both under- and overstated (see Lewandowski et al. 2013; Steinaker and Wilson 2008); (7) lack of recognition of effects of plant disease and other stressors leading to distorted quantification of mycorrhizal contributions (Hilou et al. 2014; Singh et al. 2013); and (8) inaccurate assessment associated with independent and interrelated climate or environmental attributes.

Risk minimisation strategies can be taken into account to deal with some or all of the factors that impede realistic economic valuation of mycorrhizas. Some of the risks apply widely, but others are more farm or paddock specific. Without even rudimentary local knowledge of AM fungi in agricultural ecosystems, there is potential that management practices will be used that fail to consider and consequently fail to capture potential benefits. Within the rhizosphere, AM fungi occur at the interface of soil biophysical and biochemical processes, and this central position warrants clarification of their role as an indicator of soil health.

AM fungi occur ubiquitously in agricultural systems and have a close affiliation with roots of most agricultural plants (Smith and Read 2008). Therefore, factors which influence their distribution, abundance, diversity, infectivity and longevity in roots and soil have the potential to be incorporated into an integrated indicator of soil health.

2.3 Arbuscular Mycorrhizal Measurement

Most demonstrations of benefits of AM fungi have been made in terms of increased early plant vigour associated with mycorrhizal function under controlled conditions, including inoculation in the field. In parallel, detrimental impacts have been widely reported, particularly during early stages of plant growth (Graham and Abbott 2000; Johnson and Graham 2013). It is more difficult to demonstrate mycorrhizal function under field conditions (Ryan and Angus 2003; Watts-Williams and Cavagnaro 2012). Gazey et al. (2004) demonstrated mycorrhizal benefits in terms of P uptake and growth of subterranean clover under field conditions in southwestern Australia using a phosphorus response curve approach that included an inoculation control. Ryan and Kirkegaard (2012) concluded there was little evidence of benefits of mycorrhizas in agricultural production systems commonly used in Australia, and indeed they found that some of these agronomic practices may reduce colonisation of roots by AM fungi. Given that the practices involved are based on considerable research to identify the best agronomic practices for sustaining production, there is an opportunity to explore whether this level of production uses practices that do not capture some components of soil biological fertility (Abbott and Murphy 2003) and that further investigation of the basis of ‘sustainable production’ that does not maximise contributions of soil flora and fauna is required. Generally, claims of mycorrhizal benefits in agricultural soils that relate to improving profitability rather than maximising productivity, as well as their possible role in the decontamination of soils polluted by residual organophosphates and their contribution to sustainability of crop production (Smith and Read 2008; Gazey et al. 2004; Delian et al. 2011; Albrechtova et al. 2012; Brito et al. 2012), are all in need of investigation within a framework that highlights intangible economic benefits.

Overall, while it is relatively easy to demonstrate mycorrhizal benefits under controlled conditions, including controlled field experiments, it is not easy to extend this to assessment of their benefits under ‘*normal agricultural field conditions*’ because the fungi are ubiquitous. Even though different fungi have been shown to differ in their effectiveness (e.g. Smith et al. 2000; Graham and Abbott 2000), the extent to which this is translated into field soils where competition between fungi leads to differences in relative abundance in roots and in infectivity (based on relative inoculum potential) is difficult to measure. However, despite their ubiquity, the contributions of different AM fungi during plant growth stages under ‘normal’ agricultural field conditions are not well established. While it is known that different AM fungi have different capabilities to scavenge for P under P-limited conditions for plant growth (Schweiger et al. 2007; Thonar et al. 2011), the extent to which this plays out during stages of plant development is not clarified in ‘normal’ agricultural field conditions. Diversity in the life cycles of AM fungi in association with plants leads to changes in their relative abundance in root systems and in soil over time. For example, Pearson and Schweiger (1993, 1994) showed how understanding the life cycles of AM fungi in both roots and soil helped identification of the mechanism of competition between two fungi that occur

Table 2.1 Risks in assessing economic value of arbuscular mycorrhizas and potential remedies for overcoming such risks

Risks in assessing economic value of mycorrhizas	Remedy for overcoming risks in assessing economic value of mycorrhizas
Inaccurate measurement of mycorrhizal hyphae in soil and in roots associated with variation in root density and/or root architecture	Understand the relationship between root growth and mycorrhizal colonisation throughout the life cycle of plants in agricultural rotations
Inaccurate measurement of mycorrhizal function, including varying contributions of different fungi throughout the stages of the plant growth cycle	Understand the extent to which different mycorrhizal fungi colonise roots during the plant growth cycle and how this affects mycorrhizal contributions at different stages
Misunderstanding of the behaviour and measurement of colonisation of roots by species, strains and/or morphotypes of mycorrhizal fungi	Understand how communities of mycorrhizal fungi interact with one another in roots and whether this affects their ability to access P and water, and the ramification of hyphae in soil
Inaccurate assessment of benefits and disbenefits due to failure to account for mycorrhizal variation according to crop rotation	Understand how mycorrhizas contribute in sequences of crop and pasture species so that benefits can be accounted for seasonally
Not recognising the discreet effects of C and N cycles on mycorrhizas and their interactions with P	Understand interrelationships between mycorrhizas and C and N cycles in soil to calculate P and N fertiliser requirements that do not override potential mycorrhizal contributions
Lack of recognition of effects of other soil organisms which may be under or overstated	Understand how other soil organisms interact with mycorrhizal fungi
Lack of recognition of effects of plant disease and other stressors leading to distorted quantification of mycorrhizal contributions	Understand how mycorrhizal fungi interact with plant pathogens either to alleviate plant disease or to influence quantification of their abundance
Inaccurate assessment associated with independent and interrelated environmental and/or climate attributes	Understand how soil conditions such as salinity, acidity, compaction and waterlogging influence the life cycles of mycorrhizal fungi

commonly within roots of agricultural plants in southwestern Australia. Factors of significance were the dynamics of colonisation of roots associated with changes in sporulation and soluble carbohydrates. Given this degree of complexity, measurement of mycorrhizal fungi as '% root colonised' at one point in time may be of little relevance to estimation of the potential contribution of mycorrhizal fungi over an entire plant production cycle. Examples of the limitations in measurement of mycorrhizas and their function in 'normal' agricultural field conditions are illustrated below.

If mycorrhizas are not accurately measured, there will be risks in assessment of their potential contributions (Table 2.1). The measurement most commonly used is the proportion of root length colonised. However, there can be large variation in the density of root colonised and fungal structures within roots (McGonigle et al. 1990) and in the diameter of roots, all of which influence the total biomass of fungi present both inside the root and in the surrounding soil (Abbott and Robson 1984, 1985). Furthermore, these differences are not usually recorded (Gazey et al. 1992) and change with time (McGonigle 2001).

2.4 Mycorrhizal Benefits and Costs

Field studies of benefits of AM fungi are fewer than are glasshouse studies primarily because of the difficulties in establishing and monitoring experiments (McGonigle 1988). However, another factor in assessing the benefit of mycorrhizas in agricultural systems is that their contribution may be diffusely distributed amongst a number of areas, none of which reaches a threshold level, but when considered together, there is a benefit. Most studies focus on one aspect, and quantification relevant to assessing a wider suite of contributions can be prohibitive in terms of time and cost (Schnepf et al. 2008).

Where AM fungi contribute to P uptake, the benefit can be measured in terms of savings in fertiliser (e.g. Schweiger et al. 2007). There has been little consideration of potential savings in nitrogen fertiliser, but the close links between P and N cycles (Johnson 2010) mean that such attention is warranted. Evaluation of phosphorus-use efficiency of plants in crop rotations, continuous cropping or pasture production could include estimations of contributions of AM fungi. If this were done, there will be a clearer estimation of nitrogen fertiliser needs in agricultural systems. While there has been in-depth analysis of P and N fertiliser requirements for agricultural production (according to crop or pasture species for particular rotations and tillage practices), little attention has been paid to the potential roles that effective communities of AM fungi might contribute to these calculations. Where such contributions are not considered, there is a greater chance for potentially useful contributions of AM fungi to be overlooked. A logical stepwise process for N and P fertiliser recommendations could include first an estimate of P requirements that takes into account the potential benefit of AM fungi that are present. This would form a baseline for estimation of N fertiliser requirements. Where AM fungi were demonstrated to be likely to provide a benefit (because the 'right' fungi were present in the 'right' amounts for the crop/pasture sequence), then this could be taken into account. Where AM fungi were demonstrated to be unlikely to provide a benefit (because the 'wrong' fungi were present in the 'wrong' amounts for the crop/pasture sequence), then this could also be taken into account in terms of remediation required through agricultural management to restore mycorrhizal communities to a state where they can make close to their potential contribution (i.e. a state of equilibrium). Thus, understanding the state of the existing community of AM fungi underpins decisions about N and P fertiliser use for a given agricultural sequence. Clearly, AM fungi will have less to contribute under some circumstances than others, but the emphasis needs to be on the extent to which they are achieving their potential in a given situation.

Other benefits of AM fungi such as (1) facilitating plant access to moisture under drying soil conditions, (2) increasing retention of soil carbon by protecting it from microbial degradation via enhanced aggregation of soil particles and (3) creating a soil and rhizosphere environment that is more resilient to development of plant disease may be co-benefits of more effective supply of nutrients to plants, but they can also stand alone in situations where the AM fungi have no particular role in nutrient-use efficiency. This could occur in soils that are already well supplied with P and N for plant growth.

2.5 Is There a Link Between Mycorrhiza Measurement and Benefit?

The only way to obtain an idea of the economic benefits of arbuscular mycorrhizas is to ascertain the link between their presence and function and the impacts that they have on agricultural ecosystems or, more particularly in this instance, on productivity and/or profitability. In some cases, there may be a negative impact, or disbenefit, on plant growth, although Smith and Smith (2011) disputed this, and Veresoglou and Malley (2012) suggested that any potential disbenefits depended on the number and type of colonising mycorrhizal fungi. This is necessarily a complex process because of the number of variables involved.

Table 2.2 Variables, impacts and risks of assessing the economic benefits of mycorrhizas: fungal factors

Variable	Potential effect	Impact	Risk	Risk minimisation strategy
Growth rate of mycorrhizal fungi in roots and in soil	Mycorrhizal fungi promote soil aggregation and plant growth	Positive	May use an inaccurate measure of mycorrhizal growth and function	Use both proportion of root colonised and absolute amount and quantify mycorrhizal biomass
Type of mycorrhizal fungi present	Different species or subspecies might grow at different rates and have differing benefits to plant and soil	Positive	Misunderstanding behaviour of individual species or subspecies could cause inaccurate assessment of their benefits	Identify growth attributes and behaviour of species and subspecies present and their interactions
Number of mycorrhizal species of subspecies present	There may be several species or subspecies present in varying amounts and they might interact competitively or synergistically	Positive or negative	Ignorance of how mycorrhizal species or subspecies interact could result in ignorance of competition or synergism	Identify the way mycorrhizal species or subspecies interact and give value for synergistic or competing effects

Table 2.3 Variables, impacts and risks of assessing the economic benefits of mycorrhizas: soil and plant variables

Variable	Potential effect	Impact	Risk	Risk minimisation strategy
Level of soil phosphorus	Promotes plant and mycorrhizal growth but needs to be balanced	Positive or negative	P see-saw effect. Both too much and too little P inhibit mycorrhizal growth	Assume ~40 ppm is optimal level of soil P for mycorrhizal growth and soil quality
Plant characteristics (e.g. size and growth stage)	Plant attributes such as size and growth stage affect mycorrhizal colonisation and function	Positive or negative	The role of plant size and growth stage might lead to inaccurate assessment of number and size of hyphae	Identify impact of plant attributes such as size and growth stage on measure of hyphae
Crop cycle characteristics	Attributes of plant type and rotation type could affect mycorrhiza activity	Positive or negative	May lead to inaccurate assessment of benefits and disbenefits due to failure to account for mycorrhizal variation according to crops in cycle	Account for mycorrhizal attributes and association for each plant in a rotation
Soil carbon and nitrogen levels	Levels of soil carbon and N affect soil quality and may interact with P	Positive or negative	Not recognising the discreet effects of C and N cycles on mycorrhizas and interaction with P	Account for carbon and nitrogen cycles and interaction with phosphorus

Table 2.4 Variables, impacts and risks of assessing the economic benefits of mycorrhizas: other environmental or climatic factors

Variable	Potential effect	Impact	Risk	Risk minimisation strategy
Presence of other key soil organisms	Other soil organisms may have a positive or negative effect on mycorrhizal function	Positive or negative	If possible effects of other soil organisms are not recognised, the effects of mycorrhizas might be under or overstated	Identify any organisms that affect soil quality, plant growth and mycorrhizal function and quantify impact if possible
Presence of plant diseases and disease vectors	The presence of plant diseases and their spread by vectors will inhibit plant growth and may affect mycorrhizal function	Negative	If presence of plant diseases and other stressors is not recognised, their impact on plant growth and/or mycorrhizal function may distort mycorrhizal benefit assessment	Identify the impacts of plant diseases on plant growth and mycorrhizal function

(continued)

Table 2.4 (continued)

Variable	Potential effect	Impact	Risk	Risk minimisation strategy
Climate attributes	Variation in temperature, sunlight and rainfall might influence plant growth and mycorrhizal function	Positive or negative	Independent and interrelated climate attributes might lead to inaccurate assessment of mycorrhizal benefits	Identify independent and interrelated climate impacts on plant growth and mycorrhizal function
Interaction of variables	Identified variables might have a linear or exponential effect on mycorrhizal function	Positive or negative	Lack of recognition of interaction of variables might lead to inaccurate assessment of mycorrhizal benefits	Identify the extent and nature of all possible interactions between variables

In order to estimate economic values of mycorrhizas at paddock or farm level, various factors affecting mycorrhizal influences on plants and soil need to be assessed, characterised and quantified (Tables 2.2, 2.3 and 2.4).

2.6 Risk Minimisation Strategies

A simplistic way to obtain an estimate of the economic benefits of mycorrhizas is to estimate the value of crop production with and without mycorrhizas present, although this is difficult to do under field conditions (see Gazey et al. 2004). Given the wide range of variables influencing either production outcomes or profitability, as well the difficulties associated with accurate measurement of the mycorrhizas themselves, it is important to employ risk minimisation strategies and to monitor and control, as far as possible, the conditions under which such an estimate is made.

Risk minimisation strategies can be taken into account to deal with some or all of the factors that impede realistic economic valuation of mycorrhizas. Some of the risks apply widely, but others are more farm specific or even paddock specific. Clearly the range of crops, soil, disease and climate conditions is almost limitless although we have attempted to identify the risks and variables inherent in this type of assessment. In the first instance, case studies should be implemented on a farm-by-farm basis whereby the independent variables associated with cropping regime, climate, soil conditions, disease organisms and vectors can be held reasonably constant with the presence and nature of mycorrhizas being characterised. While it may not be possible to cultivate a plot devoid of mycorrhizas if, within the same vicinity, a plot with a significantly different mycorrhizal profile can be identified, then any difference in productivity can be attributed to the difference in mycorrhizal profile (see Gazey et al. 2004). A dollar value can then be calculated for the mycorrhizas present, at least in terms of production.

If case studies for multiple farms that accommodate identified risks and conditions can be designed for a range of cropping regimes, their benefits for different production systems and environments can be estimated and the magnitude of their influence on soil health can be inferred. In this way, evidence of the overall economic benefits of mycorrhizas in agricultural and horticultural ecosystems can be painstakingly constructed (Table 2.4). Because different crops have different responses to and aptitude for mycorrhizal colonisation, it is very important to ensure that the case studies cover a wide range of crops. As Smith and Read (1996, p. 454) have observed: 'Both cultivation and monoculture appear to change the species composition of the fungal populations and reduce their diversity, but the impact of these changes on crop production has not been adequately evaluated'. It is thus likely that mycorrhizas not only respond differently to different regimes but that their benefits might vary significantly between agricultural and natural ecosystems: they not only constitute an important element of biodiversity but they also respond to ecosystem biodiversity.

2.7 Conclusion

Although some of the contributions of mycorrhizas are well documented for reasons mentioned earlier, it is difficult to quantify their economic benefits in agricultural ecosystems. This is because there has been little work done, either to identify systematically all such benefits or to identify how variables that influence mycorrhizal function might interact with each other to influence overall benefits. To complicate matters further, it is possible that the nature and magnitude of such benefits might be site specific, so that all possible mycorrhizal impacts for specific rotations in specific paddocks during a particular season might need to be considered. Numerous studies have claimed explicit benefits for soil health and agricultural production from mycorrhizal colonisation. For example, Chaurasia (2004) viewed AM as having universal benefits for agriculture as well as for forests and other ecosystems, Smith and Read (1996, 2008) and Gazey et al. (2004) discussed their potential for improving crop productivity, while Delian et al. (2011) specifically referred to their role in increasing profitability. Albrechtova et al. (2012) mentioned their 'numerous benefits for sustainable crop production' as well as their possible role in the decontamination of soils polluted by residual organophosphates. Brito et al. (2012) also saw arbuscular mycorrhizas as having an important role in sustainable crop production, while other authors (e.g. Smith and Read 1996; Schulz 2001) explicitly mentioned economic benefits. It is important to note that all of the benefits mentioned above are, in fact, economic benefits. While most people tend to think of economics as particularly relating to commerce or finance, anything through which benefits accrue to humanity is deemed to be economic ('economics' means 'humanity's household', while 'ecology' means 'nature's household'). This is one reason that the importance of nonmarket (intangible) values has been stressed here, especially as it relates to soil biodiversity. In its briefing paper, 'Valuing Nature', UNEP (2014, p. 1) observed that 'Part of the challenge is that the sheer range of benefits from ecosystems is often poorly understood. The term "ecosystem services"—the benefits derived from nature—is a useful concept for making the value of nature more explicit and relevant to human well being'. As mycorrhizas are part of soil biodiversity, and that they are part of an agricultural ecosystem, the 'sheer range' of benefits even from a relatively small-scale ecosystem is difficult to reflect accurately. While it is possible that unidentified elements and unknown benefits of mycorrhizas might be omitted from agricultural studies, thus reducing perceptions of their economic worth, it is also probable that their presence in agricultural ecosystems will have wider, undervalued, benefits to natural ecosystems, and vice versa.

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