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Review

The agronomic potential of vesicular-arbuscular mycorrhiza (VAM) in cereals– legume mixtures in Africa

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Low yield currently experienced in mixed cereal-legume systems in Africa, is a manifestation of different biotic and abiotic constraints to crop production. These constraints include low availability of different soil mineral elements, toxicity due to heavy metals and hence tissue damage by reactive oxygen species, low N_2-fixation from legumes, poor soil structure leading to low soil moisture availability, weeds, pests and diseases. However, mycorrhiza association involving cereal-legume mixed culture system may alleviate most of these constraints, thus, improving plant growth in crop mixtures. In this review, we report the agronomic potential of mycorrhiza association in cereal-legume mixed cultures.

Key words: Diseases, drought, heavy metals, intercropping, nutrient uptake, nitrogen fixation, pollution, soil structure, water use efficiency.

INTRODUCTION

Mycorrhiza association is a symbiotic non-pathogenic relationship between plant roots and fungal hyphal with a fungal connection between the soil and the root (Harley and Smith, 1983; Sieverding, 1991) . In this relationship, the fungi obtain carbon compounds and other nutritional requirements from the symbiotic plant roots, and in return, supply the plant with most of the immobile mineral elements such as Nitrogen (N), Phosphorus (P), Potassium (K), Calcuim (Ca), Copper (Cu) and Zinc (Zn) from the soil solution, thus, becoming a significant component in low-input agricultural systems (Barea and Jeffries, 1995). For example, Vesicular Arbuscular Mycorrhizas (VAMs) can supply 80% of P and 25% of N required by its symbiotic partner (Marshner and Dell, 1994). The importance of mycorrhiza association in both agricultural and ecological systems has therefore been widely recognised (Hayman, 1978; Mosse, 1978). It is well documented that the increase in plant growth resulting from VAM association is usually due to increased mineral elements uptake by the hyphae from the soil (Rhodes and Gerdeman, 1975; Harley and Smith, 1983; Hardie, 1986), improved water relations and pest resistance of host plants (Gange and West, 1994; Augé et al., 1994, 1995; Singh, et al., 1997; Smith and Read, 1997; Farahani et al., 2008), plants tolerance to a variety of abiotic stresses (Wilcox, 1990; Siqueira and Franco, 1988; Smith and Gianninazzi-Pearson, 1989; Jeffries, 1987), increased resistance to soil pathogens (Newsham et al., 1995; Lingua et al., 2002; Pozo et al., 2002) and increased tolerance in salinity in heavy metals (Shetty et al., 1995; Diaz et al., 1996; Al-Karaki et al., 2001; Feng et al., 2002; Mohammad et al., 2003). Increased uptake of macro- elements other than P has also been reported (Smith and Read, 1997; Clark and Zeto, 2000; Hodge et al., 2001) as well as increased uptake of some micro-elements (Gildon and Tinker, 1983; Faber et al., 1990; Kothari et al., 1991a; Li et al., 1991; Azaizeh et al., 1995). In addition, mycorrhizas have been shown to play an important role in maintaining soil physical properties (Tisdall and Oades, 1979; Tisdall, 1991; Degens et al., 1996).

Arbuscular mycorrhizal fungi belong to the order Glomales, sub orders Glomineae and Gigasporineae in the Zygomycetes (Morton and Benny, 1990). They involve aseptate fungi, characteristically named due to

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the structures found in the root cortex. Although different types of fungi do exist, the major types are ectomycorrhiza, ectendomycorrhiza and endomycorrhiza (Morton and Benny, 1990). Included in the endomycorrhizas is the so-called vesicular-arbuscular mycorrhiza (VAM). The endomycorrhiza (VAM) is common in most tropical agricultural soils (Jeffries, 1987) such as those found in Africa.

The functioning of these symbiotic agents is mainly affected by many factors. For instance, the degree of their infection and structural development is influenced by plant signals such as root exudates, seed diffusates and volatiles such as carbon(IV)oxide (CO_2) (Hepper, 1979; Graham et al., 1981; Gemma and Koske, 1988), root geometry (Mosse et al., 1973), mineral elements level in the soil (Mosse, 1973, Crush, 1974; Hayman, 1975; Hall, 1975; Daft and Hacskaylo, 1977), soil type (Menge et al., 1978) the presence of shade or light (Hayman, 1974), temperature (Furlan and Fortin, 1973) and finally the plant growth rates (Hall, 1975).

It is well established that benefits derived from VAM differ between plant species (Gerdermanns, 1975) due to their ability to absorb mineral elements from soil with low nutrients such as P (Ross, 1971; Mosse, 1973; Crush, 1974; Hall, 1975). For example, *Trifolium repens* is known to benefit more than maize (*Zea mays* L.) in low fertile soils (Hall et al., 1977; Hall, 1978).

Although relationship between VAM and soils in low input agricultural systems compared with conventional management have been reported (Limonard and Ruissen, 1989; Sattlemacher et al., 1991; Douds et al., 1993; Galvez et al., 1995, 2001), limited literature is available relating the role of VAMs on mineral elements uptake in cropping systems involving mixtures of symbiotic legumes and cereals such as those found in Africa. Understanding the role of mycorrhizas in these cropping systems, will further improve the manipulation of agronomic strategies and planning to maximise the benefits derived from mycorrhiza association, thus, improving the plant growth. This review will discuss the role of vesicular arbuscular mycorrhizal fungi and their potential different agronomic attributes in cropping systems involving cereals and symbiotic legumes such as those found in Africa.

Role of VAM on the availability and uptake of phosphorus

Phosphorus (P) is an essential mineral element in all living organisms because of the role it plays. Perhaps the structure of nucleic acid and phospholipids, carbon metabolism and enzymes activation/deactivation would not have existed, if it wasn't for P. This mineral element is quantitatively rated as second most important inorganic mineral element for plant growth after N, and its deficiency is known to limit productivity in most cropping systems. Contrary to N which can symbiotically be fixed by leguminous plants, P is a non-renewable resource and highly immobile (Lambers et al., 1998; Vance et al., 2003). Although it is reported that applied P levels in most agricultural systems are increasing despite global depletion, it is nevertheless non available for plant growth especially in plants lacking specific adaptation mechanisms to P deficiency (Gerke et al., 1994; Jones, 1998a) . So, there is a need to urgently explore different natural microbial associations in different cropping systems such as those used in Africa, which may efficiently access P and make it available to plants for growth. One reliable option is the association between mycorrhiza and plants such as those involving cereals and legumes.

In Africa and other tropical areas, intercropping cereals and symbiotic legumes is the commonest cropping system for many farmers (Okigho and Greenland, 1976; Chui and Shibles, 1984; Seyoum, 1990; MAPA, 1999; Ndakidemi, 2006; Makoi et al., 2009). This system may offer a broad scope for sustainable agriculture and improved soil health through N_2 fixation and excretion from the legume (Papendick et al., 1976; Wiley, 1979; Eaglesham et al., 1981). In addition, the introduction of mycorrhiza fungi in such systems may enhance nutrient uptake and further improve plant growth. Such interaction is important because intercropping systems are intensive, explore more resources and mostly limited with plant growth resources such as nutrients including P (Jackman and Mauat, 1972; Papendich et al., 1976; Evans, 1977; Wiley, 1979; Ssali and Keya, 1983; Pereira and Bliss, 1989; Hart, 1989a, 1989b). Thus, introduction of appropriate mycorrhiza in such systems can ultimately improve P acquisition to the crop plants involved. For example, Brundrett (2002) reported that over 82% of higher plants are capable of forming symbiosis with VAM. This is also possible with the commonest cereal-legume mixtures such as those found in Africa. The enhancement of plant inorganic phosphorus (Pi) availability by mycorrhiza is more efficient in plants which have root system with relatively course, but few root hairs which may require support from mycorrhiza hyphae in accessing P from the soil (Jayachandran et al., 1992; Joner and Jakobsen, 1994; Graham and Eissenstat, 1994; Cade-Menun and Berch, 1997). Most cereal-legume mixtures have combination of these characters that may benefit each other in the associated culture. The enhancement of P could be due to positive increase in surface area and phosphatase activities of the extraradical hyphae (Li et al., 1997a; Tarafdar and Marschner, 1994, 1995; Song et al., 2000; Feng et al., 2002) resulting from acid phosphatases released into the soil and finally made available for plant growth (Saito, 1995; Joner and Johansen, 2000). Research evidence suggest that under favourable conditions, mycorrhizae association involving legumes and cereals in other parts outside Africa can access P, water, and other related mineral nutrients up to a radius of about 5 m (Teste and Simard, 2008). Thus, appropriate cereal- legume mixtures can eventually improve P acquisition of the component crop through enhanced root colonisation by appropriate mycorrhizal fungi.

VAM role in facilitating the acqusition of other mineral elements to plants

Current reports on VAM association and mineral elements availability have constantly concentrated on P uptake (Thompson, 1987; Smith and Read, 1997; Graham, 2000; Plenchette et al., 2005). However, there is evidence that VAM association can also lead to acquisition of other mineral elements for their own uses as well as the growth and development of their hosts in mixed culture systems (Gidon and Tinker, 1983; Fabier et al., 1990; Kathari et al., 1991a; Li et al., 1991; Azaizeh et al., 1995). For example, Zn nutrition is reported to be influenced by the VAMs association (Bell et al., 1989). Enhancement of N, K, Ca, Mg, Fe and Cu uptake by VAM have also been reported (Raven et al., 1978; Francis et al., 1986; Harley and Smith, 1983; Rabatin and Stinner, 1989; Smith and Read, 1997; Clark and Zeto, 2000) . Although in many instances VAMs simultaneously leads to changes in the absorption of several mineral nutrients in the host, the effect on different mineral elements is rarely similar (Lambert et al., 1979; Kothari et al., 1990; Wellings et al., 1991; Thompson, 1987, 1991, 1994; Azaizeh et al., 1995; Smith and Read, 1997; Srivastava et al., 2002; Mohammad et al., 2003). For example, Kothari et al. (1990) reported that colonisation by VAM may result into mineral element antagonism in the host, an effect which may be mediated by the con-centration of other soil mineral elements (Liu et al., 2000). For instance, high aluminium (Al) concentration in soil led to significant reduction in tissue Ca and Magnesuim (Mg) concentrations (Cumming and Ning, 2003). Highly mobile nutrients such as nitrate (NO_3)- uptake was also enhanced by VAM during drought conditions (Azcon et. al., 1996; Subramanian and Charest, 1999). Similarly, absorption of NH_4^+-N mineral fertilizers was improved by transferring it to the host plant (Ames et al., 1983; Johansen et al., 1993). Additionally, reduction of manganese (Mn) absorption by host plant following VAM colonisation for instance, is especially common even where uptake of other mineral elements has increased (Kothari et al., 1991b; Azaizeh et al., 1995). The greatest challenge however, will be the field identification of different associations, degree of selectivity between the host and the fungi, and quantitative assessment of mineral elements in mixed culture systems. This is because, it was previously reported that different VAMs have varying effects on different plant species, ranging from strongly positive increase to decreases in mineral elements uptake and/or plant growth (Monzon and Azcon, 1996; Bever et al., 2001; Van der Heijden, 2002; O'Connor et al., 2002; van der Heijden et al., 1998b, 2003; Vandenkoornhuyse et al., 2003; Munkvold et al., 2004). Therefore, understanding of the interaction of this association in cereal and legume mixed culture systems will widen a scope of additional strategies needed in improving the acquisition of macro and micro nutrients in different cropping systems associated with VAM.

Role of VAM on nitrogen fixation

High-quality food production rich in protein is highly dependent on the availability of sufficient N. Nitrogen deficiency is the major constraint to productivity in small holder cropping systems. Plant acquires N from two principal sources: (a) the soil, through external input, manure, and/or mineralisation of organic matter; and (b) from the atmosphere through symbiotic N_2 fixation. It is generally acknowledged that cereals gain more N from the associated N-fixing legume partner under conditions of limiting soil nitrogen (N) (Vest, 1971; Eaglesham et al., 1981; Ndakidemi, 2005; Makoi et al., 2009). The actual mechanisms of the presumed N-mediated benefit from legumes to cereals are still well not understood. In this regard, lack of understanding may limit our ability to successfully manipulate cereal-legume mixtures to fully exploit both the N_2 fixing capacity of the symbiotic legumes and N transfer to the associated cereal component crop.

One means by which symbiotic legumes can partner with cereals in mixed culture systems is to share the N-fixed from the legume. Since N_2 fixation is done by symbiotic legumes, an elaborate transport system needs to be in place so that part of the nitrogen fixed reaches the cereal for growth and yield formation. Several workers have reported transfer of the nitrogen fixed from symbiotic legume to cereal via decomposition and mineralisation of legume roots and/or nodules (Burity et al., 1989; Haynes, 1980) and root exudates released from the legume roots (Makoi et al., 2009; Ndakidemi, 2005; Brophy and Heichel, 1989; Burity et al. 1989; Wacquant et al., 1989). There is evidence that such N-fixed or mineralised in the soil can be transferred by vesicular arbuscular mycorrhizal (VAM) fungi to the cereal partner through interplant reeves hyphal connections (Haystead et al., 1988; van Kessel et al., 1985). Similarly, VAM fungi are known to assimilate and transport both NH_4^+ ions and some organic-nitrogen compounds to their host plants, particularly under conditions of low N availability and low pH (Raven et al., 1978).

In a field experiment involving ryegrass (*Lolium perenne*) and clover (*Trifolium repens*) Haystead et al. (1988) suggested that direct N (applied as $(^{15}NH_4)_2SO_4$.) transfer via hyphal connections between roots of the two closely associated living plants was enhanced via VAM infection. In a glasshouse experiment with soybean and maize in mixed culture, similar direct transfer of N via hyphal connections has also been reported (Ames et al., 1983; Francis et al., 1986; Van Kessel et al., 1985). Mycorrhiza can also increase the symbiotic performance of the nodulated legumes by alleviating stresses imposed to such legumes in their mixed culture (Allen, 1991) and by modifying the effect of competition of the immobile mineral elements such as P and K (Vandeemer, 1989). Inoculation with *Glomus mosseae* sativa enhanced the activity of *Rhizobium meliloti* when applied as inoculant (Azcon-Aguillar et al., 1979) . Availability of plant N in a cereal-legume mixed culture can also be affected due to increased uptake of N by mycorrhizal fungi, resulting from increased mycorrhizal surface area, or by altering the forms of soil N available to the host plant (Paul and Clark, 1989; Ibijbijen et al., 1996). Although VAM could also enhance plant N uptake from organic sources (Hodge et al., 2001; Read and Perez-Moreno, 2003), more work is required to fully understand the mechanisms involved. This information is important in understanding that VAM's role is not only of N transfer between crop components in mixed cropping systems, but also how its extended surface area can affect the soil N uptake and the forms in which N is available to component crops in mixtures.

VAM as protectant of plants against heavy metals and induced oxidative stress in the tissues

Heavy metals are a group of metal elements with specific weight greater than 5 g cm^{-3} (Weast, 1984; Holleman and Wiberg, 1985). Unlike other mineral elements such as Iron (Fe), Cu, Mn, and Zn which are considered essential for normal plant growth in many cropping systems, heavy metals such as cadmium (Cd), lead (Pb), mercury (Hg) and arsenic (As) are not essential for normal plant growth (Mertz, 1981). At elevated levels, they are very toxic to most organisms (Hall, 2002; Schutzendubel and Polle, 2002; Järup, 2003). In the polluted areas involving cereals and legumes in mixed culture systems, roots of both component crops may be in close and immediate contact with heavy metals. Their acquisition at the root-soil interface, partitioning throughout the plant organs and cellular homeostasis must be well controlled by the plant so as to avoid both deficiency and toxicities resulting from excessive uptake. The non essential heavy metals can enter the root system via passive diffusion or by low-affinity metal transporters with broad specificity (Hall and Williams, 2003).

Heavy metals of high concentration than normal in agricultural soils where majority of crops grow, is a subject of growing concern as they may have long term effects on soil functioning (Brookes and Verstraete, 1989; Tyler et al., 1989) . They are known to interfere with important functions in the plant. For example, the metals are known to alter important plant membrane's intrinsic proteins such as H+-TPases (Hall, 2002), produce reactive oxygen species (ROS) which damage plant tissues (Schutzendubel and Polle, 2002) leading to chlorosis, growth retardation, browning of roots, and other harmful effects on the photosystems. Since heavy metals are biodegradable with a possibility of entering the food chain, they are therefore a long term threat to both the environment and human health (Järup, 2003). Although conventional remediation methods involving physical displacement transport and storage do exist, they are nevertheless very expensive and it only postpones the problem to the future generations.

Interestingly, VAM have been reported to evolve strategies which can alleviate heavy metal threats in mixed culture systems and, thus, from the food chains (Salt et al., 1998; Clemens, 2001; Li and Christie, 2001; Hall, 2002; Macova et al., 2003; Kramer, 2005; Pike and Rennenberg, 2005). Amongst the strategies used include immobilisation of metal compounds, precipitation of polyphosphate granules in the soil, adsorption to chitin in the fungal cell walls and chelation of heavy metals inside the fungus (Gaur and Adholeya, 2004). For example, VAM can bind heavy metals beyond the plant rhizosphere by releasing an insoluble glycoprotein commonly known as glomalin (Gonzalez-Chavez et al., 2004; Wright and Upadhyaya, 1996, 1998). These authors reported that 1 g of glomalin could extract up to 4.3 mg Cu, 0.08 mg Cd and 1.12 mg Pb from polluted soils (Gonzalez-Chavez et al., 2004). In addition, hyphae binding in the soil are an important sink for heavy metals due to their large surface area. For instance, passive adsorption to the hyphae leads to binding of up to 0.5 mg Cd per g dry biomass (Joner et al., 2000). In other studies, the immobilisation and uptake of Pb was found to be greater in roots of mycorrhizal relative to the non-mycorrhizal plants (Chen et al., 2005). There is also scientific evidence suggesting that fungal vesicles may provide additional detoxification mechanisms by storing toxic compounds (Gohre and Paszkowski, 2006). In maize for example, heavy metals are selectively retained in the inner parenchyma cells coinciding with fungal structures (Kaldorf et al., 1999). Similarly, in cropping systems involving legumes such as pea (Rivera-Becerril et al., 2002) and clover (Medina et al., 2005), VAM can provide mycorrhizal buffer to stress imposed by Cd (Rivera-Becerril et al., 2002) or Cd tolerance by changing its polyamine metabolism, thus, stabilising Cd in the root system of colonised plants (Paradi et al., 2003).

Comparatively, mycorrhiza colonised plants bioremediated. As from contaminated soils by removing 88.1 g As kg^{-1} soil compared to only 0.06 mg As kg^{-1} soil by non-colonised plants. Similarly, mycorrhiza colonised plants bioremediated the Nikel (Ni) contaminated soil by 30% more than non-colonised plants (Turnau and Mesjasz-Przybylowicz, 2003) . The As and Ni bioremediation from the soil through colonised plants could have antagonistically increased soil P which could be available for plant growth and development (Liu et al., 2005; Leung et al., 2006). There is evidence that inorganic phosphate (Pi) for non-colonised plants was 36.3 mg pot^{-1} relative to 257 mg pot^{-1} in colonised plants. The challenge is that the whole VAM system is complex, difficult to identify all VAM species and their classification, levels of tolerance to heavy metals in the study area, and the complex soil interaction which could influence the efficiency of heavy metals stabilisation. This process is important, because heavy metals are likely to be bio-stabilised before they get their way to the rhizosphere of crop components in mixed culture systems and subsequently to the food chain.

Role of mycorrhizas on crop water relations

Plant growth in mixed culture systems is closely associated with moisture supply and the amount of storage that is readily available in the root zone for plant consumptive use. To maximise plant growth, soil moisture content should be maintained at field capacity either naturally through rainfall or artificially by irrigation throughout the critical stages of plant growth. In stressed conditions, there is substantial evidence suggesting that VAM may increase the host plant's tolerance to water stress (Davies et al., 1992, 2002; von Reichenbach and Schonbeck, 1995; Smith and Read, 1997; Auge´, 2004), including that caused by high salinity (Al-Karaki et al., 2001; Feng et al., 2002; Mohammad et al., 2003) . The mechanisms used by VAM include increased root hydraulic conductivity, improved stomatal regulation, osmotic adjustment in the host, enabling extraction of water from smaller pores through improved contact with soil particles as a result of the hyphae binding effect (Auge, 2001, 2004), increased evaporative leaf surface area (Filler, 1985; Nielsen, 1987), and increased finely divided roots for greater root surface area to increase water absorption (Allen et al., 1981; Ellis et al., 1985; Osonubi et al., 1994; Okon et al., 1996). These mechanisms suggest that VAM association with component crops growing in moisture stressed mixed culture systems, may benefit from improved moisture supply, thus, improving grain yield. VAMs have similarly been reported to alleviate moderate drought stress, and in more severe drought conditions they become ineffective (RuizLozano and Azcon, 1995; Ryan and Ash, 1996; Bryla and Duniway, 1997; Bryla and Duniway, 1998). Surely, the role of VAM in drought tolerance remains unclear (Auge et al., 1992a). These contradictions pose a challenge to scientists to come up with effective combinations of VAM and host plants in mixed culture systems, with a view to minimise moisture stress in arid and semi arid regions of Africa.

Role of mycorrhizas on soil structure

Soil structure creates a unique three dimension framework solid and voids (pores). The configuration of particles within peds forms numerous crevices and cavities (pores) that trap and store soil water. Likewise, irregular void spaces created between peds play major role in water dynamics. The abundance and size of the soil pore are probably the most important aspect of soil structure. Preservation of soil structure is difficult. Rather, weak forces bind particles into peds, making them very susceptible to natural and man-caused physical/chemical disruption. Raindrop impact, machinery compaction, dispersion, oxidation losses of organic binding agents through excessive tillage are probably the most prevalent aggregate destroying factors.

Aggregation of soil particles can occur in different patterns, resulting in different soil structures. The circulation of soil water varies greatly according to soil structure (Auge, 2001), thus, making it an important element for plant growth and development. Interestingly, VAM associations have a direct effect on soil structure, which is especially important in mixed culture systems, where cultivations and low levels of soil organic matter tend to result in damaged soil structure. For example, Jakobsen and Rosendahl (1990) reported that as much as 20% of all fixed carbon (C) in host plant is transferred to the fungal partner and in return, VAM produces significant biomass to the agricultural soils which then plays the role of building up the soil structure (Miller et al., 1995; Rillig et al., 1999).

VAM association with crop components in mixed culture systems have been reported to have a great impact in soil structure (Wright and Upadhyaya, 1998; Borie et al., 2000; Franzluebbers et al., 2000; Wright and Anderson, 2000; Rillig et al., 2003; Rillig, 2004) . For example, through the enmeshing effects of hyphae, VAM bind soil microaggregates into macroaggregates (Tisdall, 1991; Tisdall et al., 1997), produces glomalin which upon accumulation in soils, sticks hyphae to soil directly (Rillig et al., 2001), release exudates into the soil, and promote aggregate stability as a result of rapid hyphal turnover which provide C to other soil micro organisms (Jastrow et al., 1998; Johnson et al., 2002; Staddon et al., 2003). Although the overall effect of hyphal enmeshment and C inputs in mixed culture systems reflects a significant increase in soil structural stability (Thomas et al., 1986; Bethlenfalvay and Barea, 1994; Bethlenfalvay et al., 1999; Piotrowski et al., 2004), the observed wide range of results suggests more understanding of different combinations in the association of host-fungal in mixed culture systems to further improve the soil structure for the benefits of plant growth and development.

The role of VAM on weed control (the case of striga)

In many cropping systems of the semi arid tropics, yield reduction due to weeds including the most notorious ones, compose a large percentage of farmer's complaints, and, is one of the reasons for their income disparity. Witchweed (Striga hermonthica (Del.) Benth. Scrophulariaceae) have been reported to seriously affect cereal production in many countries of the tropics. Sorghum (*Sorghum bicolor* (L.) Moench), millet (*Pennisetum glaucum* (L.) R. Br.), and maize (*Zea mays* L.), the major staple food crops produced in mixed culture systems in Africa, are hosts of *S. hermonthica* and suffer to varying degrees from striga infection. For example, infection of striga resulted in a significant reduction in cereal grain yield between 20-100% (Ndakidemi and Dakora, 2003; Lendzemo et al., 2004). This weed has been described as parasitic in nature and prolific. An individual striga plant produces thousands of tiny dust-like seeds that can remain dormant in the soil for 15–20 years (Ramaiah et al., 1983). Germination and haustorial formation are dependent on striga seeds receiving chemical cues from host roots (Stewart and Press, 1990).

Considerable evidence suggests that VAM can affect the nature of weed communities in mixed culture systems in a variety of ways, including changing the relative abundance of mycotrophic weed species (hosts of VAM), and non-mycotrophic species (non-hosts) . These effects may merely change the composition of weed communities. However, it is quite plausible that interactions with VAM can increase the beneficial effects of weeds on the functioning of agro-ecosystems. Through a variety of mechanisms, weed VAM interactions may reduce crop yield losses due to weeds, limit weed species shifts, and increase positive effects of weeds on soil quality (Templeton et al., 1979). If beneficial effects of VAM on the composition and functioning of weed communities can be confirmed by more direct evidence, then, VAM could provide a new means of ecologically-based weed management. For instance, with VAM fungal inoculation, numbers of *S. hermonthica* in shoots were significantly reduced by 30% and more than 50% on maize and sorghum, respectively (Lendzemo et al., 2005). Similarly, striga performance in the presence of VAM fungi was negatively impacted, with reduced and/or delayed germination, attachment (Lendzemo, 2004), and emergence (Lendzemo and Kuyper, 2001; Gworgwor and Weber, 2003). Sustainable systems targeting striga management on cereals in particular might benefit from managing this symbiotic interaction.

Role of Vam on pests and disease control in cropping systems

Pests and diseases in many cropping systems has been a hindrance factor to most of the farmer's economy in Africa. Many techniques including chemical measures to arrest the situation have not until recently been 100% successful. However, researchers are using different and/or a combination of techniques to further reduce this problem. It has been reported that VAM association plays a role in the suppression of crop pests and diseases, in particular soil-borne fungal diseases (Schonbeck, 1979; Paulitz and Linderman, 1991; Linderman, 1994; Azco´n-Aguilar and Barea, 1996; Borowicz, 2001; Harrier and Watson, 2004; Whipps, 2004). The reductions in disease severity is reported to occur and caused a significant increase in grain yield compared to plants not inoculated with VAM (Torres-Barraga´n et al., 1996; Dar et al., 1997; Karagiannidis et al., 2002). In some cases, the apparent resistance of plants to pests or diseases may be simply the result of improved mineral elements (Cordier et al., 1996; Karagiannidis et al., 2002), and/or multiple mechanisms of resistance, probably operating simultaneously (Whipps, 2004). Perhaps the most important of these, is exclusion, which seems to be a simple case of competition for space (Azco´n-Aguilar and Barea, 1996).

VAM colonisation does not in itself cause a significant defensive response by the plant but induces the plant to respond faster to infection by pathogenic fungi (Whipps, 2004), by evolving several mechanisms. For example, most effective control is achieved when colonisation by VAM takes place before attack by the pathogen (Slezack et al., 1999; Matsubara et al., 2001; Sylvia and Chellemi, 2001), and when there are changes in root exudates (Filion et al., 1999; Norman and Hooker, 2000). Released root exudates may lead to changes in the rhizosphere microbial community and populations (Dar et al., 1997), host root architecture (Yano et al., 1996; Vigo et al., 2000) or root biochemistry connected with plant defence mechanisms (Azco´n-Aguilar and Barea, 1996; Gianinazzi-Pearson et al., 1996). The different VAM operating mechanisms have also been attributed to suppression of plant pathogenic nematodes (Jaizme-Vega et al., 1997; Vaast et al., 1998; Habte et al., 1999; Nagesh et al., 1999; Talavera et al., 2001), above ground fungal disease (West, 1995; Feldmann and Boyle, 1998) and herbivores (Gange and West, 1994; Gange et al., 2002). Despite the positive results presented above, future success of this association in the control of pest and disease will depend on the interaction between VAM, host plants in mixtures and disease and/or pest specificity (Matsubara et al., 2000; Gange et al., 2003). However, most studies of pest and disease involving VAM as control have mostly been in form of simplified glasshouse experiments, often, not representative of most field conditions, hence, making them difficult to reproduce in the field (Bødker et al., 2002). More understanding of VAM association in mixtures involving cereals and legumes and its relationship with pest and diseases will enable us to ascertain the potential role(s) of these biological agents in complex farming systems.

Conclusion

In some mixed cereal-legume cropping system used in Africa, the crop production systems may be improved by introducing strategies which are environmental friendly. Biological systems such as those involving mycorrhiza and cereal-legume mixtures may be used to supplement the expensive chemical fertilizers and in the alleviation of various biotic and abiotic constraints. The mycorrhiza fungi live symbiotically with the roots of different architecture such as those involving cereal-legume mixtures. They may enhance the uptake of water and nutrients (macro- and micro-elements) from the soil making them available to plants and hence meeting some of the mineral nutritional requirements. This could also help to reduce some of the fertility constraints, moisture requirements, and increases the drought resistance of the crops. Generally, mycorrhiza will improve soil struc-ture, enhance plant health and vigor and minimize stress caused by pathogenic fungi, weeds and pollution from heavy metals. This review highlights the existing potential(s) of mycorrhiza in the complex cereal-legume mixtures such as those used in smallholder farming systems in Africa.

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