Alfalfa Productivity & Nutrient Uptake Are Related to Interaction with Soil Microbiome

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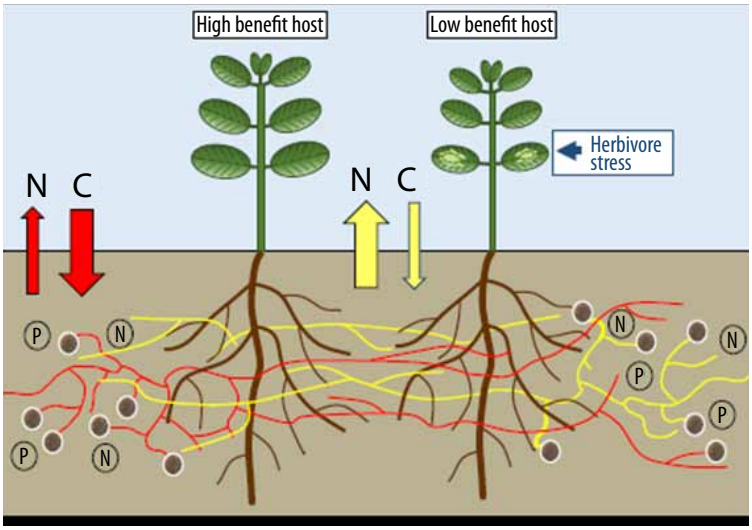
Alfalfa is key to sustainable agriculture, contributing to soil health of entire cropping systems by providing nitrogen credits to following crops, reducing nitrate leaching (cutting back water pollution), increasing biodiversity, offering pollinator food sources, maintaining good soil structure, and providing a habitat for a diverse wildlife. In addition, alfalfa provides feed to livestock. Alfalfa productivity and stand persistence are closely related to its interaction with the soil microbiome. Arbuscular mycorrhizal (AM) fungi colonize the roots and form arbuscules in the root cortex of host plants. AM fungi significantly improve the supply of their host plant with important soil nutrients (N, P, K), but also increase the resistance of plants against many abiotic (e.g., drought, salinity, heavy metals) and biotic stresses (plant pathogens). AM fungi facilitate plant P uptake by increasing the nutrient-absorbing surface area through their extraradical mycelium and by mobilizing sparsely available P resources. In return for these benefits, host plants, such as alfalfa, provide 20-25% of their carbohydrates to their AM fungal communities. AM fungi form extensive hyphal networks in soil and can connect multiple plants through common mycorrhizal networks (Figure 1). Similarly, host plants are simultaneously colonized with several AM fungi, and complex AM fungal communities. Plants and fungi reciprocally reward partners providing more benefit with resources (Figure 1). Host plants compete with carbon for nutrients available for the common mycelia network and regulate carbon supply to their symbiotic partners according to nutrient demands. Similarly, AM fungi preferentially allocate nutrient resources available for their common mycorrhizal networks to plants providing more carbohydrate benefits, and not to plants with reduced photosynthetic activity (e.g., herbivore stress).

Figure 1. Common mycelial networks of a low and high benefit host.



Adapted from Bücking et al. 2016.

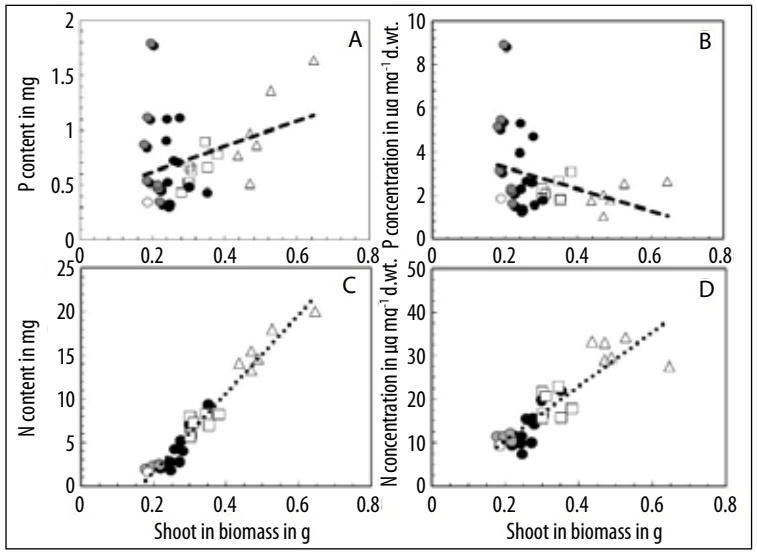
Previous research has demonstrated AM symbiosis can improve alfalfa photosynthetic rates under water deficit, increase biological N_2 fixation, enhance P and N nutrition, improve alfalfa tolerance to K^+ deprivation, and increase forage yield in low fertility or high-saline soils. Mycorrhizal alfalfa plants exposed to elevated CO_2 concentrations showed higher leaf, stem, and root biomasses, and reduced lignin concentrations in their cell walls than non-mycorrhizal alfalfa plants. AM colonization can improve forage nutritive value by increasing hemicellulose levels in cell walls and glucose and fructose contents in stems. Changes in cell wall composition are due to carbohydrate redirection usually used for shoot growth to AM fungal communities in detriment of secondary metabolite synthesis (e.g., lignin). These mutualistic associations with AM fungi play an important role in alfalfa performance, especially in areas with low soil fertility, water stress, and high salinity.

Thirty-one AM fungal isolates from 11 fungal species were tested to evaluate the effect on P and N nutrition in alfalfa plants. Based on biomass response, fungal isolates were classified as low-, medium-, and high-quality isolates, and correlated to mycorrhizal growth responses. Shoot growth was positively correlated to P content (Figure 2A), but not to shoot P tissue concentration (Figure 2B) and several of the low-quality fungal isolates led to higher P contents and tissue concentrations in the shoot than high-quality fungal isolates. The distinguishing factor between high-quality isolates and low- or medium-quality isolates was their effect on N nutrition. Shoot biomass was positively correlated to N content and tissue concentration, and particularly high-quality isolates improved plant N nutrition substantially (Figure 2C, D).

Mycorrhizal colonization and shoot and root P concentrations in alfalfa are greater under saline conditions than non-saline conditions. Inoculation of alfalfa with AM fungi considerably increased forage yield under saline and non-saline conditions, biomass regrowth, and concentrations of C, N, and P in leaves and roots, especially under water stress. AM colonization also reversed salinity effect on K^+ and Na^+ contents by enhancing K^+ absorption under saline conditions. Results indicate AM fungi can play a significant role in alfalfa regrowth potential after harvest under salinity and water stress.

Despite positive effects of AM associations, their large-scale application is limited due to low availability of inoculum in bulk quantities at reasonable costs. Biofertilizers containing AM fungi are being promoted as tools for sustainable agriculture, but too expensive for large acreages of alfalfa. Additional research will allow for improved alfalfa management practices not only for increased yield and quality, but also for more beneficial AM fungal communities.

Figure 2. Correlation between shoot biomass of *Medicago sativa* and effect of 31 different AM fungal isolates on P and N contents (A, C) and tissue concentrations (B, D). Non-mycorrhizal control – open circle; low-quality fungal strains – gray circles; medium-quality fungal strains – open squares; high-quality fungal strains – open triangles; other fungal isolates – black circles.



Adapted from Mensah et al. 2015.

References

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