

Novel mechanisms of biological weed inhibition effected by common mycorrhizal networks.

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While two-thirds of all plant species are symbionts with arbuscular mycorrhizal fungi (AMF), certain species of plants do not form such associations. Most agricultural crop species, with exceptions such as sugar beets, form a symbiotic association with AM fungi (Smith & Read, 2008). Conversely, many ruderal weeds that interfere in agricultural settings are non-mycorrhizal (Goodwin, 1992). AMF is capable of affecting the ecology of weeds (Jordan, Zhang, & Huerd, 2000) in addition to desired crops. Weed management issues persist in production agriculture. Globally, the number of herbicide-resistant weeds is increasing, especially with resistance to multiple modes of action (Heap, 2015). Mechanical control systems present problems with erosion, fuel and labor costs (Wicks, Burnside, & Felton, 1995). Novel weed control mechanisms demand exploration. I hypothesize that AMF can be managed to function as a biological weed inhibitor in summer-annual production systems.



This weed suppression occurs as a result of one of two possible mechanisms depending on a weed's hosting characteristic: a host-dominance effect on weeds that are also hosts to AMF (host-dominance) and antagonism to weeds that are not hosts to AMF (non-host interference). The most likely scenario for the operation of these mechanisms would appear to be in established AMF extra-radical mycelia (ERM) that form prior to the planting of summer-annual crops. The ERM extends the area of the fungi in the soil as well as penetrates plant cells. The plants interact by means of a common mycorrhizal network (CMN) that occurs where two or more root systems are interconnected by mycorrhizal fungal hyphae (Newman, 1988). While the research shows antagonism of weeds by AMF, it has not been shown in a summer-annual crop host with both host and non-host weeds interacting in an established ERM.

Host –Dominance Mechanism As a host plant that is able to provide more carbon in exchange to the ERM than a subordinate plant; a dominant host such as maize will receive more phosphorus or nitrogen. The plant that makes contact and establishes with a CMN first will garner more benefit as long as it provisions more carbon via photosynthate. Conversely the host that is subordinate in provision of C will receive less P and N in exchange (Hammer, Pallon, Wallander, & Olsson, 2011). This exchange would ensure that the dominant host would inhibit the subordinate host. In this case, the desired crop would inhibit the undesired weed.

The crop host that is dominant in supplying to the CMN will limit the nutrients available for the growth of weed species that germinate later in the mycelia, and this weed will subsequently receive less P or N by providing less carbon to exchange. This increasing gap in fitness between the crop host and suppressed weedy host will potentially continue until light also becomes limiting for the weedy host, further reducing competition to the crop.

AMF suppression of host weeds by the host-dominance mechanism is supported by results from several pilot experiments within the Jordan lab. Based on preliminary findings, a dominant host negatively affected subordinate weeds in a CMN. External funding will allow this work to be pursued on a larger scale to investigate weed biocontrol in a summer-annual host crop.

Non-host Interference Mechanism Many weed species that consistently appear in crops settings belong to families that are predominantly AMF non-hosts such as Amaranthaceae, Brassicaceae, Caryophyllaceae, Chenopodiaceae, Cyperaceae, and Polygonaceae (Jordan et al., 2000). Multiple examples exist of the effects of AMF inhibiting early growth of weedy species (Francis & Read, 1995), (N. C. Johnson, Graham, & Smith, 1997), (N C Johnson, 1998), (Muthukumar, Udaiyan, Karthikeyan, & Manian, 1997). A specific example of this effect, *Chenopodium album* experienced a 33% reduction in survivorship when grown with AMF (Francis & Read, 1995); as well as an 80% reduction in biomass in a diverse AMF community (Jordan et al., 2000). The experimental system of Francis and Read (1995) observed weed seedlings that germinated in soil containing an AMF ERM with mycorrhizal connections in a living host plant. This CMN produced strong effects on germination, early growth and survivorship rates (all decreased). The single AMF *G. intraradices* exhibited antagonistic effects on *Stellaria media*, from the Caryophyllaceae family, in an established ERM (Veiga, Howard, & Heijden, 2012). While AMF have been found to suppress non-host weed species, the previous work has not been done with agroecosystems and agricultural weeds. Germinating both non-host weeds and host crop plants in an established CMN allows the investigation of the non-host interference mechanism of weed biocontrol. This action of this mechanism has potential for weed management in a summer-annual crop setting.

To test either mechanism, a CMN will be established with a nurse crop (a non-crop, non-weed host) in a nutrient-limited soil container, allowing the mycelia to maintain its network after removal of the nurse or cover crop. The container will need a root-blocking barrier that will allow the hyphae of the fungi to establish a CMN. The barrier would block roots in the host-dominant setting from contacting one another or a nutrient source. In the non-host interference experiment, that barrier will physically prevent plant roots from interacting with one another, which could confound results of weed suppression by the fungal mechanism. Both proposed mechanisms occur early in the growth of the crop plant and the weeds; from time of planting through the closing of the canopy which reduces light resources for the already suppressed weed. As a summer-annual crop plant that serves as an AMF host, *Zea mays* responds positively with growth and yield to the presence of an ERM (Kabir & Koide, 2002).

Both mechanisms depend on limited soil disturbance as tillage practices can inhibit diversity of AMF and the presence of the CMN (Douds & Millner, 1999)(Mcgonigle & Miller, 1996). In terms of these potential weed suppression mechanisms, a depth and distance limit may exist for type of tillage or of soil disturbance of an existing CMN. The tillage practice (chisel plow, no-till, or ridge-till) may affect the amount of time the CMN requires to cycle the nutrients and make them available to the resource pool for host plants. The tillage practices of summer-annual production demand investigation to their ability to allow or enhance a CMN for weed suppression to occur.

In addition to weed suppression, an active CMN of AMF can provide other ecosystem services. Both phosphorus and nitrogen are important nutrients in plants of both crops and weeds (Fitter, Helgason, & Hodge, 2011)(Rinaudo, Bàrberi, Giovannetti, & Heijden, 2009). These macronutrients are concerns to production agriculture in terms of overall yield, controlling future input costs and managing the nutrients efficiently to reduce leaching or runoff. AMF has potential for agricultural crops of reducing inputs of these nutrients by maximizing their efficiency (van der Heijden & Horton, 2009). Additionally, the presence of an active CMN provides benefits of increased soil organic matter and soil aggregation (Rillig, 2004). In future agroecosystems, with movement toward reduced tillage and cover crops, a CMN with weed management benefits is possible. Understanding the services of AMF in different crop settings or tillage practices will achieve steps toward more sustainable agriculture whether employed in organic or conventional systems.

Bibliography

- Douds, D. D., & Millner, P. D. (1999). Biodiversity of arbuscular mycorrhizal fungi in agroecosystems. *Agriculture, Ecosystems and Environment*, 74(1-3), 77–93. [http://doi.org/10.1016/S0167-8809\(99\)00031-6](http://doi.org/10.1016/S0167-8809(99)00031-6)
- Fitter, a. H., Helgason, T., & Hodge, a. (2011). Nutritional exchanges in the arbuscular mycorrhizal symbiosis: Implications for sustainable agriculture. *Fungal Biology Reviews*, 25(1), 68–72. <http://doi.org/10.1016/j.fbr.2011.01.002>
- Francis, R., & Read, D. J. (1995). Mutualism and antagonism in the mycorrhizal symbiosis, with special reference to impacts on plant community structure. *Canadian Journal of Botany*, 73(S1), 1301–1309. <http://doi.org/10.1139/b95-391>
- Goodwin, J. (1992). The role of mycorrhizal fungi in competitive interactions among native bunchgrasses and alien weeds: a review and synthesis. *Northwest Science*, 56, 251–260. Retrieved from <http://www.cabdirect.org/abstracts/19932328810.html>
- Hammer, E. C., Pallon, J., Wallander, H., & Olsson, P. A. (2011). Tit for tat? A mycorrhizal fungus accumulates phosphorus under low plant carbon availability. *FEMS Microbiology Ecology*, 76(2), 236–44. <http://doi.org/10.1111/j.1574-6941.2011.01043.x>
- Heap, I. (2015). The International Survey of Herbicide Resistant Weeds. Retrieved from www.weedscience.org
- Johnson, N. C. (1998). Responses of *Salsola kali* and *Panicum virgatum* to mycorrhizal fungi, phosphorus and soil organic matter: implications for reclamation. *Journal of Applied Ecology*, 35(1), 86–94. <http://doi.org/10.1046/j.1365-2664.1998.00277.x>
- Johnson, N. C., Graham, J. H., & Smith, F. a. (1997). Functioning of mycorrhizal associations along the mutualism-parasitism continuum. *New Phytologist*, 135(4), 575–585. <http://doi.org/10.1046/j.1469-8137.1997.00729.x>
- Jordan, N. R., Zhang, J., & Huerd, S. (2000). Arbuscular-mycorrhizal fungi : potential roles in weed management. *Weed Research*, 40, 397–410.
- Kabir, Z., & Koide, R. T. (2002). Effect of autumn and winter mycorrhizal cover crops on soil properties , nutrient uptake and yield of sweet corn in Pennsylvania , USA. *Plant and Soil*, 238, 205–215.
- Mcgonigle, T. P., & Miller, M. H. (1996). Mycorrhizae, Phosphorus Absorption, and Yield of Maize in Response to Tillage. *Soil Science*, 60, 1856–1861.
- Muthukumar, T., Udaiyan, K., Karthikeyan, A., & Manian, S. (1997). Influence of native endomycorrhiza , soil flooding and nurse plant on mycorrhizal status and growth of purple nutsedge (*Cyperus rotundus* L .). *Agriculture, Ecosystems & Environment*, 61, 51–58.
- Newman, E. I. (1988). Mycorrhizal links between plants: their functioning and ecological significance. In *Advances in Ecological Research*, Volume 18 (pp. 243–270).
- Rillig, M. C. (2004). Arbuscular mycorrhizae and terrestrial ecosystem processes. *Ecology Letters*, 7(8), 740–754. <http://doi.org/10.1111/j.1461-0248.2004.00620.x>
- Rinaudo, V., Bàrberi, P., Giovannetti, M., & Heijden, M. G. a. (2009). Mycorrhizal fungi suppress aggressive agricultural weeds. *Plant and Soil*, 333(1-2), 7–20. <http://doi.org/10.1007/s11104-009-0202-z>
- Smith, S. E., & Read, D. (2008). *Mycorrhizal Symbiosis*. *Mycorrhizal Symbiosis*. <http://doi.org/10.1016/B978-012370526-6.50015-5>
- Van der Heijden, M. G. a., & Horton, T. R. (2009). Socialism in soil? The importance of mycorrhizal fungal networks for facilitation in natural ecosystems. *Journal of Ecology*, 97(6), 1139–1150. <http://doi.org/10.1111/j.1365-2745.2009.01570.x>
- Veiga, R. S. L., Howard, K., & Heijden, M. G. a. (2012). No evidence for allelopathic effects of arbuscular mycorrhizal fungi on the non-host plant *Stellaria media*. *Plant and Soil*, 360(1-2), 319–331. <http://doi.org/10.1007/s11104-012-1256-x>
- Wicks, G. A., Burnside, O. C., & Felton, W. L. (1995). *Mechanical weed management. Handbook of Weed Management Systems*. New York: M. Dekker.