



SOIL ACIDITY IMPACTS BENEFICIAL SOIL MICROORGANISMS

Soil Acidification Series

By

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Abstract

Soils harbor more diverse microbial populations than any other habitat on earth. Only a very small fraction of those organisms are responsible for any type of plant or animal disease. In fact, the vast majority of these microscopic soil organisms are highly beneficial in terms of nutrient cycling, soil tilth, and soil health. Because of their important roles in these crucial soil properties and their direct interactions with plants, beneficial soil microorganisms are also absolutely critical to soil fertility and plant nutrition. Unfortunately, the rapid acidification of soils in the inland Pacific Northwest is having detrimental impacts on the populations and effectiveness of beneficial soil microorganisms.

Introduction

Every teaspoonful of soil typically contains hundreds of millions of microorganisms, including bacteria, fungi, protozoa, and nematodes, the majority of which are absolutely essential to healthy, productive soils (Chaparro et al. 2012). Microbes in soil are important to healthy soil processes and good soil quality. Many aspects of most nutrient cycles are controlled by soil microbes. For example, without microbes, organic matter decomposition simply wouldn't occur, legumes would not be able to fix nitrogen, and ammonia would not be converted to plant-available nitrate. Without important beneficial soil fungi, most plants would be much more limited in their ability to acquire nutrients and water from the soil, resist drought, and produce economically viable yields. Additionally, soil microbes also play a key role in the breakdown and degradation of a huge number of widely used herbicides (Forlani et al. 1999). (For more on herbicides and soil acidity, please see [How Soil pH Affects Activity and Persistence of Herbicides](#) in this series.)

As shown in Figure 2 of [Soil Acidification: Implications for Management](#) in this series, soil acidity influences many chemical and biological characteristics of soil, including availability of nutrients and toxicity of metals (McBride 1994), which can also affect microbial communities in many ways (Sylvia et al. 2005). The silt loam soils of the Palouse region, and most soils around the world, are composed primarily of aluminum-silicate minerals. These minerals are solid or crystalline at neutral pH (a pH of 7), but exhibit pH-dependent aluminum (Al) solubility. This means the amount of Al available to plants and microbes in a soil increases dramatically as soil pH drops below roughly 5.5 (Figures 1 and 2). Because Al can cause plant toxicity, the effects of soil acidity on crop yields are, in large part, due to Al toxicity in acid soils (Foy 1984).

Acidity, Microbes, and Nutrient Cycling

Beneficial soil microbes and plants prefer a near-neutral pH range of 6 to 7, so increased soil acidity is often accompanied by shifts in the types of microbes in soils and their activities. This means significant changes in the rate of decomposition which can lead to immobilization of basic nutrients and decreased nutrient availability to plants (Figure 1).

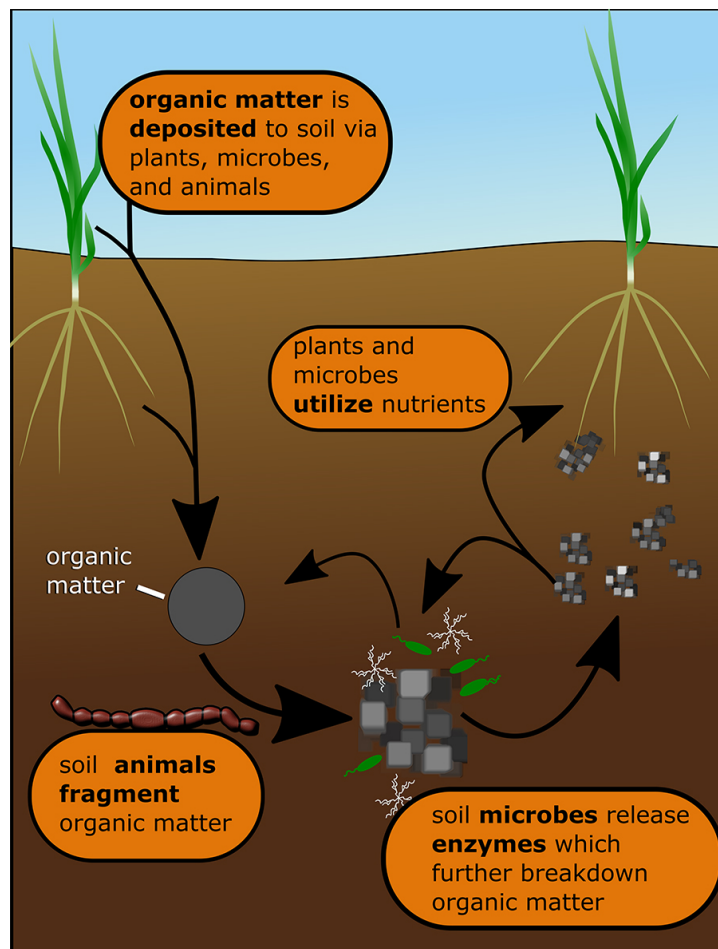


Figure 1. Importance of microbial communities in decomposition of organic matter and release of nutrients from organic compounds in soils and rooting systems of plants. (Original artwork created by Ricky W. Lewis, PhD)

The structure and function of the soil microbial community can be both directly and indirectly affected by soil pH. The direct interaction of hydrogen ions (H^+), which are at high concentrations when pH is low, with microbial cells may influence microbial communities in a number of ways, including disruption of cell membranes, altered enzyme production, and limited reproduction. This equates to reduced overall microbial function towards the health and productivity of soils (Birgander et al. 2014). Also, soil fungi are favored by

a low soil pH, meaning that with a lower soil pH the community shifts from a balance between bacteria and fungi to a much more fungi-dominated soil (Rousk et al. 2010). This may allow the invasion of fungal root pathogens, but also change the way organic residues are decomposed. Because soil fungi and bacteria play different roles in the decomposer community and interact to release nutrients to plants, a lower soil pH will change those relationships and soil carbon and plant nutrients may become immobilized, slowing turnover and nutrient release (Rousk et al. 2009).

Rhizobia and Soil Chemistry

Rhizobia are the soil bacteria that form nodules on plant roots, fixing nitrogen (N) from the atmosphere to provide available N to the plant (Figure 2). This relationship is critical to plant success in both agricultural and natural systems due to the steady supply of plant-available N that the bacteria provide to the plant. Like most other soil bacteria, rhizobia flourish and

function best in neutral to basic soil pH. When soil pH is around 6 or 7, legume roots naturally form an association with rhizobia in the soil and symbiotically fix N. However, application of ammonia-based fertilizers reduces the efficiency of this symbiotic relationship and how effectively rhizobia can provide N to their host plant (Weese et al. 2015), while also further acidifying the soil solution.

While some rhizobia can survive in acidic soils, low soil pH can significantly reduce nodule numbers, nodule function, and N-fixing capabilities within the roots of legumes, such as lentils and chickpeas (Tang and Thomson 1996). This can result in reduced plant vigor and productivity, as well as significant crop loss where soil pH drops particularly low. In soils where the pH drops below 5, nodules per soybean plant can drop by as much as 40–60%, compared to a soil with a pH above 6 (Lin et al. 2012). Low pH can inhibit nodulation by limiting the legume’s ability to secrete the required signals into the rhizosphere that attract the rhizobia and cause the

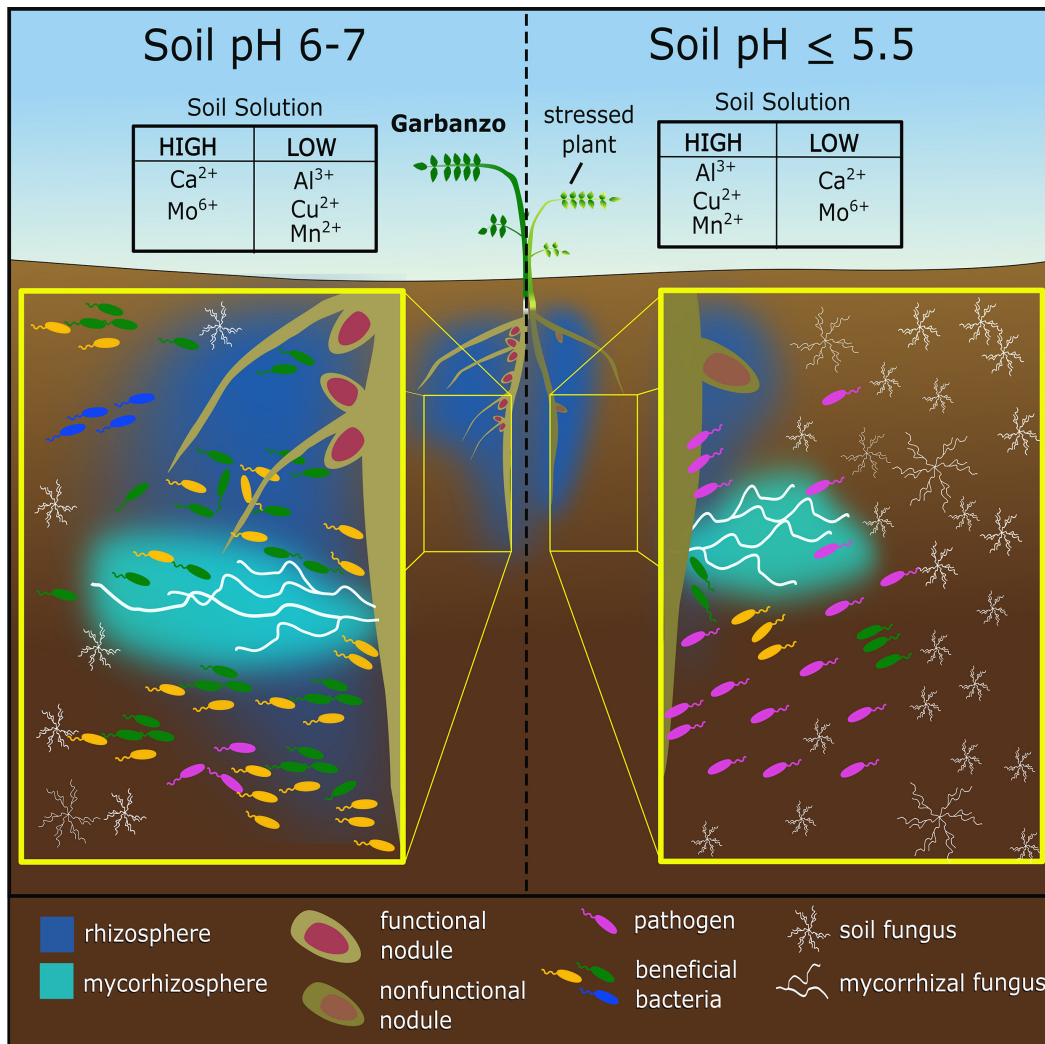


Figure 2. Soil microbial community shift in response to acidic soil conditions and altered soil and rhizosphere chemistry; also demonstrating the dynamic, reciprocal interaction with leguminous plants and their N-fixing rhizobia. (Original artwork created by Ricky W. Lewis, PhD.)

formation of the root nodules (Hungria and Stacey 1997). Also, calcium (Ca^{2+}) and molybdenum (Mo), both known to be essential to root nodule formation and N fixation, become basically unavailable below pH 5, further limiting rhizobial N-fixation. Furthermore, metals like Al and manganese (Mn), which become increasingly available in soil solution as pH drops, are toxic to the legume-rhizobia symbiosis (Bordeleau and Prevost 1994).

Beneficial Fungi and Mycorrhizal Symbiosis

As stated above, acid soils favor a higher proportion of fungi in soil communities because many soil bacteria do not tolerate acidic conditions well (Sylvia et al. 2005). Fungi typically account for as much as 75% of the soil microbial biomass, and hyphal length can be as great as almost 176 miles per ounce of soil in agroecosystems (Ritz et al. 2011). Many of these soil fungi function primarily in decomposition processes and nutrient cycling, but they may also help with remediation of

metals, including Al, in acidic conditions. Fungal-driven binding of Al at low soil pH is one of the many ways fungi can help improve soil and plant health (Gadd 2007).

Plant-symbiotic fungi, called mycorrhizas, have been found to protect plant root systems against stresses ranging from nutrient depletion to drought and disease, as well as metal toxicity (Seguel et al. 2013). These fungi increase access to limiting nutrients such as phosphorus (P), which is particularly important in acid soils due to the reduced P availability at lower pH (Seguel et al. 2013). The hyphal networks surrounding the rooting system constitute the ‘body’ of fungi sometimes called a mycorrhizosphere. This hyphal network is often complex with many plant growth-promoting characteristics. Fortunately, mycorrhizal fungi are known to be associated with many of the crop species found throughout the Palouse, including wheat (Figure 3) and chickpea (Figure 2). However, research is ongoing concerning the capacity of mycorrhizal fungi to buffer Al toxicity for these specific crops in Palouse soils.

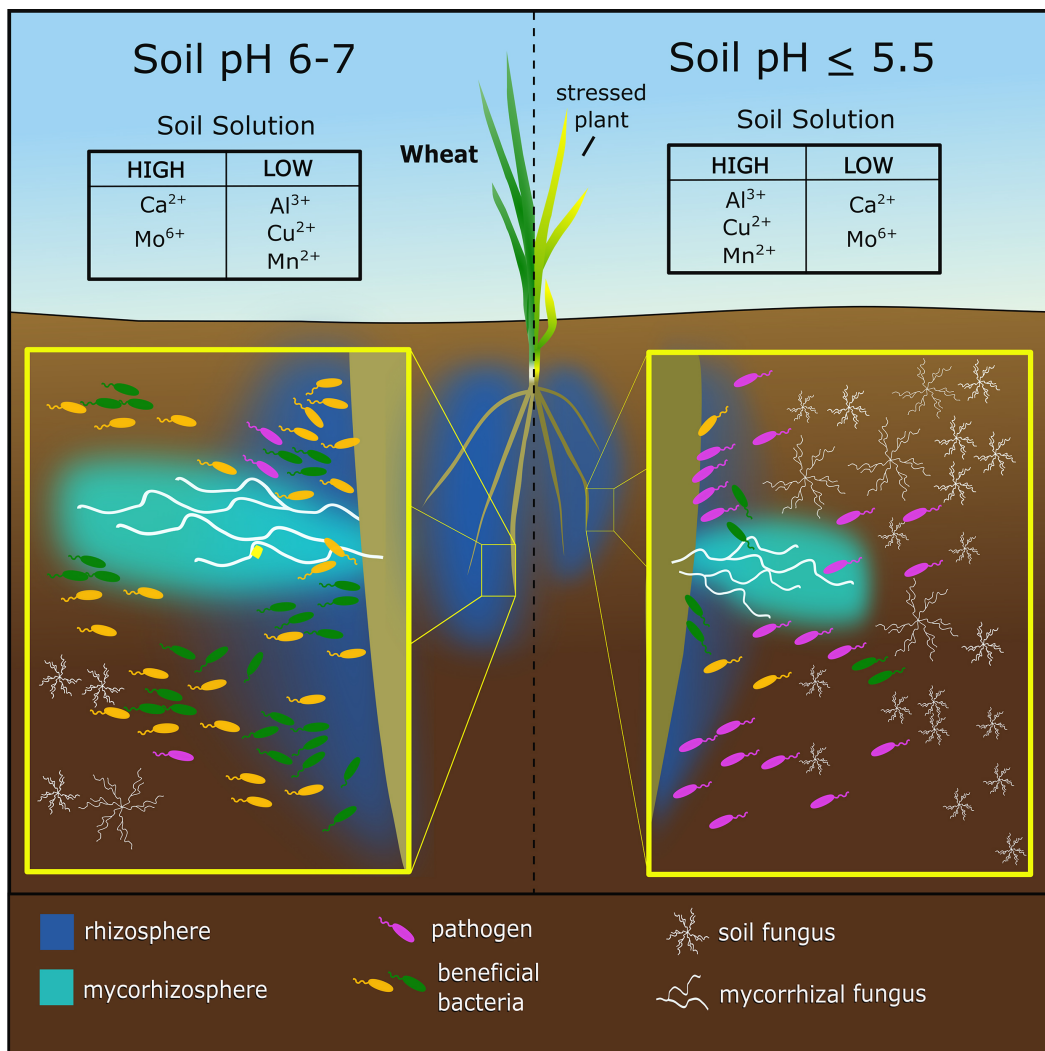


Figure 3. The complex mycorrhizosphere, or root-associated mycorrhizas that surround the rooting system, is altered under acidic conditions versus neutral soil pH for many reasons, including root exudates and basic soil chemistry changes. (Original artwork created by Ricky W. Lewis, PhD.)

Conclusions

Soil acidification in the Palouse has clearly been documented over the course of the last few decades, as discussed by Koenig et al. (2011). Al toxicity, along with other pH-driven changes to soil chemistry and biology, can have a major influence on microbial community structure and function, consequently altering nutrient cycling crop productivity and overall ecosystem services. It is clear that any imbalance in the microbes in soils can lead to reduced soil microbial health which impacts cropping system productivity. Fortunately, liming has begun to have dramatic impacts on soil health, decreasing soil acidity so that these beneficial organisms can flourish and continue to contribute to soil health and crop productivity. (For more information, please see the three part section of this fact sheet on [Agricultural Lime and Liming](#). Understanding more precisely the response of beneficial soil microbial populations to acidification and subsequent liming may provide valuable insights into sustainable approaches to soil acidification problems in the Palouse and around the world.

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