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EMPHASIZING NEW IDEAS TO STIMULATE RESEARCH IN ECOLOGY

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NITROGEN MINERALIZATION: CHALLENGES OF A CHANGING PARADIGM

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Abstract. Until recently, the common view of the terrestrial nitrogen cycle had been driven by two core assumptions—plants use only inorganic N and they compete poorly against soil microbes for N. Thus, plants were thought to use N that microbes ''left over,'' allowing the N cycle to be divided cleanly into two pieces—the microbial decomposition side and the plant uptake and use side. These were linked by the process of net mineralization. Over the last decade, research has changed these views. N cycling is now seen as being driven by the depolymerization of N-containing polymers by microbial (including mycorrhizal) extracellular enzymes. This releases organic N-containing monomers that may be used by either plants or microbes. However, a complete new conceptual model of the soil N cycle needs to incorporate recent research on plant–microbe competition and microsite processes to explain the dynamics of N across the wide range of N availability found in terrestrial ecosystems. We discuss the evolution of thinking about the soil N cycle, propose a new integrated conceptual model that explains how N cycling changes as ecosystem N availability changes, and discuss methodological issues raised by the changing paradigm of terrestrial N cycling.

Key words: microsites; nitrogen availability; nitrogen mineralization; N-mineralization paradigm, evolving; plant uptake; soil N cycle.

DEVELOPMENT OF THE ''CLASSICAL'' PARADIGM OF N CYCLING

Since the late 1800s, N mineralization has been the perceived center point of the soil N cycle and the process that controls N availability to plants (Russell 1912, Waksman 1932, Harmsen and Van Schreven 1955, Aber and Melillo 2001). This view grew from two parallel and complimentary threads in the development of our understanding of plant–soil interactions. The first thread was the adoption of the mineral-nutrition theory of plant nutrition: with the writings of Liebig (1842), it became the widely accepted view that plants use only inorganic materials for their nutrition. Despite reports as early as the late 1800s that some plants actually can use organic N (Waksman 1932, Harmsen and Van Schreven 1955), the mineral nutrition theory remained effectively unchallenged for 150 years, as suggested by Black (1993:383):

> *A small amount of organic nitrogen is found in the soil solution, but plants are not known to take up any significant part of it, and must depend upon the inorganic forms that are released when microorganisms decompose the compounds containing the organic forms.*

The second key thread in developing the current view of the nitrogen cycle was the recognition that decomposition is a microbial process with NH_4^+ as a waste product, as described by Waksman (1932:444):

> *As long as there is free available energy, in excess of the available nutrients, there will be only a minimum accumulation of available plant food. When the energy approaches exhaustion ammonia (or nitrate) begins to accumulate. . . Since the microorganisms are unable to assimilate it, due to the absence of sufficient available energy material, it is left in the soil for the use of higher plants.*

These ideas framed the two core assumptions of N cycling studies that established mineralization as the perceived center point of the N cycle, and that most researchers have used for the last century when ex-

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