NUTRIENT USE EFFICIENCY: AN ECOLOGICAL APPROACH

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Introduction

The practice of agriculture by humankind intentionally disturbs the nutrient and energy balance (especially N and C) of natural ecological systems to produce the food, feed, and fiber needed to sustain human activities. These disturbed ecological systems are generally referred to as agroecosystems. A sustainable agroecosystem is one managed for the long-term profitable production of food, feed, or fiber while utilizing the full potential of biological, chemical and physical processes to conserve natural resources and minimize environmental damage (Elliott et al., 1993). Low nutrient-use efficiency is a major factor contributing to the non-sustainability of agroecosystems. To improve efficiency, a more complete understanding of the processes and mechanisms controlling nutrient cycling is needed to develop sustainable agricultural practices. An understanding of nutrient cycling will help refine farming practices to maintain long-term productivity; protect, preserve, and enhance soil resources; and minimize adverse environmental effects, such as sediment, nutrient, and pesticide contamination of our water resources.

Compared to natural systems, agricultural systems are extremely leaky, especially with regard to N. Recoveries of fertilizer N by corn have been reported to average about 25% (Olson, 1980; Meisenger et al., 1985; Sanchez and Blackmer, 1988). In any given year, corn plants may derive up to 75% of their N from the N-pool created by mineralization of soil organic matter. Therefore, soil organic matter must be considered an important resource in agroecosystems that is capable of providing substantial amounts of N for crop growth. However, if corn plants derive such a small percentage of the N they need from fertilizer, why do we observe any yield response in traditional N fertilizer trials? One possibility is that there may be a positive interaction between fertilizer N and soil organic matter such that higher rates of fertilizer N result in increased corn yields for some years in some locations. The mechanisms of this proposed interaction are poorly understood, but current research is being conducted to improve our level understanding so that soil organic matter can become a more reliable and manageable source of N in agricultural systems.

Understanding the dynamics of soil organic matter first requires the knowledge that all soil organic matter fractions are not the same. Efforts to improve our ability to predict and manage nutrient dynamics and soil quality in agroecosystems depend to a large extent on increasing our understanding of the processes that control the turnover of soil organic matter among the various fractions. Researchers believe that only the most reactive (i.e. labile) forms of soil organic matter are involved in supplying nutrients for plant growth. More stable forms may have direct effects on water relationships in soil (i.e. infiltration and water holding capacity) and soil structure. Soil organic matter turnover and N cycling in soil are intimately linked and interactions between soil C and N impact not only nutrient availability to plants, but also the quality of soil. Soil organic matter accumulates when inputs from above- and belowground residues exceed harvest and decomposition losses. Climate, especially precipitation, and agricultural management practices affect both inputs and outputs, and as a result, control whether a soil is functioning as a source (outputs > inputs) or a sink (outputs < inputs) for C and N.

Improving N-use efficiency is a concept that requires more than simply adjusting fertilizer application rates. Any attempt to "tighten" the soil N cycle in order to improve N-use efficiency must take into account all sources and sinks of N in soil. An ecological approach, where the underlying focus is increased efficiency of resource utilization, both in time and space (Coleman et al., 1992) may be the most useful for addressing these questions. In other words, to sustain profitability and environmental quality, release of available N (through mineralization) from soil organic matter must be synchronized so that N is present both when the plant needs it and where the plant needs it.

No single soil and crop management strategy can be developed or implemented to influence all biological cycling and transformation processes. Practices must be optimized considering inherent soil, landscape, and climatic characteristics (King, 1990). However, by understanding the effects of basic processes occurring in the soil, it may be possible to select practices that will optimize N-use efficiency and maintain or improve soil quality. This would help ensure an economically viable, environmentally safe, and socially acceptable form of sustainable agriculture (Karlen et al., 1992).

Experimental Approach

Current research has been designed to assess soil-N use efficiency, as opposed to simply fertilizer-N use efficiency. The first step is to establish a link between N-use efficiency and sustainability. Insight into this linkage is gained by considering the statement, "Native prairie ecosystems cycle nutrients more efficiently than the agroecosystems derived from them". With our current understanding, the validity of this statement is based on the following factors:

1. In prairie systems, there are highly active communities of soil microorganisms living in close association with the organic substrates they are using for growth and reproduction. This results in rapid internal recycling of N through several soil N pools including the microbial biomass, labile soil organic N, and soil mineral-N. Therefore, at any point in time, the amount of mineral-N present in the soil is relatively small, and the native prairie system has a low susceptibility to both leaching and gaseous loss of N.

2. The dense plant roots in prairie systems result in increased water- use efficiency and increased effectiveness of N uptake across space and time.

3. Increased plant diversity in prairies extends the length of time for active N uptake by plants.

The overall effect of these three factors is a synchronized release and uptake of N in time and space. Prairie systems can maintain high plant productivity despite low mineral-N pools due to rapid internal recycling of N. This fact, coupled with the high rooting density and plant diversity, results in efficient N uptake and use by plants. Thus, prairie systems, which are considered to be sustainable, have a high soil N-use efficiency. The relationship between sustainability and N-use efficiency is assumed to hold for agroecosystems as well. Unfortunately, in developed countries, agroecosystems have been developed primarily as monoculture plant communities based solely on production per unit area. The critical need for the future is to balance production with its full impact on soil and environmental quality.

Based on the established link between N-use efficiency and sustainability, it is possible to develop an index of soil quality where sustainability can be inferred from soil N-use efficiency. The premise for this approach is that sustainability can be defined based on the long-term (>15 years) dynamics of soil organic matter N. Agroecosystems that exhibit decreasing organic N pools would be considered nonsustainable, while those with constant (or increasing) soil organic N pools, would be considered sustainable. A major disadvantage to assessing soil quality with this type of index is the long time frame that is needed. An alternate approach is to redefine N-use efficiency based on availability of N to the plants and losses of N from the rooting zone. To utilize this approach, the synchrony of mineral N availability, relative to plant N requirements, must be determined and variations in the spatial distribution of N-supplying and N-uptake (roots) sites in soil must be quantified, and N loss from the rooting zone must be determined.

Conclusions

An approach is described to assess soil N-use efficiency as opposed to fertilizer N-use efficiency. Application of this approach for predicting long-term status of the soil organic N pool is based on quantitative knowledge of soil N cycling, N inputs, N outputs, and interactions affected by yearly and seasonal climatic variations and soil type/landscape position effects. This requires a detailed assessment of the spatial and temporal variability of the processes and interactions that contribute to: i) N uptake by plants, ii) N storage in the rooting zone and iii) N loss from the rooting zone. This information will increase our understanding of the processes that control N cycling in soil and improve our ability to predict and manage nutrient dynamics and soil quality in agricultural systems.

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