Fertilizer Nutrient Recovery in Sustainable Cropping Systems

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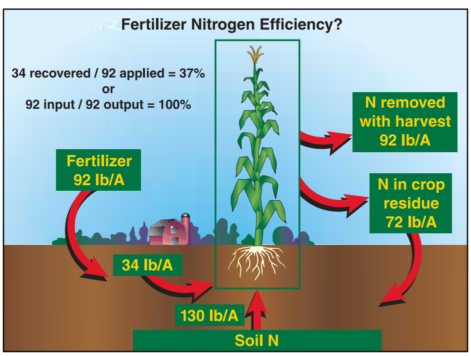
While single-year crop responses often recover less than half the nutrients applied as fertilizers, cropping systems are more efficient. Nutrient additions support the maintenance of soil organic matter and fertility as well as crop yields.

Current estimates of recovery efficiencies for nitrogen (N), phosphorus (P), and potassium (K) fertilizers used in North American crop production vary considerably. They vary largely because of differences in definition. Recovery by the crop's response differs from recovery by the cropping system.

Recovery efficiency is defined as the amount of nutrient in the crop as a ratio of the amount applied or available. Its calculation varies widely depending on the system being considered: the soil-plant system, the whole plant, the above-ground portion of the plant, or the harvested portion of the plant may be considered the vessel of recovery. The inputs may or may not include: applied manures, mineralization of soil nutrients, atmospheric deposition, and contribution of soil micro-organisms, in addition to applied fertilizers. Recovery can be calculated for each single source or for the total of all sources.



Fertilizer N efficiency is influenced by long-term dynamics of a soil's organic matter.

Recovery from a single source is often estimated from the single-year response: the difference in nutrient uptake between fertilized and unfertilized plants. It can also be measured using tracers. Both methods are subject to error.

Error arises in the difference method because plants respond to nutrient deficiencies by altering root growth and the capacity of roots to acquire nutrients. These mechanisms may not be operative in—or compatible with—the type of plant growth associated with the higher yield levels of fertilized plants.

Recovery estimates using tracers are confounded by internal cycling of nutrients in the soil. For example, the rapid uptake and release of ammonium and nitrate forms of N (mineralization-immobilization turnover) generally reduces the concentration of the tracer in the N made available to plants.

A recent study measured the difference between N uptake in fertilized and unfertilized plots in 55 producer-managed corn fields in the north central U.S. (Cassman et al., 2002). Recovery of N in above-ground plant biomass averaged only 37% of fertilizer N applied. This is a disturbingly low figure. Assuming a typical N harvest index (portion of above-ground N in grain) of 56%, it implies that as little as 21% of the fertilizer N applied is removed in the grain. In actual practice, this level of efficiency would be difficult to match, since optimum rate was selected in hindsight from a rate study. Where is the rest of the fertilizer going?

Let's look more closely at the meaning of 37% recovery in this example. What it means is that in these fields, when fertilizer was added at an optimum rate (which averaged 92 lb/A), it boosted the uptake of N into the above-ground portion of the plant by 34 lb/A (37% of 92).

The fertilized corn took up an average of 164 lb N/A: 130 from the soil and 34 from the fertilizer. The total amount of N in its grain would be 56% of 164 = 92 lb/A: equal to the amount of fertilizer applied. So is the recovery 21% (as estimated by single-year-response recovery in grain) or 100% (assuming the observed balance of input and output is sustainable long-term)?

The answer cannot be known unless the longer-term dynamics of the soil's organic matter are understood. If the cropping system is maintaining organic matter, and if the 130 lb/A of N from the soil came from mineralization of organic matter, an equivalent amount of N must be returned in the form of crop residues, and also stabilized to protect it from loss.

If the soil is gaining organic matter, even more N is required. The crop converted at least 164 lb/A of mineral N into organic forms; more if below-ground assimilation by roots and associated microflora is considered. How much will be held in that form depends on the dynamics of decomposition, controlled to some degree by tillage management.

Mineralization of N from soil organic matter is a large but unsustainable source for the replacement of crop removal. Depletion of organic matter eventually reduces the productivity of soils. In a sustainable cropping system, N contributed by mineralization needs to be returned to rebuild soil organic matter. Crop residues—exudates, roots, and stover—return this N.

In recent years, through a combination of reduced tillage and the return of increased residues from higher-yielding crops, many areas have reversed the trend of organic matter decline. Since 1970, soils of the central U.S. Corn Belt are sequestering N at the rate of 20 lb/A/year as their organic matter increases through reduced tillage (Lal et al., 1998). As conservation tillage expands, requirements for N can be expected to increase, and part of the reason is that a source of N is needed for soil organic matter accumulation.

Table 1. Soil organic carbon (SOC) accumulated from 1965 to 1995 in the top foot of a soil cropped to continuous corn.

Applied N, lb/A/yr	SOC derived from corn, tons/A	%
150	7.6	21
75	5.8	17
0	4.5	12

Source: Wilts et al., 2004

Nitrogen boosts the return of crop residue to the soil and enhances its conversion to stable soil organic matter. Many experiments have shown that fertilizing crops with N results in higher levels of soil carbon over time. An example from Minnesota is shown in **Table 1**. Paustian et al. (1997) documented 20 sites worldwide that gained soil carbon (C) in response to application of N fertilizers over periods ranging from 7 to 120 years. As shown in **Figure 1**, N is integral to the chemical structure of soil organic matter, and is stabilized within it.

The conversion of N into organic forms by plants and associated soil

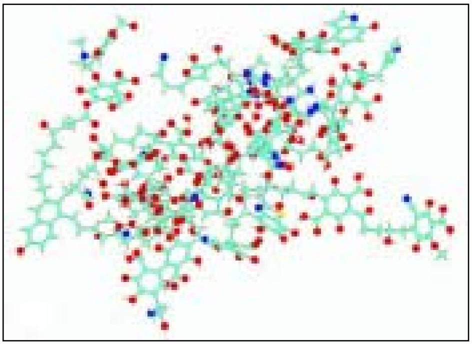


Figure 1. Chemical structure of soil organic matter (Schulten and Schnitzer, 1997). The element colors are: N-blue, C-cyan, hydrogen-white, oxygen-red, sulfur-yellow.

microflora gives the mobile nutrient N properties similar to the relatively immobile nutrients P and K. Recovery of all three nutrients is greater in the long term than in the short term. While single-year-response recovery of fertilizer P often ranges from 15 to 25%, longer-term recovery in cropping systems is more typically 50 to 60%, and for some systems as high as 70 to 90% (Smil, 2000).

Among the producer-managed fields described above, five had single-year-response recovery efficiencies in excess of 60% even when fertilized at rates of 160 lb N/A or more. This suggests that high rates of nutrient application can be compatible with high recovery efficiencies.

A study in France reported recovery of 71% of labeled fertilizer N in corn, with 26% of the remainder recovered as soil organic N and only 3% as inorganic forms subject to losses.

Recent data for U.S. corn suggest that the harvested grain removes amounts equivalent to 81, 122, and 77% of the N, P and K applied as fertilizers. Removals relative to applications have increased significantly in recent decades (**Figure 2**).

Removal by all North American crops relative to nutrients supplied in the form of fertilizers and manures amounts to 95% and 143% for P and K, respectively. The comparable figure for N is 77%, but considering non-legume crops only, it declines to 64%. The lower recovery for N could be taken as an indication of priority for

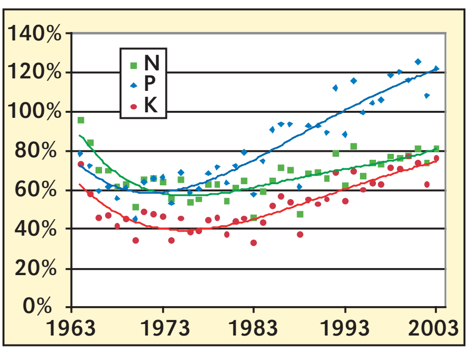


Figure 2. Grain nutrient removal as percentage of fertilizer use on corn in the U.S.

efforts at enhancement, or more thorough documentation of its role in contributing to increased soil organic matter. Appropriate management of P and K can contribute to improved N recovery.

Conclusion

Low nutrient recovery in a single-year response does not imply that the remainder is permanently lost. We need to improve short-term response recovery, but not at the expense of long-term sustainability. Nutrient inputs to cropping systems have important roles in supporting the maintenance of soil organic matter and fertility, in addition to directly supporting crop yield. **Enhancement of use efficiency of nutrients must be integrated with that of all resources essential to sustainable crop production.** BC

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