Does Long-term Use of Mineral Fertilizers Affect the Soil Microbial Biomass?

By Daniel Geisseler and Kate M. Scow

Analysis of 64 long-term crop fertilization trials from around the world found that application of mineral N fertilizer was associated with an average 15% increase in microbial biomass and 13% increase in soil organic carbon compared to an unfertilized control. The effect of fertilization on the microbial biomass is strongly pH dependent. Increases in microbial biomass were largest in studies with at least 20 years of fertilization.

Mineral fertilizer use, especially N, has contributed to substantial increases in crop yields. However, reports from natural ecosystems, such as grassland and forests, suggest that long-term mineral N inputs might have a negative effect on soil microbial biomass.

We analyzed the response of soil microorganisms to mineral fertilizer inputs in 107 datasets from 64 long-term field trials, ranging from 5 to 130 years (37 years average) from across the world (**Figure 1**). Though we focused on N fertilizer, in most long-term trials both P and K are also applied. Therefore, the observed effects cannot be attributed solely to N inputs. All datasets included were from trials with annual crops (except lowland rice cropping systems in paddy soils), initiated at least five years prior to soil sampling, and contained an unfertilized control for comparison.

Most samples were collected from between 0 to 8 in. and received an average of 120 lb N/A each year, most commonly as a urea or ammonium-based fertilizer. The effect of N fertilization on the microbial biomass was determined using a meta-analysis, a statistical method that allows combining results from different studies to identify patterns across studies.

Soil Organic Carbon (C_{org})

The addition of mineral fertilizers significantly increased C_{org} content, by an average of 12.8%, compared to the unfertilized control (**Figure 2**). This was not surprising as increases in C_{org} are often associated with higher yields of crops and a higher return of crop residue to soil, resulting in a rise in the organic matter content. In soils where the pH dropped below 5 due to repeated ammonium or urea fertilizer applications, crop yields declined and in some cases, yields dropped below the unfertilized control. Soil acidification is a natural consequence of nitrification, the conversion of ammonium to nitrate. Nitrate fertilizer, which is already oxidized, had little effect on soil pH.

Soil organic matter is a complex mixture of organic materials that makes up a small but vital part of all soils. Soil organic matter consists of decomposing plants and soil animals, soil microbial biomass, and stable organic compounds. Soil organic matter is determined by measuring the loss of weight after burning, or after chemical oxidation with strong reagents.
Soil organic carbon is the carbon occurring in soil organic matter, but omits inorganic carbon materials, such as calcium carbonate. Soil organic carbon can be determined by measuring the carbon dioxide gas released by combustion.
Microbial biomass of soil is the part of the organic matter present in living microorganisms, such as bacteria, archaea and fungi. Only a portion of the total living microbial biomass consists of carbon.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

Figure 1. The long-term agricultural field trials included in our meta-analysis were from every continent and 18 countries.

Long-term field trials, such as the Century Experiment at the Russell Ranch Sustainable Agricultural Facility at the University of California, Davis, are crucial to studying long-term effects of management practices on crop production, soil health and the environment (Photo by Bob Rousseau).

Microbial Biomass Carbon (C_{mic})

Fertilization significantly increased C_{mic}—by an average of 15%. The positive effect of N fertilization on C_{mic} differs from similar analyses done on data from studies in predominantly natural ecosystems. Several factors may contribute to this difference. Nitrogen additions to natural ecosystem often lead to changes in plant species composition and diversity, which in turn may affect the soil microbial community. Furthermore, if N fertilizer input decreases soil pH, aluminum (Al) may be more soluble and nutrient cations may be leached. In the studies included in our analysis, soil pH only decreased by an average of 0.26 units. This relatively small change observed is likely due to the fact that lime is regularly added to buffer soil pH in many trials.

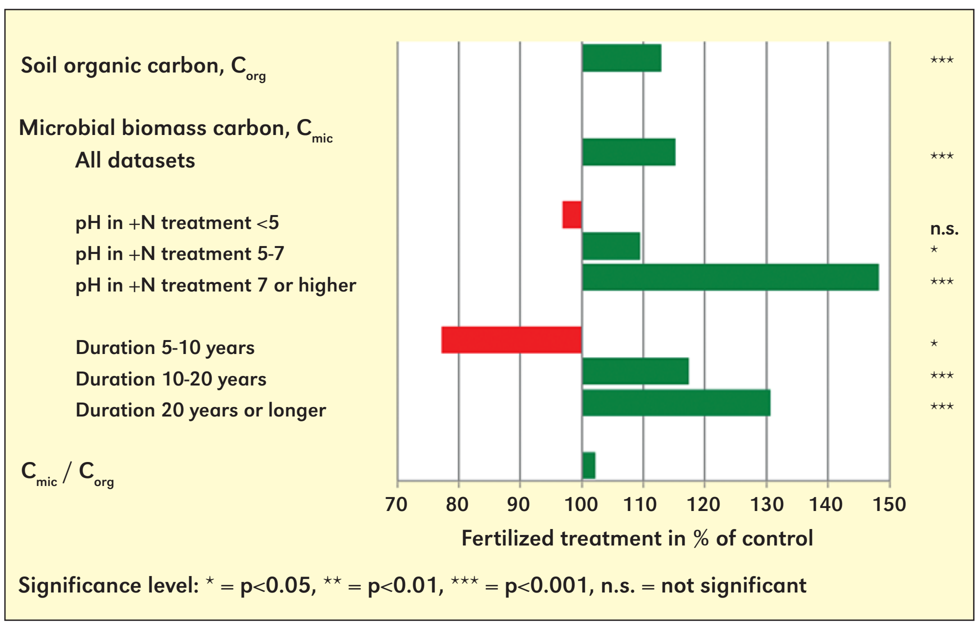

Figure 2. Effect of fertilization on soil organic carbon (C_{org}) and microbial biomass carbon (C_{mic}).

The effect of fertilization on C_{mic} was strongly pH dependent. While fertilization slightly reduced C_{mic} in soils with a pH below 5, it had a strong positive effect at higher soil pH values (**Figure 2**). When the soil pH was at least 7, the fertilization-related increase in C_{mic} averaged 48%. Studies carried out in a number of ecosystems have shown that pH exerts a strong influence on the biomass and composition of soil microbial communities. Therefore, our results agree with those from other ecosystems.

The duration of the trial also affected the response of C_{mic} to fertilization, with increases in C_{mic} noticeably higher in studies older than 20 years (**Figure 2**).

Microbial biomass C was positively correlated with C_{org} concentrations as has been previously observed. The C_{mic}/C_{org} ratio was little affected by fertilization across all datasets (**Fig-**

ure 3), suggesting that the higher C_{org} content in the fertilized treatments is a major factor contributing to the overall increase in C_{mic}. An exception may be with the use of anhydrous ammonia. Only two of the 107 datasets used anhydrous ammonia, but it resulted in a very low C_{mic}/C_{org} ratio, and C_{mic} decreased with increasing N additions (**Figure 3**). Furthermore, one trial included three N application rates of either anhydrous ammonia or urea. At all N rates, C_{mic} was considerably lower in the anhydrous ammonia than urea treatment.

Microbial community composition

The composition of the microbial community is far more sensitive to long-term inputs of mineral fertilizer than C_{mic}. The microbial community response to mineral fertilizer is strongly influenced by environmental and management factors. Differences in the microbial community were more pronounced between years and different sampling times during the same season than between the unfertilized control and the fertilized treatment.

Conclusions

Our meta-analysis revealed that long-term N fertilization of agricultural soil results in increased C_{mic} content, most likely due to associated increases in C_{org} resulting from higher crop productivity. Increases in C_{mic} in fertilized soils under annual crops contrasts with observations in natural ecosystems, where N inputs may decrease C_{mic}.

Applications of ammonium and urea fertilizer, when not buffered, gradually lower soil pH. When soil pH drops below 5, C_{mic} is generally decreased. However, when pH is maintained near neutral, the input of N fertilizer does not seem have long-term negative effects on C_{mic} in annual cropping systems. However, long-term repeated mineral N applications can alter microbial community composition in many cases even when pH changes are small, but no clear patterns were evident. Future research using advanced tools is needed to advance our understanding of the relationships between microbial communities and addition of plant nutrients. BC

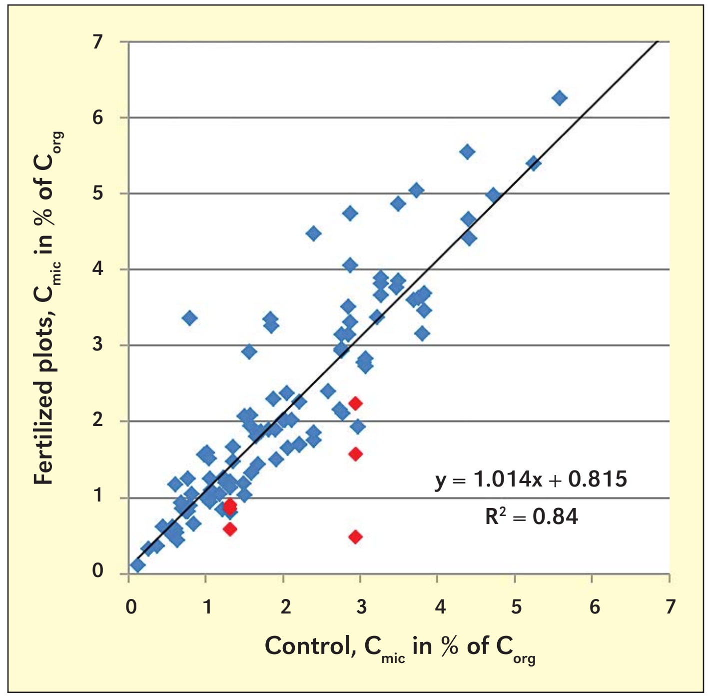

Figure 3. Microbial biomass carbon (C_{mic}) in % of total soil organic carbon (C_{org}) in unfertilized soils plotted against C_{mic} in % of C_{org} in soils receiving mineral N fertilizer. The red symbols are treatments from two trials with anhydrous ammonia additions. All data points were included in the regression analysis.

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Crop Nutrient Deficiency Photo Contest Entries Due December 11

The deadline for submitting entries to the annual IPNI contest for photos showing nutrient deficiencies is fast approaching.

This year, in addition to the four nutrient categories (N, P, K and Other Nutrients) we have added a new "Feature Crop" category focused on Hay and Forage Crops.

Our prizes are as follows:

- US$300 First Prize and US$200 Second Prize for Best Feature Crop Photo.
- US$150 First Prize and US$100 Second Prize within each of the N, P, K and Other Nutrient categories.
- In addition, all winners will receive the most recent copy of our USB Image Collection. For details on the collection please see http://ipni.info/NUTRIENTIMAGECOLLECTION

Entries can only be submitted electronically to the contest website: www.ipni.net/photocontest. Specific supporting information is required (in English) for all entries, including:

- The entrant's name, affiliation and contact information.
- The crop and growth stage, location and date of the photo.
- Supporting and verification information related to plant tissue analysis, soil test, management factors and additional details that may be related to the deficiency.

Winners will be announced in January of 2015. Winners will be notified and results will be posted at www.ipni.net. BC