Emerging Issues in Animal Agriculture

# Manure effects on soil organisms and soil quality

### OVERVIEW:

Soil quality was first defined by the Soil Science Society of America in 1997 as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997). The Natural Resources Conservation Service of the United States Department of Agriculture (USDA) explained the concept in much simpler terms: "soil quality is how well soil does what we want it to do" (Janvier et al., 2007; NRCS, 2009).

While soil quality may be easily defined, it is less easily described; soil quality depends on many different biological, physical, and chemical factors, all of which interact to influence soil function and productivity (Harrigan, Mutch, & Snapp, 2006). Biological characteristics that determine soil quality include: mobilization of nutrients, microbial and enzyme activity, effects of soil fauna and suppression of plant disease. Physical characteristics include aggregate structure, porosity and bulk density; chemical factors include nutrient supply and cycling.

Any attempt to improve soil health must take into account all of these various factors and interactions. For example, many farmers have begun to apply soil amendments, such as livestock manure and compost, to their fields to increase their crop yields. But how and why do such amendments work? The short answer is that these amendments can dramatically change the biology of the soil. These changes to the biology, in turn, influence the physical and chemical environment of the soil in ways that alter crop productivity.

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## Manure effects on soil communities

### Microbes and Enzymes

When discussing management effects on soil quality, researchers have conventionally targeted physical and chemical responses first. In part, this has been because soil organisms, in particular the microscopic bacteria and fungi, have been difficult to study. New methods have improved our ability to see the diversity of life underground. We start with changes to the living components of the soil, because these serve as the foundation for the variety of ways soils respond to manure additions. Studies have shown that adding organic amendments such as manure results in increased microbial biomass (soil bacteria and fungi) and higher microbial activity. The carbon and other nutrients in manure can increase microbial biomass and soil respiration rates by two to three times. Much of the increase in microbial activity is due to increases in bacterial populations. To date, the available evidence suggests that fungi may be less responsive to manure additions.

Accumulation of organic carbon as a result of manure additions not only results in increased microbial biomass but has also been linked to changes in microbial community structure and increased functional diversity. For example, Jangid et al. (2008) found that bacterial diversity, in terms of both species richness and evenness, was higher in soils amended with poultry litter than in those treated with inorganic fertilizers. Furthermore, Gomez, Ferreras, & Toresani (2006) were able to demonstrate a positive linear regression relating microbial diversity to soil organic carbon, suggesting that increases in functional diversity may be explained by the increase in carbon availability resulting from manure amendments. Increased microbial biomass and diversity are beneficial for soil quality because soil microorganisms play a key role in soil nutrient cycling. They accelerate the breakdown of organic substances and mineralize the organic nitrogen (N) and phosphorus (P) contained in manures into plant-available inorganic forms.

Soil enzymes are also crucial to nutrient cycling and the decomposition of soil organic matter. Together, microbes and enzymes control nutrient availability, organic matter quality and quantity, and soil decomposition potential, and thus, control soil quality and functioning. The majority of soil enzymes are extracellular enzymes produced by soil microbes. Similar to microbial biomass, enzymes are very responsive to manure applications. In fact, enzyme activities may be even more responsive to manure application than microbial biomass or soil community structure, and twofold to fourfold increases have been reported. It may not be the carbon alone in manure that increases enzyme activities. Soil nitrogen availability regulates the competitive interaction of soil microorganisms and thus the relative production of different soil enzymes. Increasing available soil N by manure additions generally leads to increases in the activity of soil enzymes that break down carbohydrates and decreases in the activity of enzymes that break down aromatic compounds such as lignin.

## Larger Soil Organisms

Other soil organisms are also influenced by manure additions. Larger soil fauna, such as protozoa and invertebrate groups including nematodes, mites and earthworms, are also strongly affected by manure amendments. In the short term, these soil organisms may react to manure amendments by increasing in both numbers and activity level as a result of the added organic matter. Manure additions can also have indirect long-term effects on soil organisms by causing changes in soil pH and physical properties (aggregation and porosity), as well as changes in productivity and soil organic matter levels (Bunemann, Schwenke, & Van Zwieten, 2006). By feeding on crop residues and other organic matter, microarthropods can enhance decomposition and nutrient availability, both of which are important to crop production and healthy soils. Estimates vary but we know that grazing on microbes by microarthropods and nematodes releases much of the nitrogen that becomes available during the growing season. Looking at this a different way, if there were no microarthropods in soil there would be less N mineralized and the need for more fertilizer nitrogen.

## Changes in soil function

The changes in soil organisms resulting from manure additions potentially have a wide range of effects on soil functions. Indeed, soil disease suppression and aggregation, as well as soil chemistry and nutrient supplying capacity, are all influenced by manure use.

## Disease Suppression

Besides increasing numbers of beneficial organisms in soil, manure has also been found to decrease the abundance of harmful organisms, such as disease-causing pathogens and plant pests. Pathogens representing a variety of different taxa, including bacteria, fungi, and nematode species, are influenced by manure amendment. Organic amendments such as manure have been shown to alter physical, chemical and biological properties of soil that can directly or indirectly affect pathogen survival and crop infection.

For example, Scheuerell, Sullivan, and Mahaffee (2005) discovered that suppression of Pythium spp., a common pathogen which causes root rot, was associated with ammonia volatilization from manure amendments. Likewise, Conn & Lazarovits (1999) found that the use of liquid swine manure reduced the incidence of wilt and common scab in potato fields, and also reduced the number of plant parasitic nematodes for three years after a single application. A significant decrease in red stele strawberry root disease was also observed in fields treated with poultry/steer and dairy manure compost, relative to a control (Millner, Ringer, & Maas, 2004).

Several mechanisms have been proposed to account for the observed suppressive effect of manure on soil-borne pathogens. One hypothesis is that soil amendments serve as a source of energy for microorganisms and therefore enhance microbial activity, competition and overall biomass, including antagonistic microorganisms that deter pathogens. These antagonistic microorganisms can be other species of competing bacteria or fungi, or parasites that prey on pathogens. In fact, it is believed that microbe-microbe interactions – such as competition, antibiosis, parasitism and predation – are often the underlying mechanism of disease control using organic amendments. It has also been suggested that application of nitrogen-rich manure amendments may reduce soil-borne diseases by releasing allelochemicals generated during microbial decomposition. High concentrations of volatile fatty acids (VFAs) in manures also inhibit plant pathogens, although VFAs are only active at low pH (less than 4.75) (Bailey & Lazarovits, 2003). Other potential disease-suppressing mechanisms include altered environmental conditions in the root zone, such as pH, electrical conductivity, porosity, water-holding capacity and nutrient concentrations, all of which can directly or indirectly affect plant health. Davis, Huisman, Everson, & Schneider (2001) found in a survey of potato fields that organic matter, organic nitrogen and increased nutrient availability were all associated with reduced disease and higher yields. In summary, the effectiveness of any particular amendment depends upon the complex interactions between these various biological, chemical and physical soil factors. Moreover, several disease-suppressive mechanisms may operate at one time against different pathogens.

## Soil Structure

Organic amendments affect the structure of soil itself. Long-term intensive cultivation causes degradation of soil structure, decreasing soil quality and productivity. Soil structure refers to the three-dimensional arrangement of particles. Soil is composed of groups or clumps of particles, called aggregates, which are held together by organic matter, primary microbially produced organic matter, and sometimes by chemical bonds between cations (positively charged particles) and silt and clay particles. Manure amendments add organic matter to the soil, which increases microbial activity and the production of microbial polysaccharides that stabilize aggregates. Stable soil aggregates have a beneficial influence on soil moisture status, nutrient dynamics, soil maintenance and soil porosity. Increases in porosity and aggregate stability also serve to improve other soil physical properties. These include decreased bulk density and compaction, increased water holding capacity, infiltration capacity and hydraulic conductivity, and decreased surface crusting and runoff volumes (Haynes & Naidu, 1998).

## Soil Chemistry/Nutrient Cycling

The use of inorganic fertilizers first became popular in the 1950s when growers began to simplify their rotations and depend more on external inputs to maintain and increase yield. The immediate result was deterioration in soil health. Now farmers must rely on fertilizers (organic and non-organic) to make up the difference between nutritional needs of crops and their supply by soil. The goal of manure amendments is to balance nutrient inputs with crop requirements while providing additional organic matter that can help reverse declines in soil quality. Historically, the application rates of organic fertilizers, including manure, were determined by N requirements, which caused systems to be overloaded with P. As a result, most organic amendments are now based on P rates.

Depending on the type of manure, most of the nutrients, particularly nitrogen, become available through mineralization. Mineralization refers to the conversion of nutrients from organic to inorganic (and thus plant-available) forms. This conversion process is often referred to as the "slow release" of amendment nutrients. Long-term manure applications can increase the nutrient pool of potentially mineralizable N and P in soils, which means that producers need to adjust application rates each year to account for the release of nutrients from manure applied in previous years. Yet another consequence of this slow-release phenomenon is that manures containing a large proportion of organic N, such as cattle feedlot or dairy manures with bedding, provide less plant available N, because the organic N must be mineralized first. In contrast to nitrogen, phosphorus availability from manure is often high (more than 70 percent) because most of the P is inorganic and readily available. Nevertheless, crop P uptake is generally much lower than N uptake and more is retained in the soil.

Carbon (C) is also a very important component of soil. Manure amendments add organic matter to the soil, primarily in the form of organic carbon (Haynes & Naidu, 1998). The amount of organic carbon present in a soil reflects the long-term balance between additions of organic C and losses through different pathways. The addition of manure typically shifts this balance and increases soil organic matter, with the magnitude of increase primarily determined by climate, soil type and characteristics of the manure. This increase in organic matter has far-reaching effects on soil properties. Let's consider aggregation as an example. When manure or other organic matter is added to the soil it is quickly colonized by millions of bacteria. These organisms derive both their energy and their nutrients from the organic matter. During decomposition of this material, bacteria produce large quantities of polysaccharides. These polysaccharides function like sticky glue in the soil and can actually stick soil particles together into aggregates. Therefore, in general, more organic matter inputs usually means more bacteria, more aggregates, and better soil structure. These increases in soil structure feed back to further increase soil organic matter concentrations.

## Environmental Effects

While manure application is beneficial to soils in many ways, it unfortunately can also have negative impacts on the wider environment. It has been observed in numerous studies that manure application causes increased dissolved N and P transfer to runoff water. Applying manure infrequently at high rates or applying manure frequently at low rates may exceed the system's capacity to assimilate nutrients, releasing N and P. Nutrient contaminated runoff from croplands treated with manure may then contribute to increased P and N concentrations in nearby streams and lakes, resulting in harmful eutrophication, algal blooms and other negative effects. Ammonium loss from manure-amended soils into surface waters can also poison aquatic organisms at high concentrations (> 2.5 mg/L) and nitrate in runoff from manured fields may also cause hypoxia (lack of oxygen) in rivers and lakes (Eghball & Power, 1999).

Fortunately, these effects can be minimized, if not eliminated, by careful application and timing of manure amendments. First, leaching and runoff can be reduced by incorporating manure into the soil, rather than leaving it on the surface. Second, manure should be applied to match crop P requirements instead of N, in order to avoid overloading systems with P. Manure application can also potentially affect air pollution and global warming. Arable soils are a major source of the greenhouse gas nitrous oxide (N2O), and emissions of this potent greenhouse gas may increase from organically amended soils (Ginting, Kessavalou, Eghball, & Doran, 2003). However, these potential effects can also be avoided by applying nutrients in quantities that match crop requirements.

## Choosing an ammendment

There are several factors to consider when deciding whether to utilize organic amendments. The first consideration is that manures differ depending on the source. The most important difference between types of manure is nutrient content. Swine manure, for example, contains the greatest proportions of total organic matter and organic carbon as well as the highest carbon to nitrogen ratio, but cattle manure has a higher percentage of organic P, and poultry manure has the highest percentage of nitrogen. Therefore one type of manure may be more effective than the others, depending on the existing nutrient concentrations in the soil and the nutrient requirements of proposed crops.

Another prime concern with organic amendments is whether or not to compost the manure prior to application. Composting changes both the physical and chemical structure of manure, which has diverse consequences, both positive and negative. Physical changes that occur during composting include: decreased water content, decreased dry matter, decreased volume and increased bulk density. These changes are generally considered advantageous, because smaller mass/volumes are much easier to transport and apply. Composting manure also helps to eliminate pathogens, parasites, weed seeds and odors, and it has been found to increase disease suppression effects. Furthermore, composted cattle manure has proven as effective as raw manure in promoting crop yields.

However, composting may increase nutrient losses. Manure nitrogen is lost during the composting process through ammonia volatilization, denitrification and leaching, and additionally, much of the plant available nitrogen is immobilized in organic forms. Due to nitrification, compost may contain higher NO3- and lower NH4+ concentrations than fresh manure. Overall inorganic nitrogen availability, however, is often less in compost than fresh manure and composting may benefit the environment because organic nutrients are less likely to run off to surface waters or to leach to groundwater.

The timing and amount of manure applications is also crucial. As mentioned, applying manure at too high a rate or too frequently (even at a low rate) can overload a soil system. Applying manure to frozen ground can increase the amount of nutrient runoff and, in general, it is best to add amendments close to known periods of plant uptake to reduce off-farm losses. Mixing manure thoroughly into the soils rather than leaving it on the surface can also reduce leaching and runoff and improve the efficiency of manure nutrient utilization by crops.

## Conclusion

The addition of manure to soils results in increased yields of many field crops. However, the short-term and long-term effects of manure amendments may differ; processes affecting yield differ at initial application and after time has passed. In nutrient deficient cropping systems, the addition of nutrients in manure – in particular nitrogen – may immediately increase yields. Long-term increases in yields may be due to delayed nutrient release or increases in soil quality. It should now be evident that the increase in crop yields associated with manure application is not simply caused by the properties of the manure, but is instead the result of a series of complex interactions between the nutrients, organic matter and organisms in the manure and the existing conditions of the amended soil. Amendments can have profound effects on soil structure, soil chemistry and soil organisms (microbes and macrofauna) and have also been found to suppress soil pathogens and disease.

Potential negative effects of manure additions such as nutrient loss and enhanced greenhouse gas emissions from soils can be minimized through careful attention to application rate and timing. Strategic management of animal manures can thus be a cost-effective way to increase soil organic matter content, stimulate soil biology, improve physical structure and ultimately improve crop yields.

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## ACKNOWLEDGEMENTS:

- Phillip R. Owens, assistant professor of soil geomorphology/pedology, Department of Agronomy, Purdue University
- Robert Mullen, assistant professor and nutrient management specialist, Ohio State University

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