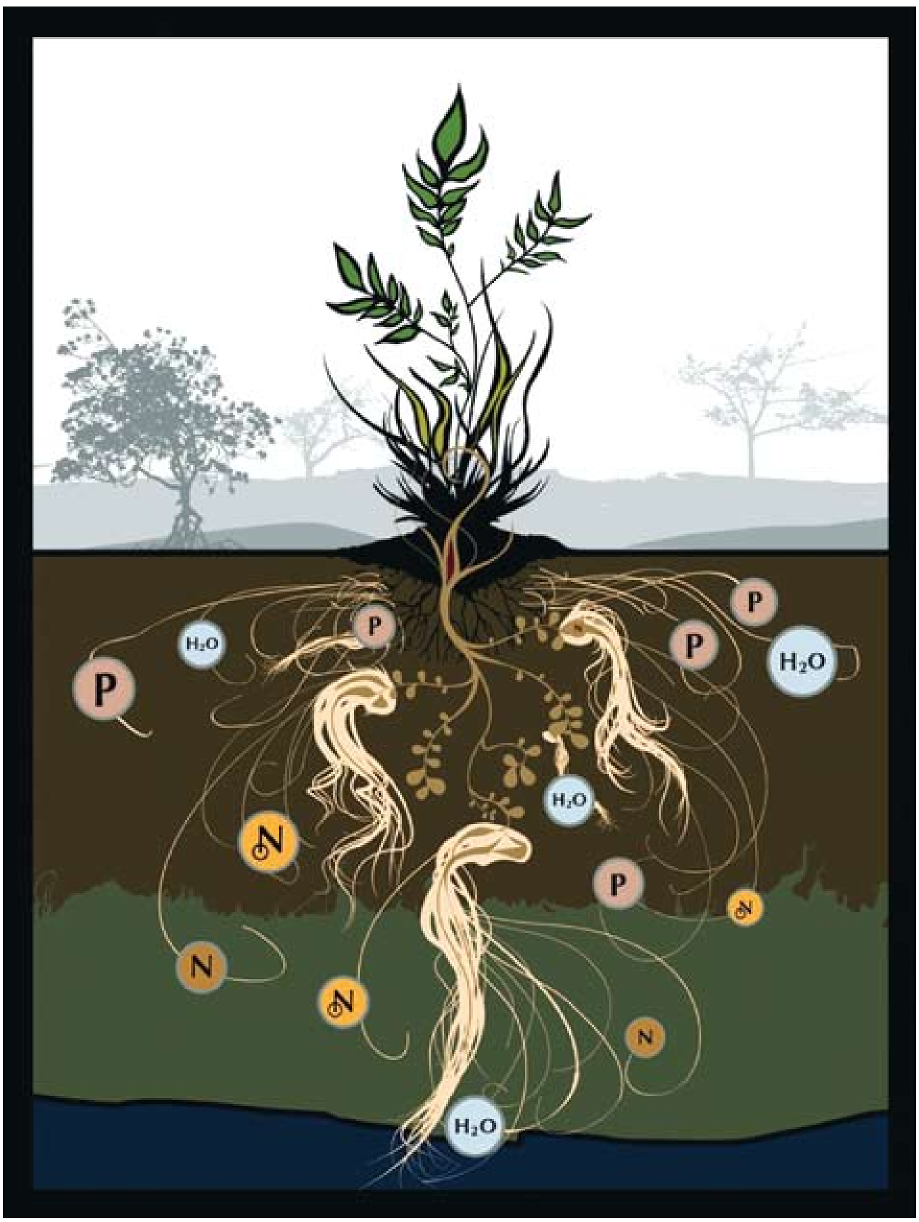
Biological Approaches to Farming

Reducing Fertilizer Use & Pollution



by Mike Amaranthus Ph.D. & Larry Simpson

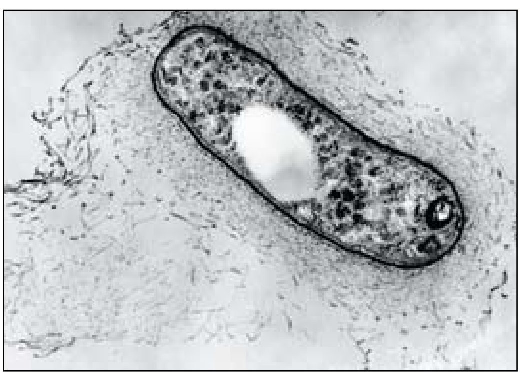
The thin skin of soil that envelops the earth's crust is a basic and critical resource supporting life on the planet. Yet, in a sense, we treat soil — that remarkable collection of microbes, minerals and processes — as if we were still in the Stone Age. Research (and just plain common sense) indicates that excessive use of synthetic fertilizers and pesticides have had far-reaching ramifications for our environment and our own survival. The time has come to change course in the treatment and management of our irreplaceable soil and water resources. For all our infatuation with the latest in computers, phones and modern gizmos, basic human survival depends a lot more on clean water and our ability to sustain soil productivity.

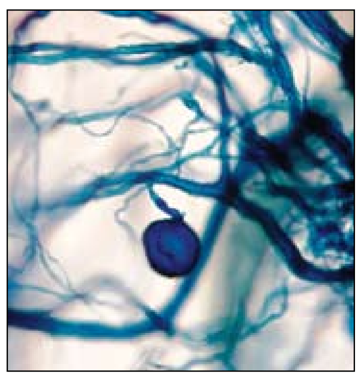
Water quality is deteriorating at an alarming rate worldwide, and farming is identified as a significant source of surface and groundwater pollution. As a result, nitrogen (N) and phosphorus (P) runoff mitigation has become a major goal of the agriculture industry. The preponderance of modern agriculture production relies on intensive synthetic fertilizer use, frequent tillage and heavy irrigation practices, all of which are highly conductive to nutrient leaching. The industry has proposed a number of Best Management Practices (BMP) in an attempt to maximize production while minimizing surface and groundwater contamination from agricultural runoff and leaching. These proposed practices vary with particular farming conditions, but most encompass proper vegetative cover and improved efficiencies in irrigation and fertilizer programs. While these practices may help, other valuable tools are available right beneath our feet.

Green algae lake buildup.

A GROWING PROBLEM

The advent of widespread synthetic fertilizer use in farming across North America in the 1940s and 1950s began to short-circuit many of the natural biological processes that keep soils and plants alive and healthy. Why care? Soil biology is critical to capturing and storing fertility in the ground. In the absence of a living soil, fertility, especially in the form of chemically derived nitrates and phosphates, can readily move into surface waters and aquifers, creating a loss of soil productivity and significant detrimental impacts on water quality and aquatic life.





Soil bacteria and mycorrhizal fungi.

Only a fraction of synthetic fertilizers applied to North American soils are actually utilized by the target plants. Much of these inputs result in the "mainlining" of inorganic nutrients into soils and waterways. Our use of synthetic fertilizers can be analogous to the much-publicized use of steroids by certain athletes. The treated plants may grow and produce yields at unnatural rates in the short term, but unfortunate side effects can become serious over time. In an Iowa State University study, corn fertilized with anhydrous ammonia utilized only 29 to 45 percent of the nitrogen input. The unused balance can end up damaging surrounding environments. Some of the unused nitrogen is volatized into the air, contributing to acid rain and global climate change, but much of it washes past the target crop roots, through the soil profile, into the groundwater and ultimately into neighboring streams, lakes or oceans. In the same Iowa State study, 49 to 64 percent of the nitrogen applied to the corn crop was volatized or leached.

Phosphorus is a nutrient essential to most aquatic plant growth, and its limited availability regulates most aquatic plant ecosystems. So when excess phosphorus becomes available to aquatic plants such as algae, growth can burgeon out of control. Just one pound of phosphorus can result in the growth of 350-700 pounds of green algae.

Excess amounts of phosphorus and nitrogen cause rapid growth of algae phytoplankton, creating enormously dense populations, or "blooms." Unconsumed algae ultimately sinks to be decomposed by bacteria in a process that depletes bottom waters of oxygen. Like humans, most aquatic life requires oxygen. When the oxygen in an aquatic environment becomes depleted (a condition known as hypoxia), fish, insects, crustaceans and most other species will die unless they migrate to other areas where the habitat remains suitable. Prolonged hypoxia can result in eutrophication, essentially the process described above in which over-abundant nutrients, especially phosphorus, develop into a biologically devoid aquatic environment. The economic consequences of excessive algal growth due to nutrient pollution can be costly and severe, leading to increased water treatment costs, degraded fishing, boating activities and negative impacts on tourism and property values.

Like phosphorus, the heavy use of nitrogen fertilizer can also cause an overload of nutrients in the waterways into which it drains. Excess nitrogen similarly stimulates algae blooms that can create oxygen-starved water, fish kills and aquatic dead zones. Nitrates and phosphates migrate downstream from Midwest farmlands, eventually reaching the Mississippi River and ultimately the Gulf of Mexico. Once in the Gulf, they stimulate runaway algae growth, which has formed a fish-smothering hypoxia zone that is sometimes as big as the state of New Jersey.

Health costs have also been linked to the excess use of synthetic fertilizers. In some places, such as Des Moines, Iowa, a "blue baby alert" is issued when nitrogen runoff from surrounding farmland is heavy. This alert cautions parents to avoid giving tap water to children because elevated nitrates in the water bind to hemoglobin in blood, blocking proper distribution of oxygen to the brain. Another human health issue can be created by blue-green algae blooms, which can produce toxins affecting the nervous system and liver of humans. Numerous states have experienced negative economic and human health impacts due to general declines in surface and groundwater water quality as evidenced by algae blooms and fish kills.

Fortunately, there are many examples in which water quality has been improved by limiting nutrient loads, including Lake Erie, Lake Geneva, Switzerland and Lake Endine, in Italy. Eutrophication in these lakes was reversed by implementing measures that reduced nutrient pollution. These examples demonstrate that a phosphorus reduction of 70-90 percent is required to significantly reverse eutrophication and improve ecological health to a body of water.

Tomato trial: without mycorrhizal inoculation and fertilizer; fertilizer only; and fertilizer and mycorrhizal inoculation. The addition of mycorrhizal fungi reduced nutrient loss and increased yield.

LIVING SOIL: RESERVOIR OF FERTILITY

Truly healthy soil contains a prodigious abundance of biological activity. One heaping tablespoon of healthy soil may contain billions of soil organisms. Just an ounce can contain numbers of organisms equal to the earth's entire human population! An acre of healthy topsoil can contain a web of life that includes 900 pounds of earthworms, 2,500 pounds of fungi, 1,500 pounds of bacteria, 130 pounds of protozoa, 900 pounds of arthropods and algae, and in most cases, even some small mammals. These soil organisms are like billions of miniature bags of fertility, each storing plant nutrients in their body tissue while slowly converting them into available forms of plant nutrients.

Scientific research confirms that fallow, tilling and compaction — all common in agricultural areas — reduce or eliminate the soil's mycorrhizal fungal populations. Furthermore, high levels of synthetic fertilizers can have a devastating effect on the soil food web. Many synthetic fertilizers are essentially salts that suck the water out of beneficial bacteria, fungi, protozoa and a wide array of other soil organisms. Yet these are the organisms that form the basis of the food web, creating, conserving and processing nutrient capital in the soil. The destruction of large segments of living soils often leave growers stuck on a treadmill requiring the continual and increasing use of chemicals to compensate for the loss of natural fertility.

Thousands of research studies document that beneficial soil organisms play key roles in the conservation, mobilization and transportation of nutrients from soils into plants. On those farmlands in which beneficial organisms have been eliminated, tasks such as supplementing nutrients and pest and pathogen control must now be done by farmers. Over time, input costs have gradually escalated due to an over-reliance on increasingly expensive chemical approaches to agricultural land management. Often solving one problem synthetically causes three others later.

MANAGING FARMS BIOLOGICALLY

Prior to World War II, growing operations were largely biologically based. Most had been successfully and sustainably managed for generations. It has only been since the late 1940s that the synthetic approach has been utilized on a large scale. Within these last 60 years, serious problems have become clearly evident. However, there are biological tools that can decrease the need for chemical fertilizers in agricultural operations. Among these are those crucial groups of microorganisms that keep soils fertile and healthy: bacteria and fungi.

Incorporating nitrogen-fixing plants into farm management practices adds nitrogen and organic matter to soils in a less leachable form. An excellent example is the use of rhizobial bacteria inoculant when planting nitrogen-fixing plant species such as legumes. Eighty percent of the earth's atmosphere is nitrogen, yet despite this abundance, plants are unable to absorb it as a gas from the air. That's where symbiotic, nitrogen-fixing bacteria associated with the roots of certain plants come in. These bacteria are capable of utilizing the vast pool of atmospheric nitrogen by converting it to an organic form that plants can use. A legume cover crop can add and store as much as 200 pounds of nitrogen in an acre of soil.

In their natural environments, most plants, including more than 90 percent of all crop species, form a root association with specialized fungi called mycorrhizae. *Mycorrhizae* literally means "fungal roots." In this mutualistic association, root-attached fungal filaments extend into the soil, helping the plant by gathering water and nutrients and transporting these materials back to the roots.

Miles of fungal filaments can be present in a small amount of healthy soil. The plant's association with mycorrhizal fungi increases the effective surface absorbing area of roots several hundred to several thousand times. In return, the plant feeds the fungus sugars produced by photosynthesis. Scientific studies with hundreds of various plants indicate that the mycorrhizal relationship can improve nutrient uptake, yields, drought tolerance and root biomass. This symbiosis is truly a win-win association for the plant, the fungus and potentially for the farmer.

Crop inoculation with arbuscular mycorrhizal (AM) fungi can be an important component of farming practices that reduce nutrient runoff while maintaining plant crop quality and yield. AM fungi are a specialized group of microorganisms that colonize the roots of most plants, establishing this mutually beneficial relationship. Attached to the roots, they develop a dense mass of tiny fungal filaments that reach out into the surrounding soil, dramatically enhancing the plant's ability to acquire mineral nutrients and water.

AM fungi have been considered as a valuable tool to decrease fertilizer inputs because numerous mycorrhiza-inoculated plant species have reached similar or greater growth with a fraction of the fertilizer rate required by non-inoculated control plants. Recent research by the University of California examined the use of mycorrhizal fungi to increase nutrient use efficiency and reduce nitrogen and phosphorus leaching. The authors found that mycorrhiza-treated plants had greater biomass than non-treated controls. Shoots from mycorrhizal-colonized plants averaged 30 percent higher nitrogen content and a whopping 300 percent higher phosphorus content than shoots of the identical plants without mycorrhizal root colonization.

Perhaps most importantly, the authors also documented a significant reduction in the concentrations of nitrates, ammonium and phosphates found in the leachates of inoculated plants receiving the full rate of fertilization. Nitrate, ammonium and phosphate losses via leachates were reduced 30 percent with mycorrhizal inoculation. This study has tremendous implications for more efficient use of fertilizers while simultaneously reducing water pollution in growing operations. Farmers can save money on the use of fertilizers while minimizing surface and groundwater contamination from runoff and leaching.

Recent research published in the journals *Nature* and *Ecology* emphasizes the important, newly discovered role mycorrhizal fungi play in delivering nitrogen to plants. This information may lead to a reduced reliance on synthetic nitrogen fertilizers in agriculture. Root colonization by mycorrhizal fungi improved nitrogen uptake for a variety of plant species by direct utilization of nitrogen in the form of organic amino acids. With this in mind, farmers may be able to harness mycorrhizal fungi for more efficient use of the organic nitrogen stored in existing soils, manures, organic fertilizers and crop residues, thus diminishing chemical fertilizer inputs.

The research authors found that beneficial mycorrhizal fungi transfer substantial amounts of nitrogen to their plant hosts. The fungus facilitates use and conservation of nitrogen by absorbing amino acid molecules, which contain nitrogen, thereby minimizing the plant's need for leachable nitrogen forms such as nitrates, which must be converted in the surrounding soil.

ESTABLISHING NATURAL, LIVING SOIL

So, how do you re-establish beneficial soil organisms after they have been lost from the farm? The beneficial bacteria, Rhizobia, has long been available as an inoculant for legumes and is usually applied as a liquid or peat-based form to the seed or plant. More recently, advancements in our understanding of mycorrhizal fungi and their requirements has led to the production of high-quality, mycorrhizal inoculum at affordable prices. Mycorrhizal inoculum is currently available in granular, powder and liquid forms.

The most important factor for re-integrating mycorrrhizae is to place mycorrhizal propagules directly with seed or on or very near the root systems of target plants. Inoculum can be banded with seed or seedlings, sprayed in-furrow, watered into porous soils, or pre-mixed into soil. The form and application of the mycorrhizal inoculum depends upon the needs of the farmer and the equipment used.

CONCLUSIONS

Over the last few decades a growing reliance on synthetic fertilizers has developed throughout the agricultural industry. This trend depends heavily on chemical inputs rather than biology-based methods to solve crop production and land management challenges. While these practices have provided nutrients in the short term, the synthetic approach has resulted in a litany of long-term problems and expenses. It is a "Stone Age mentality" to keep bombarding our soils with practices that destroy its valuable biology. In addition to the steadily escalating expense of chemicals themselves, collateral costs include the major deterioration of many aquatic systems and increased health concerns.

It's clear that the need to manage nitrogen and phosphorus biologically is especially urgent. Before the advent of synthetic nutrient sources and the fossil fuels that deliver them, biologically sound practices proved successful and sustainable for thousands of years without detrimental impacts to water quality. In Stone Age times, man's inability to heed the negative consequences of his actions can be attributed to ignorance and lack of sophistication. What's our excuse today as we witness the deterioration of our soils, waterways and health due to flawed agricultural practices?

The modern farmer has many biological tools with which to improve the health of the land and its people by putting the living soil back to work. A biological methodology works by incorporating important soil organisms that build and maintain soil fertility as a cornerstone of farm management. This approach is now spreading rapidly across America as we begin to recognize the fact that rich, productive soils are dynamic, living ecosystems made up of a mixture of minerals, air, water, organic materials and a healthy population of beneficial soil organisms.

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Larry Simpson is director of education and training at Mycorrhizal Applications, Inc. He previously spent nearly 20 years specializing in organic soils and fertilizers in the retail lawn and garden industry, where he formulated and developed numerous innovative and successful natural/organic soil and fertilizer products, including some of the first to contain mycorrhizal inoculants.