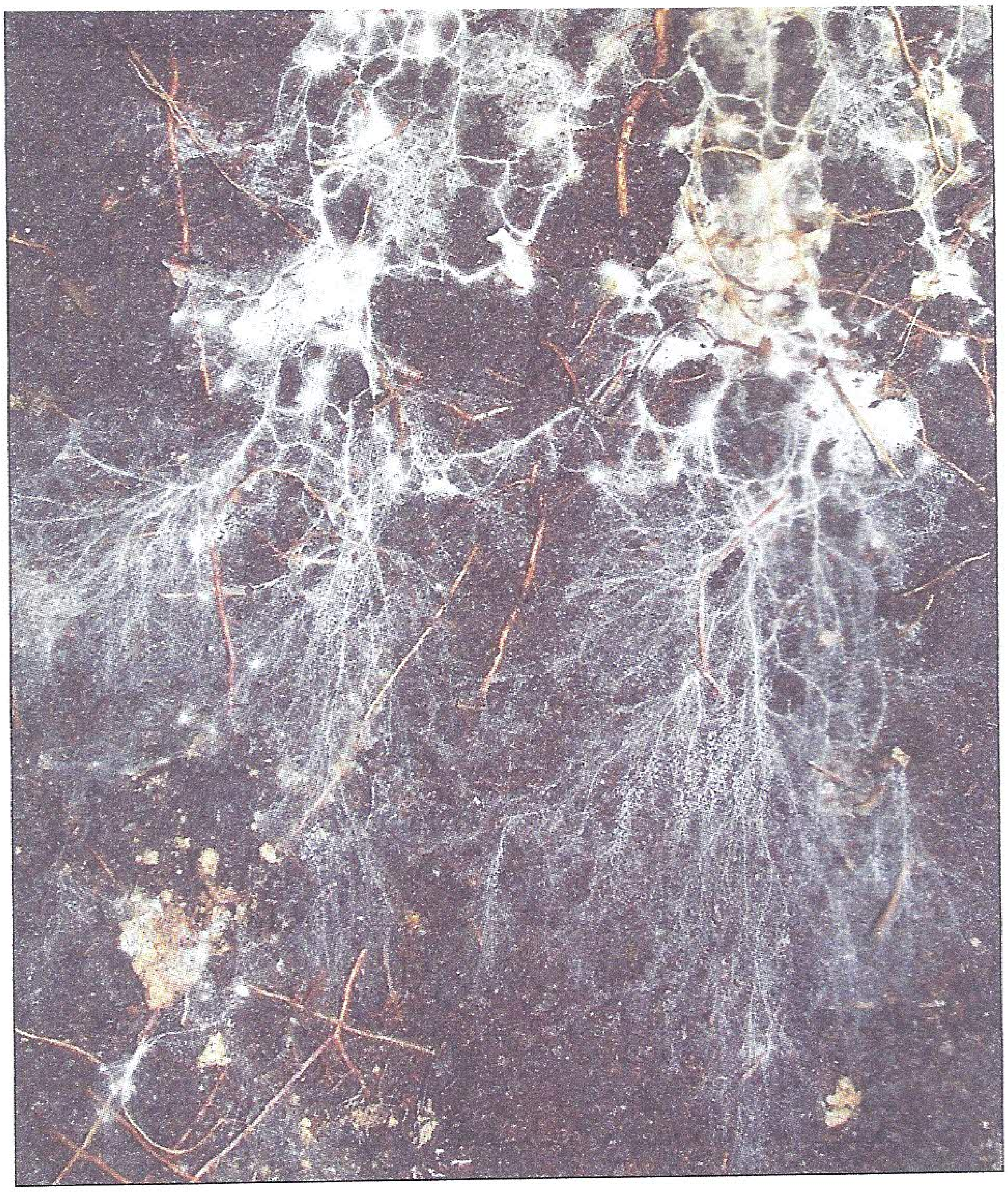


A thimble of soil can contain miles of mycorrhizal threads.

Nursery trial with 30 percent less fertilizer. Inoculated with MycoApply (left) and without.

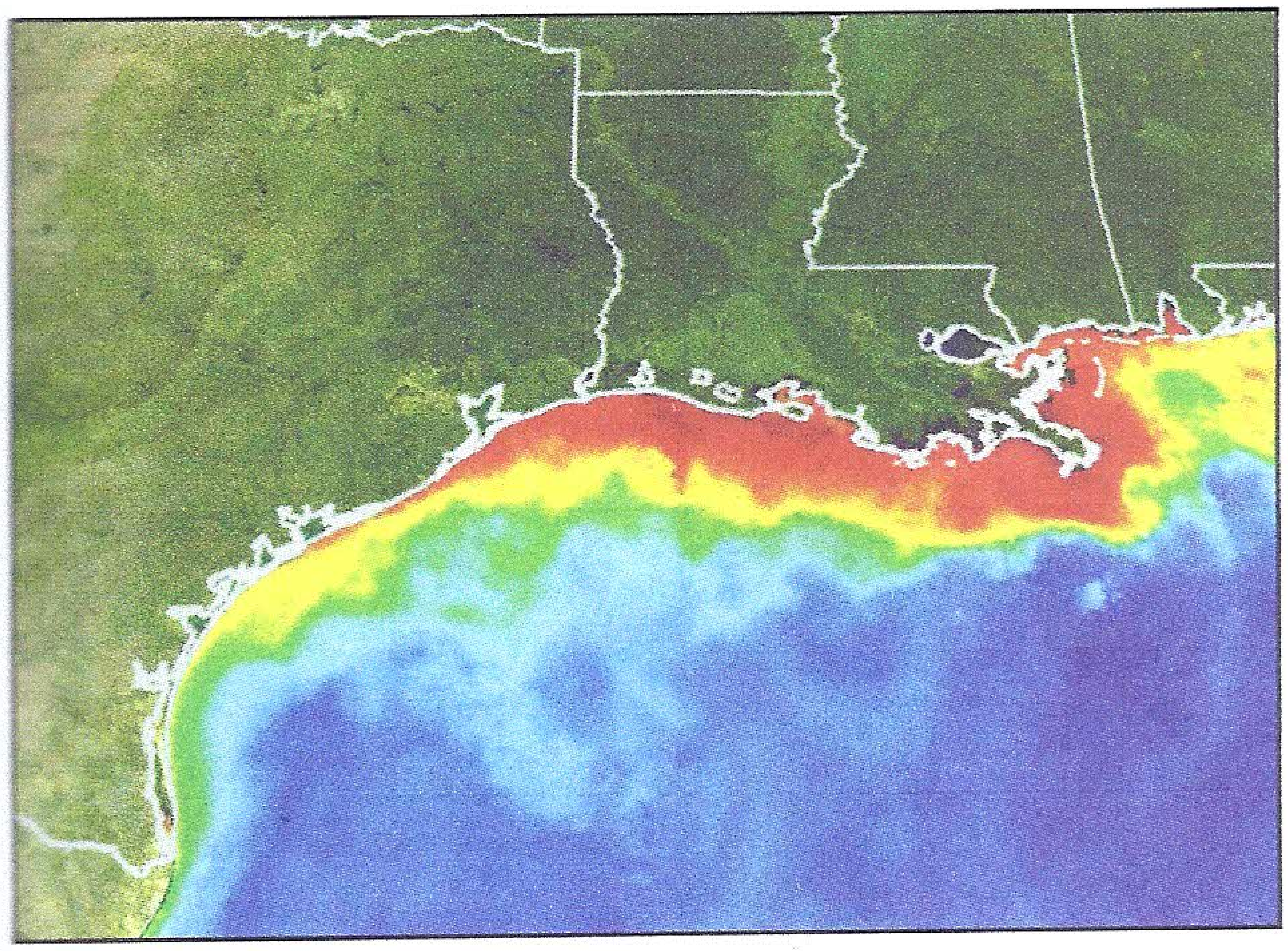
NITROGEN PROCESSES & PROBLEMS

The Below-Ground Connection

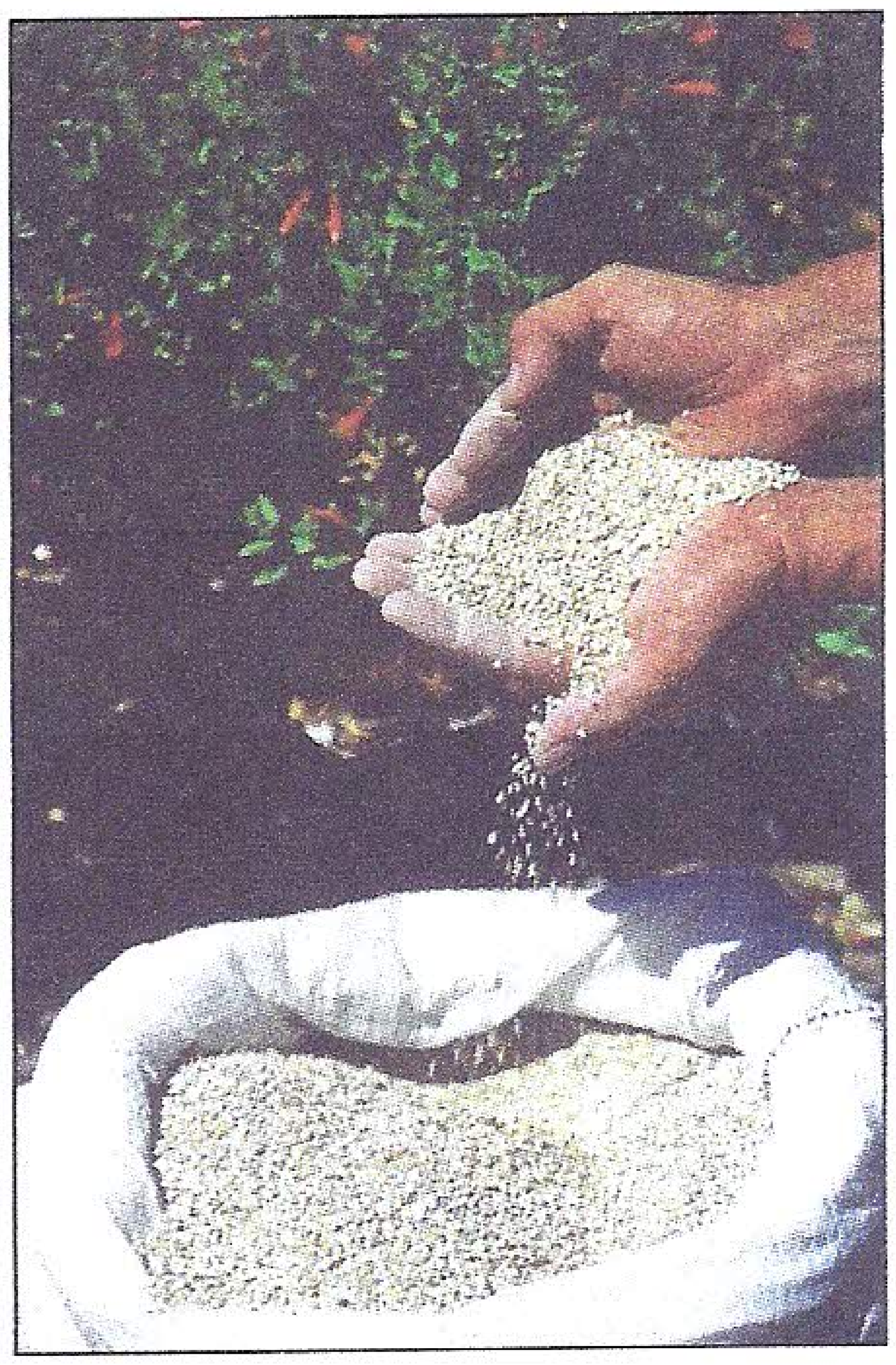
by Dr. Mike Amaranthus

A few colorless drops of liquid appearing at the end of a tube one afternoon in Germany, July 1909, represents perhaps one of the most important technological breakthroughs in human history. This discovery 100 years ago continues to have unintended effects on our modern world. The liquid was ammonia and the scientist, Fritz Haber, demonstrated that nitrogen (N) could be taken directly out of the air. This revelation on a German tabletop had vast implications for the future of humanity. It provided the world with a mechanism for a new source of fertilizer. The discovery opened the floodgate, making it possible to dramatically expand the world's food supply and, as a consequence, the human population.

Ammonia is a combination of nitrogen and hydrogen (NH_3), and nitrogen is most often the nutrient limiting plant growth. Nitrogen is a critical building block of plant and animal tissue and rests at the core of all 10 amino acids upon which humans depend. Nitrogen is key for the vegetative growth, protein content and yield of cereal grains such



The Gulf of Mexico hypoxia zone.



A granular mycorrhizal inoculant.

as wheat, rice, barley and oats; the staple crops that have fueled human population growth from 1.6 billion to 6 billion in the course of the 20th century.

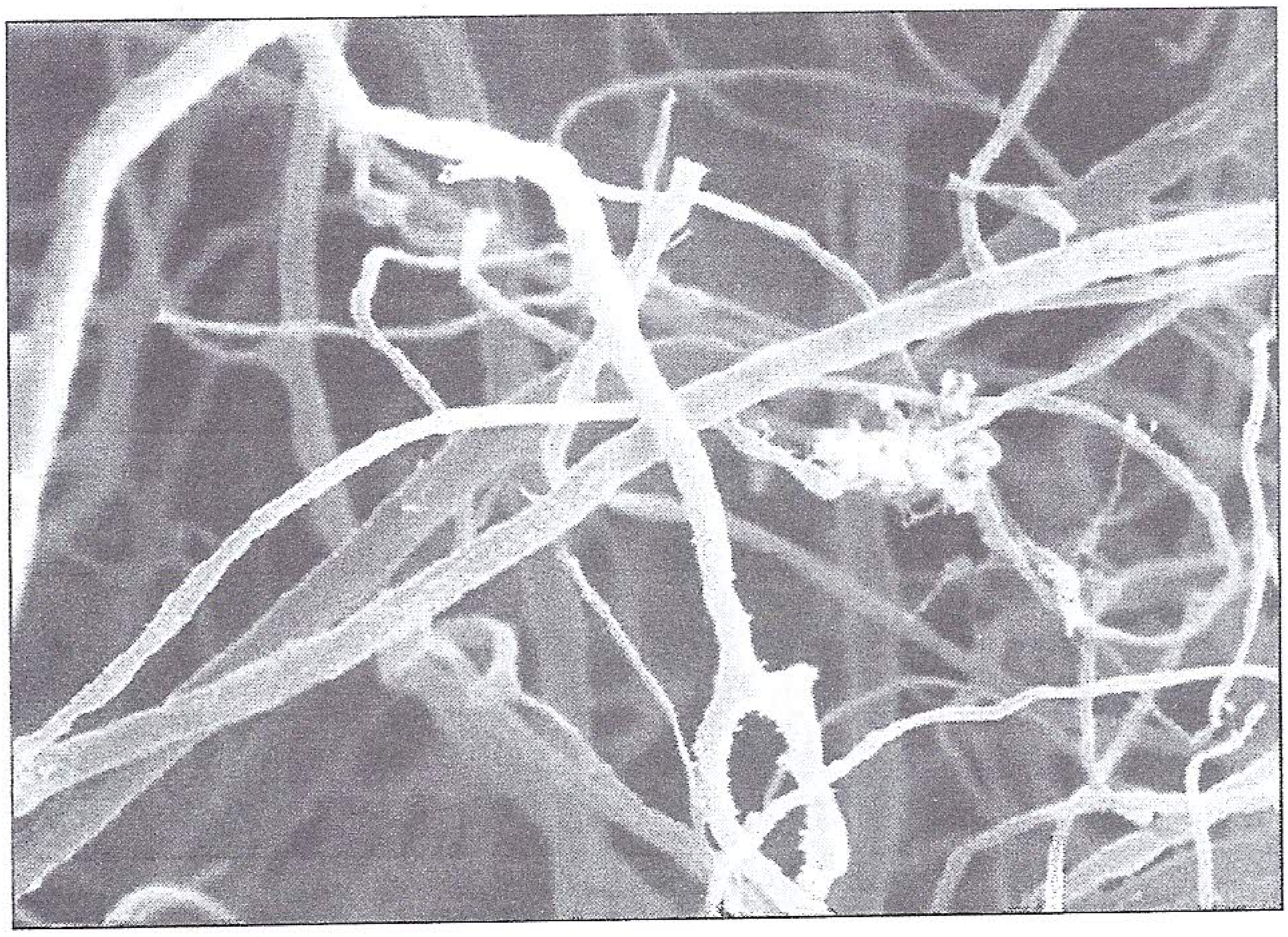
A lack of nitrogen in these grain crops results in stunting, yellowing, reduced protein and yield. Abundant nitrogen, on the other hand, improves growth and increases both protein and yield. Nitrogen compounds are important not only for plants but for animals as well. Nitrogen is a component of amino acids, proteins and DNA and is present in every living cell. Amino acids form proteins that synthesize tissue growth and support metabolism. These amino acids come from our crops or the crops that are fed to the animals we eat. Without these essential amino acids humans cannot function. Therefore, nitrogen is truly a key limiting factor in overall human nutrition.

The synthesizing of ammonia launched the era of chemical fertilizers. Chemical fertilizers, along with plant breeding and the development of high-yield seed varieties, is largely known as the "green revolution" which began in a big way in the 1950s, leading to unparalleled growth in the world's food supply over several decades. The use of chemical nitrogen fertilizers increased rapidly in developing countries between 1960 and 1980. This facilitated a large increase in the production of feed and food grains (corn, wheat and rice) per unit of cultivated land and an enrichment of surface and groundwater with various forms of nitrogen. Without this seven-fold increase in food production in the 20th century, hundreds of millions or perhaps even billions of people would have faced malnutrition or starvation.

Today, commercial nitrogen fertilizer is primarily manufactured as gaseous ammonia using the Haber-Bosch process. Carl Bosch was a senior scientist for BASF Corporation who was given the task of converting Haber's method to a large volume enterprise at a low cost. This challenge resulted in the creation of a vessel that could withstand the enormous pressures required by the reaction. The stage was set for the logarithmic increase in the use of chemical fertilizers and its power to increase the world's food supply.

FRANK-N-STEIN: PROBLEMS WITH NITROGEN POLLUTION

Many have argued that the so-called "Green Revolution" has been anything but green. A reliance on chemical fertilizers and pesticides has caused widespread environmental damage. Over-fertilization encourages crop pest and disease outbreaks requiring the increased use of pesticides. Nitrogen washes into aquifers, lakes, rivers and oceans poisoning water supplies, affecting human health, killing fish and shellfish, and leading to rampant algae growth. While nitrogen on the farm and garden feeds the world, much is wasted. And when it travels off-site, it becomes one of the world's most troublesome pollutants. Nitrogen contamination of surface and ground water increased significantly after 1960 as the widespread and intensive use of N fertilizers rapidly expanded. In the United States, 75 percent of N fertilizer is applied to corn, while in other countries, N fertilizer is primarily used on wheat and rice. Prior to 1960, nitrogen for crop production was obtained primarily through crop rotation that included legumes such as alfalfa, clover and vetch, which can establish a symbiotic relationship with the soil bacteria Rhizobium. These specialized bacteria convert atmospheric nitrogen gas to biologically available forms of N within nodules formed on the roots of associated plants. Such practices began to fall from use with the massive introduction of cheap chemical fertilizers. Chemical fertilizers, however, are not the only source of nitrogen that can cause contamination of surface water and factories can also contribute to nitrogen enrichment of water bodies. Additionally, under some conditions, nitrogen applied to the soil may be converted to greenhouse gasses capable of trapping up to 30 times more heat than carbon dioxide (CO_2). Research has shown that the amount of contamination from fertilizer varies depending on the amount of fertilizer applied, the characteristics of the soils, crops and climate, and the nature of the receiving water bodies. There are several water quality concerns associated with different forms of nitrogen. First, the combined concentrations of nitrate (NO_3) plus nitrite (NO_2) in excess of 10 mg N per liter can contribute to methemoglobinemia ("blue baby syndrome") in infants. Nitrogen replaces oxygen in the bloodstream of infants who ingest N-contaminated water. The blue color refers to the lack of oxygen in the blood. To guard against this, the U.S. Public Health Service has established a 10 mg N per liter concentration limit for combined nitrates and nitrites in public drinking water supplies. Another water quality concern is ammonia (NH_3) that may be toxic to fish at concentrations



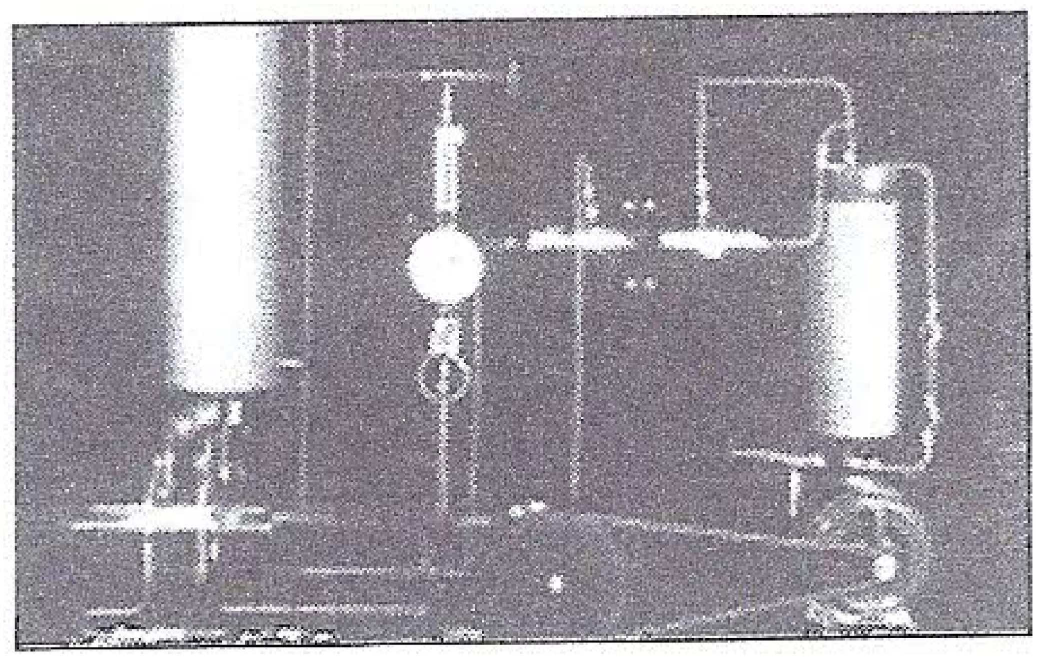
A mass of mycorrhizal fungal mycelia.

cess of eutrophication and hypoxia in waterways in which elevated production and decomposition of algae leads to reduced dissolved oxygen concentrations. Research has traced fertilizer run-off from agricultural lands to coastal waters where it suffocates or drives off sea life. Algae blooms deplete waters of oxygen causing widespread "dead zones" that are growing at an alarming rate around the world. For example, an 8,000 square-mile dead zone has developed in the Gulf of Mexico at the mouth of the Mississippi River and represents just one of an estimated 400 such dead zones identified worldwide. The problem is "growing" and ignoring this environmental degradation derived largely from nitrogen pollution is simply de-N-ial.

N: THE GREAT ESCAPE

The challenge before us is how to maximize nitrogen's benefits while diminishing its negative effects. It is estimated that 40 percent of nitrogen applied in the U.S. does not end up in the target crop plants. In some countries such as China, where up to 75 percent of all nitrogen used to grow rice may be wasted, the situation

which further compound the problem. So how does nitrogen escape from the soil? Rainfall, snowmelt or irrigation water input to the soil periodically exceeds the soil and root zone's water holding capacity. Depending on the characteristics



The Haber apparatus extracted ammonia from air.

of the soil, this may lead to saturation of the root zone allowing surface and/or drainage water to pass through the soil profile and into the groundwater and/or surface water bodies. The root systems themselves are not extensive enough to capture N as it moves through the soil. Improper flow of water through the soil profile and into groundwater and surface waters appears to be a hydrologic pathway that frequently leads to problematic N contamination in agricultural watersheds. This occurs via natural drainage as when groundwater contributes to stream and river flow. Another source includes artificial subsurface drainage mechanisms such as perforated pipes or drain tiles buried beneath the soil to remove excess water during saturated conditions. Such installations are meant to protect crops and enhance production, but often result in increased N contamination.

N-ATURE TO THE RESCUE

Efforts to improve the utilization and efficiency of nitrogen fertilizers are needed. One of the most promising solutions is right beneath our feet: mycorrhizal fungi. In natural habitats, loss of nitrogen does not occur because beneficial soil organisms such as mycorrhizal fungi are so efficient at absorbing and translocating nitrogen into plants. While mycorrhizal fungi form a relationship with 90 percent of the world's plants in their natural habitats, they are negatively affected by soil disturbance. Removal of native vegetation, cultivation, fallow and the use of certain chemical fungicides has reduced and, in many cases, eliminated these beneficial fungi from our agricultural lands.

Just how do nutrients such as nitrogen get into plants? Where they are present, it is the job of the mycorrhizal fungi. New findings show that these beneficial soil fungi play a large role in nitrogen uptake and utilization for their host plants. In the journal *Nature*, scientists Philip Pfeffer and David Douds have reported that beneficial arbuscular (also known as endomycorrhizal) fungi transfer substantial amounts of nitrogen to their plant hosts. Arbuscular mycorrhizal fungi are the most common type of symbiotic (mutually beneficial) fungi colonizing the roots of most crop plants. The fungi are supplied sugars provided by the plant to fuel the growth of thousands of filaments beneath the soil surface. In exchange, the fungi's miles of tiny threads greatly enhance the plant's ability to take up nutrients including nitrogen. The surface absorbing area available to the plant root system is increased by several hundred to several thousand times. Scientists have also identified specific enzymes produced by the mycorrhizal fungi that breakdown and absorb nitrogen. Their research indicates that the symbiotic relationship between mycorrhizal fungi and plants has a much more significant role in the worldwide nitrogen cycle than previously believed. With this information in hand, farmers can benefit by promoting the proliferation of mycorrhizal fungi, decreasing their fertilizer inputs and making more efficient use of nitrogen stores in their agricultural soils.

An expert in soil biology, Dr. Mike Amaranthus has more than 30 years of research experience as a scientist with the USDA, Oregon State University, and Mycorrhizal Applications. International research efforts have taken him to jungles and testing grounds from one end of the earth to the other, including Australia, New Zealand, France, Italy, Spain, Costa Rica, Mexico, Canada and Thailand. He is the founder of Mycorrhizal Applications, Inc.