Bombs, Beans, and Dirt

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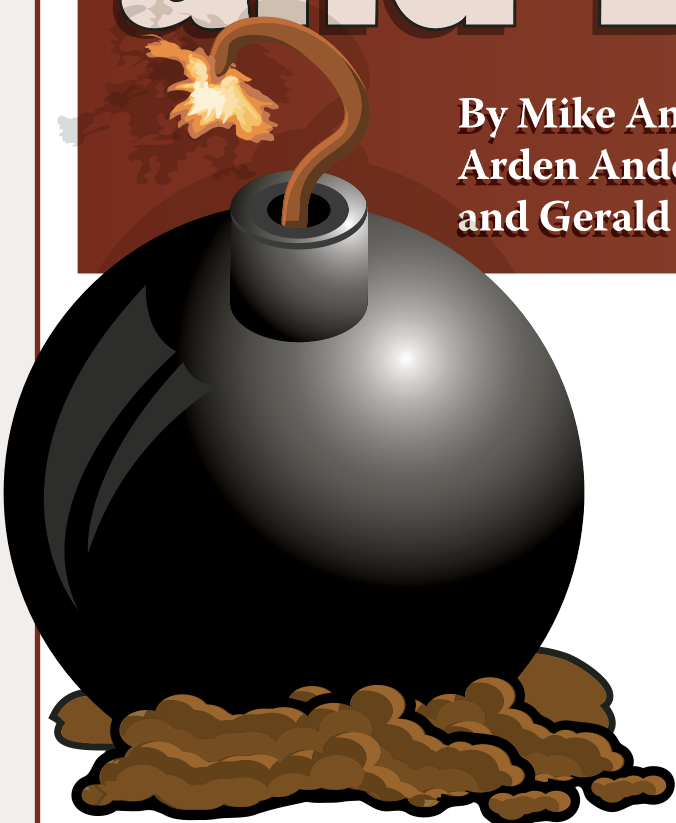


A critical turning point in the health of North American farm soils can be traced to a single day in 1947. On this day the gigantic munitions plant in Muscle Shoals, Alabama switched from bomb making to manufacturing chemical fertilizers. When World War II ended, the government was left with an extremely large surplus of ammonium nitrate that had been used in the manufacturing of bombs. This same chemical is also a powerful source of nitrogen that is essential for plant growth. Initially, this surplus was targeted for the timber industry as a cheap source of nitrogen to spray on the nation's forests. However agronomists at the US Department of Agriculture had another idea in mind. Ammonium nitrate could be spread on agricultural land as fertilizer. Indeed, nerve gases developed for wartime purposes were already being used, with minor modifications, for insect control on the nation's farmland. While fertilizer craving crops benefited from cheap sources of chemical "N" (Nitrogen) fertilizer, life in the soil suffered.

Bye Bye Biology

With the advent of synthetic fertilizers farmers could short-circuit many of the "biological" practices that kept soils alive and healthy (Figure 1). The negative effects have also had an impact on the environment. Soil organisms are critical to capturing and storing fertility in the ground (Read et al. 1992). In their absence, fertility, especially nitrogen in the form of nitrates is readily leached into surface waters and aquifers. This has a significant and detrimental impact on drinking water and aquatic life (Runge 2002). Because only a fraction of the synthetic fertilizers farmers put on their fields are utilized by crops, much of its application results in "mainlining" inorganic nitrogen into soil. In an Iowa State University study, corn fertilized with anhydrous ammonia utilized only 29% to 45% of the added nitrogen. The balance of it ends up damaging the surrounding environment. Some is volatilized into the air contributing to acid rain and global warming, but much of it travels off farms, washing down through the soil profile into groundwater and neighboring streams. In the same Iowa State study 49% to 64% of the added nitrogen was volatilized or leached.

Figure 1

The Biological Approach. Legume cover crop adds lots of nitrogen and organic matter to the soil without synthetic fertilizer.

The environmental costs of the use of chemical fertilizers have been high. In some places, such as Des Moines, Iowa, "blue baby alert" is issued when the nitrogen runoff from surrounding farmland is heavy (Ward et al. 1998). It is a warning to parents not to give tap water to children because nitrates in water bind to hemoglobin in blood and block the distribution of oxygen to the brain. Nitrates move downstream from Midwest farmlands traveling down the Mississippi and into the Gulf of Mexico. There they form a "hypoxic" or dead zone as big as the state of New Jersey (Goolsby et al. 1999). Nitrates poison the marine world, stimulate the wild growth of algae, and consume oxygen, which smothers fish. In essence we have been "bombing" non-target organisms with excess nitrates leaching from farmlands.

Nitrogen fertilizers and fossil fuels

In 1909, Fritz Haber, a German chemist, discovered how to artificially take atmospheric nitrogen and fix it into a chemical form that could be used by plants. Until that time, the vast majority of usable nitrogen on the planet was converted to plant-available forms biologically by soil organisms such as Rhizobia (Figure 2). These beneficial soil organisms were supported by the sun's energy in a symbiotic relationship with certain plants. With the advent of cheap synthetic fertilizers these biological processes were no longer necessary, at least in the short run, to maintain fertility on the farm.

Figure 2

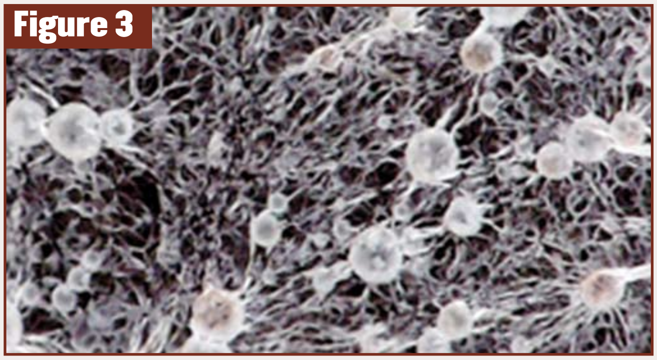
Nitrogen-fixing rhizobia on legume plant roots and a close-up of the nodule

When humans discovered how to fix atmospheric nitrogen, the massive conversion of farms to synthetic nitrogen fertilizer resulted in an agricultural system heavily dependent on fossil fuels. On average, these fertilizers account for about 30% of a conventional farm's energy consumption (Manning, 2001). University of Kentucky researchers attributed 42% of the energy cost of corn production to nitrogen fertilizer compared to 29% for drying the grain and 7% for plowing and disking the field. As a result, it tasks 50 gallons of oil to produce an acre of industrial corn (Pollan 2006). In fact, it takes more than a calorie of fossil fuel energy to produce one calorie of food.

Chemical fertilizers and the living soil

Rod Arkley, a soil science professor at the University of California, Berkeley has stated that," Dirt is what you get under your fingernails, soil is what gives the earth life." When soil is healthy it contains an abundance of biological activity. One heaping tablespoon of healthy soil may contain billions of soil organisms, which is equal to the whole human population of the earth! An acre of healthy topsoil can contain a web of life

Figure 3



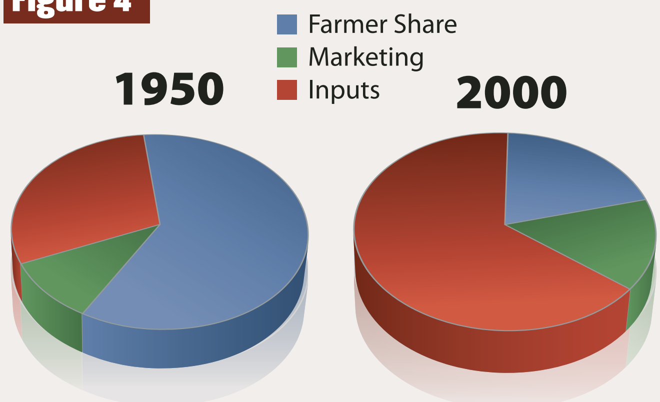
Fungal filaments can total several miles in a spoonful of healthy soil

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, it even contains small mammals (Amaranthus et. al 1989). (Figure 3).

The farmers share of farm income has declined because tasks such as controlling pests. High levels of chemical fertilizers can have a devastating impact on the soil food web (Lowenfel and Lewis 2006). This is obvious even in what table salt does to a worm. Chemical fertilizers are essentially salts that suck the water out of beneficial bacteria, fungi, protozoa and a wide array of other organisms in the soil. It is these organisms that form the basis of the food web which conserve and process nutrient capital in the soil. By destroying large segments of living soils, farmers are stuck with an agricultural regime that requires the continued and on-going use of synthetic chemicals.

Consequently, tasks such as controlling pests, pathogens and releasing stored soil fertility once accomplished largely by beneficial soil organisms must then be done by farmers. Input costs have skyrocketed because of this reliance on increasingly complicated chemical approaches to managing the farm (Figure 4).

Figure 4



Farmer's Dilemma 1950-2000. Over 50 years input costs for fertilizer, fuel and pesticides have increased, reducing the farmer's share of farm income.

Bottom line: Declining food quality

Recent studies show an alarming decline in the quality of food over that last 50 years. Davis and others in 2004 analyzed USDA Food composition data for 43 crops from 1950-1999 and found statistically reliable declines for 6 nutrients. In another study, Dr. Mayer, 1999, found significant reduction for 7 minerals in 20 fruits and 20 vegetables between the 1930s and 1980s in the United Kingdom. Experts have wondered if the reliance on chemical fertilizers and large-scale destruction of life in the soil may have had an effect on the nutritional value of food. Thousands of research studies have shown that beneficial organisms play key roles in the conservation, mobilization and transportation of nutrients from soils into plants (Read et al. 1994). The relationship between the quality of soil and the quality of food is undeniable (Figure 5).

Prior to WWII, farms were biologically based, and most had been successfully managed in a sustainable manner for

Figure 5

Tomato trial: right without mycorrhizal inoculation and fertilizer, center: fertilizer only, left: fertilizer and mycorrhizal inoculation. The addition of mycorrhizal fungi improved nitrogen utilization and yield

generations. It has only been since WWII that the synthetic approach has been utilized and within those 50 years serious problems have become clearly identifiable. There are biological tools though that can decrease the need for chemical fertilizers on farms. Two examples of beneficial organisms are nitrogen-fixing bacteria and mycorrhizal fungi. Farmers once knew how important these organisms were to the farm.

Beans and Nitrogen-fixing Rhizobia bacteria

Before the advent of chemical fertilizers, farmers could not maintain high levels of production with the same crops on the same ground year after year. Such practices would produce soils devoid of fertility. In the old days, farmers were careful about rotating crops and incorporating nitrogen-fixing legumes into management practices, which added fertility and organic matter into soils. An excellent example of these practices is the use of Rhizobia inoculant when growing beans and other nitrogen-fixing legume crops on farmland. Eighty percent of the atmosphere is nitrogen, but in spite of it being so plentiful, plants aren't able to utilize it as a gas form. It is important to note that symbiotic nitrogen-fixing bacteria associated with the roots of legumes are capable of taking substantial quantities of the vast pool of atmospheric nitrogen and convert it to an organic form usable by plants. A good cover crop can add 200-300 pounds of nitrogen per acre into the soil.

From ancient times until recent decades, these soil organisms were essential partners in building soil productivity. Until recently, these organisms were among the most important tools in maintaining the productivity of the farm. The expense and environmental costs of chemical forms of nitrogen fertilizer are increasingly making biological or "bean" approaches more profitable to farmers.

Mycorrhizal fungi

Most plants, including more that 90% of all agricultural crops, form a root association with specialized fungi called mycorrhizae. Mycorrhizae literally means "fungus roots." In this association, fungal filaments extend into the soil and help 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 (Harley and Smith 1983). In return, the plant helps the fungus by giving it sugar produced by photosynthesis. This symbiosis is a win-win association (Figure 6).

Figure 6

A highly productive mycorrhizal inoculated oat crop on a biologically managed farm in Manitoba, Canada

Recent research published in the *Journal Nature* (Govindarajulu et al. 2005) has emphasized the important role mycorrhizal fungi play in delivering nitrogen to crop plants, thus lowering the need for synthetic fertilizers. With this in mind, farmers may benefit from promoting the proliferation of mycorrhizal fungi through diminished fertilizer input, thereby making more efficient use of the nitrogen stores in agricultural soils. The authors found that beneficial mycorrhizal fungi transfer substantial amounts of nitrogen to their plant hosts. The researchers also discovered a novel metabolic pathway. An ammonium form of nitrogen, not subject to leaching losses compared to nitrates, is taken up by the mycorrhizal fungus in soil and incorporated into plant tissue. The fungus facilitates conservation of nitrogen through the uptake of ammonium and the minimizing of a plant's need for conversion to leachable nitrates in the soil.

Agriculture - the first and most precious of all the arts

Thomas Jefferson, Third President of the United States

1+1=3

Well-documented research trials are also available that document the important role of mycorrhizal fungi with most legume crops. The Rhizobia bacteria that form with important legume crops have a high phosphorus requirement, which help optimize their level of nitrogen-fixation. Two examples of biological tools are nitrogen fixing bacteria and mycorrhizal fungi. Mycorrhizal fungi produce specific enzymes to extract phosphorus out of the soil and make it available to nitrogen-fixing bacteria. The synergetic effect of a combined treatment with nitrogen-fixers and mycorrhiza can increase yield (Linderman, 1991). In soybeans, inoculation with mycorrhizal fungi increased the amount of biological-fixed nitrogen and stimulated phosphorous uptake, soybean growth and yield (Shabayev et al. 1996). Other studies have shown mycorrhizal inoculation improve rates of nitrogen fixation for other species (Tian 2003). Yield increases of 30% or greater have been realized for corn and soybeans with savings of 160 and 213 lbs/acre phosphorus respectively (Plenchette and Morel 1996).

Thousands of research studies have documented mycorrhizal benefits:

Go to www.mycorrhizae.com to request info for your particular crop

Benefits include:

1. Increased nutrient uptake.
2. Increased flower, grain and fruit production
3. Enhanced water relations
4. Improved soil structure and porosity

For the farm 1+2+3+4 = decreased input costs + increased yields + environmental benefits.

Biological nitrogen management aims to provide crops with enough nitrogen at the appropriate time while avoiding resource depletion and nitrogen pollution. Strategies include growing cover crops such as legumes that utilize nitrogen-fixing Rhizobia bacteria to replenish nitrogen exported at harvest. Another approach is to keep the ground covered with live vegetation that supports a mycorrhizal web of filaments below the soil surface so as to capture and transport nitrogen directly to the plant itself. The millions of tiny mycorrhizal filaments prevent leaching losses and supports the closed nitrogen cycle found in nature.

Putting the good critters back in soil

How do you re-establish beneficial soil organisms when they have been lost from a farm? The beneficial bacteria, Rhizobia, have long been available as inoculants for legumes and is usually applied as a liquid or peat-based form to the seed. 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, seed coat, and liquid forms (Figure 7).

Figure 7

Picture of powder mycorrhizal inoculum

The most important factor for re-integrating mycorrhizae is to place mycorrhizal propagules near the root systems of target crops. There are a variety of ways to achieve this. Inoculum can be incorporated into the planting hole at the time of transplanting, watered into porous soils, mixed into soil mixes or directly dipped on bare-root systems using gels. For agricultural purposes it is best banded or applied with seed at sowing. The form and application of the mycorrhizal inoculum depends upon the needs of the farmer and the equipment used on the farm. (Figure 8). It is clear that on

Figure 8

Wheat farmer adding powder inoculant to his seed box

farms where mycorrhizal fungi have been lost, inoculation can cut input costs and increase yields.

Bombs and dirt vs. the living soil

Over the last few decades many farms have developed a growing reliance on pesticides and synthetic fertilizers. This approach to managing the land relies on chemical inputs rather than biological approaches to solving land management issues. While this practice has allowed farmers to control pests and nutrient supply in the short term, the ”bombs and dirt” approach has caused more problems and expense in the long-term. The costs include deterioration of many aquatic systems and a decline in food quality. For example, in Great Britain the estimated cost of removing nitrates from drinking water is 2 billion dollars. Such costs fail to include the impact on human health such as the fact that childhood-onset diabetes has been linked to increased nitrates in drinking water (Parslow et al 2004). The biological or “ beans” approaches to managing nitrogen are especially needed and have been successfully practiced for hundreds of years before the development of cheap synthetic nitrogen sources powered by fossil fuels. It is time to get back to nature’s solutions.

Biological management of nitrogen is a key ingredient in many organic approaches to managing farmland. The low nitrogen availability associated with organic production systems is considered a chief obstacle to organic farming competing with conventional agriculture. The Rodale Institute, in collaboration with USDA Agriculture Research Service, designed a well-replicated and randomized field trial to respond to performance gaps between the two methods (Hepperly et al. 2006). This trial is the longest running comparison of organic and conventional maize and soybean cropping systems in the world and is presently in its 25th season.

Over the years, this experiment has demonstrated the following:

1. **Increased soil carbon and nitrogen levels in the organic vs. conventionally farmed plots.**
2. **Crop yields are similar for organic vs. conventional in years of average precipitation, and greater in organic during drought years due to higher moisture availability,**
3. **Fossil energy inputs for organic crop production were over 30% lower than for conventionally produced maize and soybeans,**
4. **Labor inputs averaged about 15% higher in organic farming systems than in conventional,**
5. **The net economic return per hectare for organic is often equal or higher than conventionally produced crops because organic foods frequently bring higher prices in the marketplace.**

In addition to yield and economic benefits, environmental benefits of organic agriculture include enhanced sequestration of carbon in the soil, in addition to less nutrient leaching into groundwater than in conventional agriculture. Clearly biological management of nitrogen is a key element in maintaining yields and profitability in organic farming.

Today, farmers have many biological tools to improve the health of the land and the people that live there by putting the living soil back to work. A “beans” approach works by incorporating important soil organisms that build ***and*** maintain soil fertility into the management of crops. This change will happen only when we begin to appreciate the fact that healthy, productive soils are dynamic ecosystems composed of a mixture of minerals, air, water, organic materials and a healthy population of beneficial microorganisms. The next step then will be to recognize the inoculation opportunities available to reestablish healthy living soils on farms. Lastly, it will be important to manage and maintain management of the soil environment where beneficial soil organisms can survive.

Mike Amaranthus, Ph.D. is adjunct associate professor at Oregon State University and president, Mycorrhizal Applications Inc. Dr. Amaranthus has authored over 60 scientific papers on mycorrhizal fungi and their uses. He has received the Department of Agricultures highest honors for scientific achievement and been featured on several national television broadcasts.

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Gerald Wiebe B.Sc.Ag, is a farmer in Manitoba, Canada. Gerald has studied the principles of biological crop production, and attempted to incorporate them into workable field scale practices. At present he operates a commercial scale certified organic farm, and consults with western Canadian growers, teaching biological soil and plant management

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