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South Dakota NO-TILL Association

Down Under

Best Western Ramkota Hotel, Aberdeen, South Dakota
January 24-25, 2001

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Moderator: Mr. David Gillen, White Lake, SD

2:15 PM – Dr. Jay Lehr; Environmental Education Enterprises, Ostrander, Ohio.
GLOBAL WARMING: A COOLING ISSUE FOR AMERICAN AGRICULTURE

3:00 PM – Mr. Jim Kinsella; Lexington, IL.
SOIL CARBON MANAGEMENT

3:45 PM – Global Warming and Soil Carbon Management Open Discussion

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WELCOME TO SOUTH DAKOTA NO-TILL ASSOCIATION DOWN UNDER

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On behalf of the board of directors and the sponsors, welcome to No-Till Down Under. We hope that this workshop will be informative and enjoyable.

Farming continues to be a challenge both economically and increasingly environmentally. As we pursue the system of no-till farming we need to continue to explore all aspects of the system. We hope that this exploration of below ground activity will enhance our understanding of no-till and help us do better with our crop production and environmental stewardship.

This is your workshop. Please do not hesitate to ask questions. Talk to people you have not met before. As much or more can be learned from fellow farmers as from the speakers. Visit the exhibits and talk with the exhibitors. They have valuable information in addition to their products. Please give us your thoughts on future workshop topics.

Thank you for your attendance and participation.

A die-hard no-tiller.

Douglas Luebke

MODERATOR

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GLOBAL WARMING: A COOLING ISSUE FOR AMERICAN AGRICULTURE

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The American farmer has played a major role in the most successful grass roots effort in American history: The Cleaning of Our Environment. When the Cuyahoga River caught fire in June of 1968 it let off the spark that lit the environmental revolution which has led the United States, in just thirty years, to possessing the cleanest environment on earth. While the job is not complete and caution toward protecting our environment must always be practiced, it is accurate to say that as we approach the end of a century we know these statements to be true.

1. The environment is cleaner than at any time in the past half century.

2. The environment is safer than at any time in recorded history.

3. Life expectancy has never been greater.

4. Cancer rates are falling not rising.

5. Predictions of global ecological disasters are untrue.

6. Most environmental problems have been or are being solved.

7. Prosperity is good for the environment.

The American farmer has contributed greatly to this progress through learning to handle the wonderful agricultural chemicals that have more than tripled crop production per acre in the past 30 years. In the early years of this chemical use farmers often over applied, misapplied, improperly stored and transported these chemicals to the detriment of our rural ground water.

Today non point source pollution from agricultural chemicals has all but been eliminated. The remaining problems of excess fertilizer running off into our rivers is being attacked with buffer strips of trees and shrubs along our waterways, lakes and reservoirs, and for a while by the benefits of the Freedom To Farm Act. Spills of manure and odor problems from highly concentrated animal feeding operations are being addressed by all levels of government such that the problems should be well in hand within a few years.

Our World is indeed getting cleaner, yet news about the environment is dominated by terrifying predictions of environmental destruction. When asked about the state of the Earth, more of us think about the threat of global warming than the reality of falling levels of air pollution.

Many environmental crises are simply manufactured out of flimsy evidence by individuals and groups who benefit from false alarms. Federal laws enacted to solve problems that do not exist are costing consumers tens of billions of dollars a year, diverting resources from more serious health problems, necessary social programs and job creating private investments.

Sometimes a problem identified by the environmental movement is real and merits attention. But care must be taken not to overreact with unwarranted actions, as we have done in the cases of radon, asbestos and ozone.

Famed astronomer Carl Sagan said shortly before his death that "Science is more than a body of knowledge. It is a way of thinking that looks skeptically. It teaches not blind obedience to those in authority, but vigorous
debate"

Judging by the sometimes sharply conflicting views of experts, there is plenty for environmentalists to debate. Probably the most talked about environmental crisis in America today is global warming, the theory that man-made pollutants are trapping warm air in the Earth's atmosphere and causing a gradual rise in temperatures. TIME magazine editorialized that the possible consequences of global warming were so scary that it is only prudent for governments to slow the buildup of carbon dioxide through preventative measures. In 1997, in Kyoto, Japan the United States helped develop and then signed a treaty that would require us to limit Carbon Dioxide emissions to the extent that by the year 2012 we would emit 45% less carbon than we are presently projected to use by that year.

While some scientists believe global warming is an urgent threat, many more doubt its existence or believe its consequences will cause more benefit than harm to plant and animal life.

A Gallup poll conducted in 1992 of members of the American Geophysical Union and the American Meteorological Society, the two professional societies whose members are most likely to be involved in climate research, found that 18
percent thought some global warming had occurred, 33 percent said insufficient information existed to tell, and 49 percent believed no warming had taken place.

In 1999 17,000 scientists signed a petition claiming that no sufficient evidence for man induced global warming existed. It was sent on to the US Congress to no avail.

While this is not the same as stating that global warming will not occur in the future, the history of global climate change is an important issue in the global warming debate. There are three principle objections to the popular view of global warming.

First records of historical temperatures fail to support the predictions of future global warming. If a build-up of greenhouse gases leads directly to temperature increases, then temperatures over the past ten years should have increase 0.5 degrees centigrade. In fact temperatures measured by modern satellites at the top of our atmosphere where they should have been most severely effected have not risen at all. Data to the contrary, which indicates significant warming, has been gathered on the ground amidst communities with growing populations. This is known as the "urban heat island effect".

Thus the discrepancies between the global temperature record and global warming theory raise serious doubts about the reliability of prediction for future climate change.

A second major problem is that the computer models used to forecast global warming are very crude and unlikely to produce reliable data. Temperatures are affected by changes in the level of solar radiation reaching the Earth, sea-air interactions and stratospheric dust from volcanoes and asteroids. None of these processes is sufficiently well understood to be accurately modeled, weakening the predictive abilities of any computer model.

The major shortcomings of current climate models are sufficient grounds to hold off any decision about whether and how to respond to the threat of global warming. At some point in the future, these models may produce information of sufficient quality to be used as the basis for public policy, but clearly this is not now the case.

Finally almost all of the slight warming in this century has occurred at night and during the winter. Whether global warming would benefit or endanger animal and plant life depends largely on whether the warming takes place during winter or summer months, and during the day or at night. If warming occurs during summer days, it could lead to crop damage, disease, and possibly other negative effects on plants and animals. But if warming occurs at night and during the winter, plants and animals will benefit from the moderating temperatures and longer growing seasons.

The empirical record for the past fifty years is very clear on this point. The small amount of global warming that may have taken place has occurred during winter months and at night.

Despite the recent worst-case scenarios issued by the U.N., the scientific basis for the theory that man is causing global warming has unraveled. The emerging consensus within the scientific community supports the position that climate changes will be far smaller and less disruptive than those originally predicted. We should therefore be very skeptical of efforts to adopt policies that could impose substantial costs on consumers and businesses in the name of ending global warming.

If the United States government were to institute controls on carbon dioxide emissions, they could only do so by placing a 25% to 50% tax on fuel. Farming is a fuel intensive industry, not in farm machinery itself, which only uses 30 percent of the fuel we consume, but rather in the refining of the many chemicals we use.

These percent increases in fuel prices will end up as almost identical percent decreases in profits on all our output, such as corn, wheat, cotton and milk, with slightly lower affects on soy beans and higher impacts on hogs. Furthermore, by increasing the energy costs of farm production in America while leaving them unchanged in many developing countries such as China, India, Mexico, Brazil and Argentina, which are emerging agricultural producers, the Kyoto Climate Control Treaty will cause U.S. food exports to decline and U.S. food imports to increase.

Of greater importance and fascination is the fact that virtually all evidence indicates that all plants prosper in the face of increased exposure to carbon dioxide. It is after all really just a gaseous fertilizer. Dutch greenhouses for example routinely and deliberately triple their CO_2 levels and crops respond with 20 to 40 per cent yield increases.

A composite of 279 research studies, many by the USDA, predict that overall plant growth rates will ultimately double as carbon dioxide increases in the atmosphere. This is partly due to the fact that in the presence of increased CO_2 virtually all plants require less water because transpiration is significantly decreased. This will be an unparalleled benefit for mankind living in desert climates.

The entire global warming controversy was hatched by eco-extremists certain that the worlds population was exploding. They are the same people who insisted the earth was running out of fossil fuel 30 years ago and then predicted global cooling 20 years ago. In short they want control of the world's energy in order to control the world's population. But in fact the world's population growth is already settling down as a result of improved standards of living and improved economies in the third world where births per women have declined from 6.5 in 1960 to 2.9 in 1998. World population is now expected to top out at 8.5 billion by about the year 2040, not the widely predicted eco-extremist projection of 15 billion.

It is time for everyone in rural America to stand up to the environmental distortions that surround us, especially in regard to global warming. Don't let the government destroy your livelihood based on junk science and eco-terrorism. Write your congressman today.

Dr. Jay Lehr, is Senior Scientist with Environmental Education Enterprises, a company that offers advanced technological short courses to environmental professionals commonly involved in environmental remediation projects. He is also Senior Scientist with the Heartland Institute and Managing Editor of their monthly environmental magazine entitled Environment & Climate news, available free of charge.

Dr. Lehr holds a degree in Geological Engineering from Princeton University and a Ph.D. in Ground Water Hydrology from the University of Arizona. He has written a dozen books dealing with environmental subjects. In 1992 his book RATIONAL READINGS ON ENVIRONMENTAL CONCERNS, was published by Van Nostrand Reinhold. This year he completed a book commissioned by the McGraw-Hill Publishing company entitled HANDBOOK OF ENVIRONMENTAL SCIENCE, HEALTH AND TECHNOLOGY for the 21st Century.

Carbon Management
Agriculture's New Role

Jim Kinsella

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Most debates over solutions to global warming have been concentrating on the combustion side of the carbon cycle. This is unfortunate because the biological side of the carbon cycle (photosynthesis and mineralization) may offer the greatest opportunities for practical solutions.

There are approximately 320 million acres of land in the U.S. which is still being tilled to grow field crops. Current and past tillage practices have mineralized much of the stored organic matter (humus) in these soils, releasing billions of tons of CO_2 into the atmosphere. This oxidation of humus, along with the increased combustion of fossil fuel (old buried humus), has surely contributed to the increasing concentration of CO_2 in the atmosphere in this century. Using our humus depleted cropland as a biological sink for some of the excess CO_2 appears to be a practical and cost effective method of reducing atmospheric CO_2 levels.

On our home farm in Central Illinois we have been growing corn and soybeans in a complete no-till system since 1975. In that period our soil organic matter has more than doubled, going from an average of 1.9% in 1974 to 3.9% in 1999. In just 26 years we have taken around 10 tons of carbon from the atmosphere and added it to the top 7 inches of soil on every acre. We have also increased SOC (soil organic carbon) below the 7 inch level due to increasing earthworm activity and increasing root volume and depth.

The adoption of no-till farming has been slow, primarily because there currently is a disincentive to no-till, called mineralization. Tillage temporarily increases the O_2 level in the soil which increases the mineralization rate of organic matter thus enhancing the release of CO_2 into the atmosphere. There is a corresponding oxidation of nutrients contained in the organic matter, the most abundant being nitrogen. These released nutrients, which become available for plant uptake, provide a short term economic advantage for tillage. Since plant nutrients have a known value and C doesn't, SOC is sacrificed to temporarily increase nutrient availability to plants. This is a short term benefit to the producer but a long term detriment to the quality of our soil, water and air.

To offset this nutrient advantage provided by tillage there must be a value placed on carbon and an economic incentive to store it. There is a wide range of estimates of the value of C, but considering its energy value, the value of humus and the liability of excess CO_2 in the atmosphere, it would seem a value of $100/T or 5¢/ lb. of C would be quite reasonable. For once farmers have the opportunity to set the price for something they produce, in this case SOC. I propose that farmers set $100/ton of C as their "minimum wage" for taking CO_2 out of the atmosphere and storing it in their soils.

The most practical method of providing this incentive appears to be a modification of our existing farm support system to pay farmers for the C they sequester and store. These incentives could come as cash payments, tax credits or credits for crop risk or income insurance. This would be similar to other voluntary farm programs such as CRP. The incentive would have to be high enough to encourage participation as well as to offset additional expenses and/or risk.

There is considerable variability between crops and environments on the amount of carbon sequestered and retained. The Agriculture Research Service could use existing information and begin gathering additional data to develop carbon retention models on which payments would be based. Models could also be developed and payments made for humus added to the soil by various cover crops, as well as from applications of manure, sludge, landscape waste and other sources.

The carbon payments should stay with the land and would be redeemable, at least in part, if and when broadcast tillage is resumed. It makes no sense to pay farmers to sequester and store carbon and then allow them, or other farmers, to till the soil sending most of the recently stored carbon back to the atmosphere without retribution.

If a carbon storage incentive was part of the 2002 Farm Bill, we would have 8 years to refine all aspects of the concept and we could lead the rest of the world into compliance with the Kyoto Accord by 2010. Besides improving air quality, a carbon storage incentive would greatly reduce soil erosion, improve soil and water quality, improve productivity and our global competitiveness and make our agriculture sustainable.

For a very minimum cost to taxpayers farmers now have the opportunity to provide the public with something beyond just abundant and cheap food; (1) A reduced risk of effects from global warming, (2) a cleaner environment and, (3) long term food security. WHAT A BARGAIN!

GREAT PLAIN SOILS

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WHAT'S HAPPENING TO SOILS IN CENTRAL SOUTH DAKOTA – AN EXAMINATION OF SOIL QUALITY

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In some ways our soils have not changed very much from the days of the pioneers. Soils in central South Dakota represent a wide variety of differences in soil properties based on differences in the five soil forming factors of climate, vegetation, parent material, topography, and time. Parent material has especially resulted in a sharp contrast between soils east and west of the Missouri River. Soils west of the Missouri River generally formed in Pierre Shale and as a result are high in clay content, difficult to work, and are of lower inherent productivity. In contrast soils east of the Missouri River are formed in glacial till parent materials. These soils tend to be more loamy with fewer shrink and swell clays, are easier to manage, and often have higher inherent productivity than those soils formed in Pierre Shale. The basic textures, mineralogy, and many of the fundamental properties of these soils are very similar to what the pioneers found when they first started to farm these lands one hundred years ago. Soil texture and mineralogy remain stable over many years and are affected very little by our management practices. These soil properties set limits for what we can expect from our soils. No matter how hard we try we will not be able to convert Promise clay into a Highmore silt loam through changes in management practices.

In other ways our soils have changed a great deal since the days when the first pioneers first broke out the native sod. One hundred years of cultivation have resulted in some predictable changes as a result of soil processes that occur when virgin land is converted to cropland . These include oxidation of soil organic carbon, soil erosion, soil compaction, and changes in soil hydrology.

The oxidation of soil organic carbon occurs rather quickly after soil is exposed by plowing. Soil organic carbon is converted into carbon dioxide faster than it is put back into the ground resulting in a sharp drop in soil carbon content. The loss of soil organic carbon translates into soil that is harder to manage, easier to erode, and less likely to retain water for crop growth. The effect of loss in soil organic carbon on soil tilth or manageability is illustrated in a story from a 1949 issue of the Farmer magazine, as retold by John Beatty, in a column published in the January 17, 1997 Brookings Register entitled "Vermont man built historic plow". The story was about the development of the steel moldboard plow.

"It began to appear as if migration westward would have to stop right there on those rich Illinois prairies. Farmers had been coming from New York, Pennsylvania, Maryland and a half dozen other states to the east to build a great farming empire, some of it right here in what is now South Dakota.

They broke that tough, centuries-old sod with wooden plows and got along fairly well. It was different, however, the second time they plowed. Something had happened to the soil. Instead of falling away from the moldboard, it would ball up and stick to it. They would plow a rod or so, stop, get a paddle out of their hip pockets, scrape, and we suppose, swear a little, then prod their oxen into motion and move another rod or so."

The story goes on to describe the development of the modern steel moldboard plow by a blacksmith named John Deere. The loss of soil tilth is a direct result of loss in soil organic carbon. Soil organic carbon increases the water content at which a soil can be tilled or driven on with minimal damage.

Soil erosion in fields is associated with cultivation worldwide. We are very familiar with water and wind erosion in central South Dakota. The results are evident in wind events usually in early spring and then in downpours in late spring and early summer. Another form of soil loss from cultivation that has been less recognized in the past, but is very significant in rolling topography is tillage erosion. This is soil movement that occurs directly through the action of tillage equipment. Tillage acts as a land leveler to smooth the tops of hills and depositing soil at the base of the slope. Gravity ensures that more soil will go downhill than uphill whether we till on the contour or up and down slope. The result of erosion whether by wind, water, or tillage is higher variability of yields within the landscape and lower yields at the top of the hillslopes.

Soil compaction is often a result of high axle loads on wet soils. The desire to enter fields in time to avoid a yield penalty in the spring from late planting or a yield loss in the fall from late harvesting can result in driving onto or tilling a field when it is too wet. As a result of this action and the loss of soil organic carbon, compaction usually increases as soils are used for cropland.

A second form of soil compaction occurs as a result of removal of crop residues. This allows the impact of raindrops to breakdown soil structure at the surface forming a thin compact layer on the soil surface. This crust results in increased water runoff and if severe enough can result in impeded emergence of seedlings. This problem is especially prevalent on soils of silt loam texture that are low in soil organic carbon.

Soil hydrology is frequently changed as a result of conversion from native grass to cropland. The example above of increased runoff means that less water is available to plants and more water leaves the field. This can alter stream flows creating a greater tendency to flood and increased streambank erosion. Less water in the field often means a greater chance of water stress for crops during the growing season.

A second problem with soil hydrology that has occurred is the unintended result of a conservation practice. Fallow was introduced to conserve water, but in some semi-humid to semi-arid regions such as in central South Dakota too much water is conserved. Instead of being transpired thorough the plant the water drains below the root zone until it appears as a seep on the side or base of a hillslope. Unfortunately many of our parent materials are high in salt content. The flow of water through the parent material dissolves salt. The now salty water flows out of the seep and as the water evaporates salt is left behind.

Lands that are cultivated for crops worldwide generally have lower soil organic carbon, more erosion, greater compaction, and changes in soil hydrology compared to virgin land. So it is not surprising to find these changes after one hundred years of cultivation of prairie in central South Dakota. If one is not careful the changes in soil structure caused by the above processes can result in a decrease in yields over time.

No-till is a soil management practice that has the potential to reduce or in some cases virtually eliminate the destructive soil processes described above. However no-till, as is true for all management systems, requires local adaptation by the producer. Not all no-till systems are created equal. The idea is to optimize the system for your unique situation. A poorly implemented no-till system can be as disadvantageous as a poorly implemented tilled system.

> *"There is no one system which fits all, or even most, or even many circumstances. Each specific system is a unique combination of components, and only the farmer can decide which grouping of components best suit her or his requirements." - Anonymous Quote from ACT (Africans for Conservation Tillage Newsletter, 2000)*

With this in mind, we examined a number of locations in central South Dakota to look at how soils have changed from management systems. The purpose was not to compare conventional to no-till, but rather to gather information about where one might work on optimizing no-till systems in terms of soils.

Soil structure and associated soil properties were measured at twelve different sites in central South Dakota. Long term grasslands, conventionally-tilled, and no-till fields were matched at each site for the same soil series. Measurements made at the sites included description of soil structure, structural stability, soil strength, bulk density, and soil organic carbon.

Soil structure of the grassland was granular while that for the till and no-till showed evidence of current and older tillage pans. There was also some evidence of compaction from equipment on the cropland that was not observed on the grasslands. On some of the no-till sites there was evidence of worm action in the old tillage pans. Aggregate stability was higher in no-till than on the till sites, but the grassland had the highest stability values. These results were related to differences in soil organic carbon between the systems. In the top foot of soil the grass had greater amounts of organic carbon than the till or no-till sites. The surface two inches of no-till had greater amounts of organic carbon than the till, but not as high as the grass. The differences in surface soil organic carbon related closely to the differences in aggregate stability of the surface soil.

The improved structural stability of the no-till surface is important for water infiltration. However evidence from other studies and observations in the field showed that increased aggregate stability is not enough to insure good water infiltration. Aggregate stability must be combined with residue cover as protection against raindrop fall even in no-till systems. No-till systems without adequate residue cover are likely to have the same degree of runoff as tilled systems especially in silt loam textured soils.

Soil bulk density tended to follow the tillage pans. In both no-till and till there was evidence of an increase in bulk density at the depth at which tillage pans were observed in the soil structural descriptions. Grass systems had significantly lower bulk densities than the no-till or till systems. However, when soil strength was measured, the grass systems had the highest values compared to the till and no-till even though all systems had similar water contents at the time of measurement. This may be the result of roots holding structural units together in the grass system.

What do the results mean? The structure observed in the cropland suggests that we need to be concerned about high axle loads on wet fields in both till and no-till systems.

No-till reduces the decomposition rate of soil organic carbon and increases organic carbon near the soil surface. However, for no-till to continue to raise soil organic carbon levels in the soil, crops that produce high amounts of residue and large root systems need to be grown.

Root systems can play a critical role in holding soil aggregates together and lessening compaction. Residue is also required in no-till to prevent aggregate breakdown and crust formation even if aggregate stability is relatively high.

Additional work needs to be conducted with cover crops in no-till systems. Cover crops have the potential to provide cover in no-till systems that for some reason have reduced residue (an example might be where corn is removed as silage). Cover crops may also have the potential to increase bearing strength, and soil organic carbon levels. The potential benefits of cover crops need to be weighed against the possible disadvantages of increased seeding expense and potential competition with crops for water and nutrients.

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UNCOVERING THE REAL DIRT ON NO-TILL

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"A soil is not a pile of dirt. It is a transformer, a body that organises raw materials into tissues. These are the tissues that become the mother to all organic life".

~ William Bryant Logan, 1995.

When we are standing on the ground, we are really standing on the roof top of another world. Living in the soil are plant roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes, worms, ants, maggots and other insects and insect larvae (grubs), and larger animals. Indeed, the volume of living organisms below ground is often far greater than that above ground. Together with climate, these organisms are responsible for the decay of organic matter and cycling of both macro- and micro-nutrients back into forms that plants can use. Microorganisms like fungi and bacteria use the carbon, nitrogen, and other nutrients in organic matter. Microscopic soil animals like protozoa, amoebae, nematodes, and mites feed on the organic matter, fungi, bacteria, and each other. Together, these activities stabilise soil aggregates building a better soil habitat and improving soil structure, tilth and productivity. Agricultural practices such as crop rotations and tillage affect the numbers, diversity, and functioning of the micro- and larger-organisms in the soil community, which in turn affects the establishment, growth, and nutrient content of the crops we grow. We have all heard our mothers and fathers say "you are what you eat". Farming practices that include diversified crop rotations, increased use of legumes, cover crops, green manures, composts, and intercropping build soil organic matter content, and increase the biodiversity of soil organisms.

In this paper, we will introduce you to the activities of soil organisms (both micro and macro in size) in terms of how they affect the cycling and availability of nutrients to crops, disease cycles, weed management, and soil tilth and erosion potential. More detailed examples with VAM fungi and earthworms will demonstrate the important role of soil biology in improving soil quality and productivity. We will finish by discussing how these activities are influenced by soil management practices, and point to ways that we can better manage and use soil biological activity to our advantage.

BACKGROUND CONCEPTS

Soils are formed from a stew of geological ingredients or parent materials (rocks and minerals), water, and billions of organisms. The interactions between climate, parent material, organisms, landscape, and time affect all major ecosystem processes which leads to the development of soil properties that are unique to that soil type and climate. The activities of and chemicals produced by, soil micoorganisms, and the chemicals leached from plant residues and roots can further influence the weathering of parent materials changing the mineral nutrient content and structure of soil. Thus, farm management practices such as crop rotations, tillage, fallow, irrigation, and nutrient inputs can all affect the population and diversity of soil organisms, and in turn, soil quality.

There are three soil properties that define soil quality: chemical, physical and biological. The chemical properties of a soil are usually related to soil fertility such as available nitrogen (N) phosphorus (P) potassium (K), micronutrient uptake of Cu, Zn, Mn, and etc, as well as organic matter content (SOM) and pH. Soil structural characteristics such as aggregate formation and stability, tilth, and texture are physical properties. The biological properties of a soil unite the soil physical and chemical properties. For instance, fungi and bacteria recycle all the carbon, nitrogen, phosphorus, sulphur and other nutrients in SOM, including animal residues, into the mineral forms that can be used by plants. By breaking down the complex carbon compounds that make up SOM into simpler compounds, soil organisms acquire their energy.

At the same time, the root exudates, hyphae of the fungi and the secretions and waste products of the bacteria are binding small soil particles and organic matter together to improve soil structure. This makes a better soil habitat that attracts more soil animals, which further increases the amount of nutrient cycling. Faecal pellets from soil invertebrates and castings from earthworms increase the number of larger sized soil aggregates, allowing for more water infiltration, aeration and better rooting. The activities of soil animals mix smaller organic matter particles deeper into the soil acting to increase the water holding capacity of the soil. Thus, biological activities hold the key to maintaining or increasing soil productivity.

Soil productivity is mostly measured in terms of yield (Brady, 1974), and is a function of soil structure, fertility, and the population, species composition, and activities of soil organisms. We further suggest that health, nutrient content and value of the crops, and environmental quality both on and off the farm should also be considered as a measure of soil productivity. Studies have shown that soil bacteria and fungi regulate the destruction of toxic environmental pollutants like nitrous oxides and methane (greenhouse gases), and some pesticides. The speed at which residues decay and nutrients are released from SOM, and pollutants and pesticides are detoxified, will in turn be largely dependent on how we manage the soil.

Farm management practices, and the effect they have on soil organisms will also influence the processes that determine the health of our environment on a broader scale. Soil erosion or leaching of soluble nutrients contributes towards the contamination of rivers with nutrients (eutrophication). For instance, the nitrogen from incorporated residues is released and readily leached by rain and melt water making its way into surface and ground water. Incorporating nitrogen rich green manures into the soil using tillage in the summer or fall and then leaving these residues until the following spring may therefore affect eutrophication. Residues left on the surface, initially release more atmospheric emissions than incorporated residues but are less subject to leaching, releasing nutrients more gradually. Soils are also less likely to erode when residues are retained. Drinkwater et al. (1998) suggested that using low carbon to nitrogen residues like those used in organic legume-based cropping systems to maintain soil fertility, when combined with more diverse cropping rotations can increase the amount of carbon and nitrogen that is retained in the soil. This could have positive effects on regional and global carbon and nitrogen budgets, sustained productivity, and environmental quality.

THE RHIZOSPHERE

In undisturbed soil, most of the nutrient cycling, roots, and biological activity are found in the top 20 to 30 cm, called the rooting zone. Within the rooting zone is the rhizosphere: the root, soil attached to the root, and the adjacent soil which is influenced by the root. The rhizosphere is characterised as a zone of intense microbial activity, and represents a close relationship between the plant, soil and soil organisms. Any outside factor affecting one member of the triad will have consequences for the other two members.

The rhizosphere is bathed in energy-rich carbon compounds, the products of plant photosynthesis, which have leaked from the roots. These include sugars, amino acids and organic acids and are called root exudates. Every plant species leaks a unique signature of compounds from their roots. The quantity and quality of these compounds depends to a certain extent on the soil chemical and physical properties, but in all cases determines the microbial community of the rhizosphere. Symbionts like the bacteria *Rhizobium* that fix nitrogen in legumes, and disease-causing pathogens, may be particularly well tuned to the composition and quantity of root exudates and be attracted to a particular plant. This means that it is also important to carefully match legume crop species with the appropriate commercial microbial inoculants**.**

More generally, bacteria and fungi use root exudates and the dead sloughed cells from the root to grow and reproduce, but competition for a space on or near the root is stiff. In the battle for carbon compounds, bacteria often produce antibiotics and poisonous chemicals and gases that remove the competition (which on occasion can also reduce plant growth), and/or plant growth promoting substances that increase root growth, the amount of root area available for colonisation, and root exudates. The sticky secretions from the bacteria in combination with exudates and dead and decaying root cells create tiny soil aggregates and a habitat for scavenging and predator protozoa, nematodes and mites that feed on the large numbers of bacteria and fungi. In turn, the faecal pellets from these microscopic animals add to the structure of soil and are a rich source of nutrients for bacteria and fungi, and plants. For instance, in greenhouse studies, plants grown in soil with added bacterial- and fungal- feeding nematodes had more shoot growth and a higher yield than plants grown in soil without the nematodes. Mega fauna like earthworms feed in the nutrient rich matrix around the rhizosphere consuming large quantities of dead plant material, fungi, protozoa and bacteria. The castings left by earthworms are rich in available nitrogen for plants and bind and stabilise smaller soil particles into larger aggregates improving soil fertility and structure. Plant roots can move easily through earthworm channels allowing the plant to take advantage of the available nitrogen that lines earthworm burrows. The sticky secretions and webs of fungal hyphae bind smaller soil particles, like those formed by bacteria, into larger aggregates further improving soil structure.

In review, the rhizosphere is a partnership between the plant, soil and soil organisms. Plants provide the carbon food source for soil organisms that bind the soil particles into aggregates and recycle soil nutrients, and soil provides the habitat, water, and mineral nutrients for both soil organisms and plants. Any factor or soil management technique that changes the amount and quality of carbon going into the soil, as either residue or root exudates, will effect change in the soil biological community. Change which ultimately has consequences for plant growth.

THE RHIZOSPHERE AND VESICULAR-ARBUSCULAR MYCORRHIZAL (VAM) FUNGI

VAM fungi probably form the most intimate relationship between the plant, soil and soil organisms, best illustrating the potential for using rhizosphere processes to improve soil quality and productivity. VAM fungi form a mutually beneficial or symbiotic relationship with 80 percent of all land plants, including warm- and cool-season cereals, pulses, forages, and some oilseeds. They appear to be essential to the establishment, growth and survival of many plant species. For instance, VAM fungi are critical in the early establishment and growth most cereals and particularly warm season grasses like maize, sweet corn, and sorghum. They are also important for early establishment and growth of some non-cereal crops like sunflower, flax, and potatoes.

VAM fungi penetrate the cells of the root without harming the plant. From the root, the microscopic hyphae extend like a network of silk threads through the bulk soil. VAM fungi can be considered a highly effective transport system, like a pipeline, between the soil and the plant, moving water and nutrients to the plant in exchange for direct access to the carbon-rich products of photosynthesis. VAM fungi are most well known for their ability to increase the uptake and plant content of less available mineral nutrients such as phosphorus (P), calcium (Ca), zinc (Zn), and copper (Cu). For instance, increasing colonisation by VAM fungi can in turn increase the mineral nutrient content of wheat (Clapperton et al., 1997a). The degree to which a particular plant relies on VAM for access to nutrients is termed its level of dependency. Highly dependent crops often have limited root systems, with thick roots and few root hairs. Less dependent plants will have larger fibrous root systems that are well adapted to competing for nutrients.

Even less dependent plant species may rely on VAM fungi when under environmental stresses such as drought. VAM fungi are also known to increase resistance of the plant host to root diseases. VAM hyphae will tie and glomulin secreted by the hyphae glue soil particles into more erosion-resistant aggregates.

TABLE 1. **THE RELATIONSHIP BETWEEN SOME CROP SPECIES AND VAM FUNGI**

High dependency	Low dependency	Non-hosts
Peas, Beans, and other legumes Flax Sunflowers Maize	Wheat and other cereals	Canola, Mustard and other brassicas Lupins

Once plant roots are colonised by VAM fungi, their physiology and biochemistry change. They have higher rates of photosynthesis, better water use efficiency, and move more and different kinds of carbon compounds to the roots. Consequently, there is a different rhizosphere community associated with the roots of VAM-colonised plants; a rhizosphere with fewer pathogens, more nitrifiers, and other changes that we still don't know about (nitrifying bacteria convert ammonia to nitrate, which is easier for the plant to absorb).

The degree of colonisation by VAM fungi and the benefits of having plants colonised by VAM fungi can be reduced by tillage and incompatible crops in rotation including non-mycorrhizal host plants, such as canola (Table 2). Although, populations of soil fauna like earthworms and nematodes tend to increase under canola. The addition of fertilisers containing easily soluble phosphorus, including non-composted manure, will greatly reduce VAM colonisation. Generally, organic farms do not use such fertilisers and therefore tend to have higher levels of VAM colonisation than conventional farms (Table 3).

Table 2. The percentage of root length colonised by VAM fungi at tillering for wheat grown after three different previous crops in SE Australia.

Previous crop	Wheat	Peas	Mustard
VAM %	58	58	30

From: M. Ryan (unpublished data)

Table 3. Percentage of wheat root length colonised by VAM fungi at tillering on neighbouring farms in SE Australia.

	Farm pair 1		Farm pair 2	
	Organic	Conventional	Organic	Conventional
VAM (%)	42	12	58	10

From: M. Ryan (1998)

On the other hand, populations of VAM fungi can be rebuilt by reducing tillage, using only the required amount of composted manure or using poorly soluble phosphorus fertilisers such as rock phosphate, and including pasture and perennial crop phases, legumes, warm season cereals like maize and sorghum, flax, and sunflower in the rotation. Thus, VAM fungi illustrate how choosing the sequence of crops in a rotation can be critical for the establishment and growth of subsequent crops. Research has shown that some species of VAM fungi can promote growth in one crop and inhibit it in another in two and three phase rotations. This is another demonstration of how important soil biodiversity is to creating flexible cropping systems. The interaction between crop rotation, VAM fungi, soil animals, and plant establishment and growth needs more research so we can take better advantage of the benefits that VAM fungi confer on some crops.

EARTHWORMS ARE SOIL MEGA FAUNA

The presence of earthworms in the soil is often considered to be a positive indicator of soil quality and productivity. Earthworm numbers increase dramatically with no tillage and in undisturbed systems. The burrowing activities of earthworms increase soil aeration, water infiltration, nitrogen availability to plants, and the microbial activity in the soil. The lining of the earthworm burrow (also known as the drilosphere) has been found to have higher populations of nitrifying bacteria than the soil outside the burrow. The increased nitrogen available in the drilosphere may be another reason why roots often grow in earthworm channels. Earthworm burrows can be stable for years, acting to increase the extent and density of plant roots as well as stabilising soil aggregates to improve soil structure and limit erosion. It has been suggested by a number of researchers that earthworms are major contributors to the breakdown of organic matter and N cycling in reduced tillage systems. Earthworms prefer plant material that has been colonised by fungi and bacteria, which can lead to the reduced incidence of fungal diseases in crops. Indeed, earthworms are probably most important in reduced tillage systems, not only because these systems encourage earthworm populations but, because without mechanical mixing and loosening, earthworm casts and burrows are left intact to encourage better root development. In long-term dryland tillage experiments at the Lethbridge Research Centre, we have found as many as 300 earthworms per square meter under no tillage compared with none under conventional tillage (Clapperton et al., 1997b). In this same field experiment there was a significantly lower incidence of common root rot under no tillage compared with conventional tillage, demonstrating the long-term benefit of maintaining the soil habitat. In Australia, the same earthworm species that are common in Canada were found to increase perennial pasture productivity by 30 percent over pastures without earthworms (Baker et al., 1999).

Earthworm populations can be increased by reduced tillage in combination with crop rotation. Introducing earthworms into soil is not recommended because scientists in Canada presently understand very little about the ecology of the more than 25 species of earthworms that have been identified. The earthworms (*Eisenia foetida* or red wigglers) used for vermicomposting are not native to Canada nor are they earth-working earthworms and therefore are not appropriate for field agriculture. The dew worm or night crawler (*Lumbricus terrestris*) used for bait is not appropriate for introduction into Prairie soils because it deposits casts containing high amounts of clay on the soil surface that when unmulched can create a clay hard-pan and problems with surface water erosion. The fastest way to increase earthworm populations is by reducing soil disturbance. This can be achieved by direct-seeding crops for as many years in a row as possible, and/or including perennial crops and/or pasture into the rotation. You can further increase earthworm populations by adding oilseeds to and retaining legumes in the rotation under no tillage. There are more and bigger earthworms under no tillage after oilseed (particularly flax and canola), and legume crops compared with cereals (Clapperton and Lee, 1998).

CREATING AND MANAGING THE SOIL AS A HABITAT

Soil management is defined by Nyle Brady (1984) as the sum of all tillage operations, cropping practices, fertilizer, soil amendments, and other treatments applied to the soil for the production of plants. Once again, the emphasis is on the interconnectedness between all farming practices and the soil.

TILLAGE

Management practices that affect the placement and incorporation of residues like tillage can make it harder or easier for the soil organisms responsible for cycling nutrients. Tillage directly affects soil porosity and the placement of residues. Porosity determines the amount of air and water the soil can hold. Placement of residues affects the soil surface temperature, rate of evaporation and water content, and nutrient loading and rate of decay. In other words, tillage collapses the pores and tunnels that were constructed by soil animals, and changes the water holding, gas, and nutrient exchange capacities of the soil. Reduced tillage and particularly no tillage reduce soil disturbance, increase organic matter content, improve soil structure, buffer soil temperatures, and allow soil to catch and hold more melt and rain water. No tillage soils are more biologically active and biologically diverse, have higher nutrient loading capacities, release nutrients gradually and continuously, and have better soil structure than reduced or cultvated soils.

No tillage dramatically increase the population and diversity of soil animals, particularly soil mites, that feed on fungi. Under no tillage, litter or residue is primarily decomposed by fungi that accumulate nitrogen in their hyphae, in response the population of fungal feeding mites increases rapidly, using some of the nitrogen from the fungi and releasing the remainder into the soil to be used by plants and other organisms. No tillage systems and rotations with perennial crops or pasture show greater resilience (they can recover faster after disturbances such as drought, flood or tillage) in terms of soil animals because populations and species diversity of animals are higher, there is more SOM, and nitrogen is recycled into the system at a greater rate compared with conventionally tilled systems.

SOIL AMENDMENTS AND CROP RESIDUES

Higher organic matter content of soils from using no tillage and rotations, and/or the direct applications of manure or composts may reduce disease. Many of the soil organisms that are rapid colonisers of organic matter are antagonistic to disease-causing organisms. For instance, in agricultural trial plots, Sivapalan et al. (1993) found a number of soil-borne fungi that cause root diseases, including Rhizoctonia solani, only on conventional vegetable plots. Fungi that are antagonistic to such disease-causing fungi, such as Trichoderma and Penicillium, were found more frequently in the organic pots, where 80-120 tonnes per hectare of compost had been applied.

Residues from some crops inhibit the growth of other plants either directly, or indirectly, from the by-products produced from the microbial decay of the residues (allelopathy). Fall rye, mustard, oats, George Black medic, hairy vetch, sunflower, oil seed hemp, and sweet clover have all been reported to inhibit the growth of weeds. Residues from oats can also inhibit the germination of some disease causing fungal spores like Sclerotina (Dr. Henry Huang and Dr. Jim Moyer, AAFC Lethbridge Research Centre, Lethbridge AB, personal communication). All these crops will also increase populations of VAM fungi.

ROTATIONS

The benefits of diversified crop rotations married together with reduced tillage and especially no tillage can dramatically increase soil productivity while reducing off-farm costs. Low residue crops like peas, lentils, mustard, tomatoes, dry beans or canola can be rotated with higher residue cereals to reduce the trash loading. Rotating cereals and oilseeds with peas, forages, or underseeding cereals with annual or biennial legumes, which fix nitrogen, increases the amount of nitrogen available to plants in the cropping systems. This nitrogen is taken directly from the atmosphere by the bacteria that are associated with the legumes, a process which obviously does not require the large amounts of fossil fuels used in the manufacture of commercial nitrogenous fertilisers. The residual benefits of nitrogen from these crops can be persistent for a number of years depending on the legume. Note that legumes are dependent on two symbionts, a nitrogen-fixing bacterium like *Rhizobium* as well as VAM fungi to supply the increased phosphorus required to more efficiently fix nitrogen. They also establish and grow well in biologically active soils while acting to build more biologically active soils. Cover cropped soil has been shown to have the largest and most diverse populations of microorganisms, compared with manure amended plots that had had a less diverse but more metabolically active population of microorganisms (Wander et al., 1995).

Soils after pasture phases and perennial crops are more structured and biologically active, have higher organic matter content, and turnover nitrogen more rapidly. Including a deep-rooted legume like alfalfa or lucerne can help increase the rate of nitrogen cycling and reduce plow layer compaction. Mixed- and inter-cropping systems increase aboveground diversity which in turn increases diversity in the below ground community. Scientists and farmers alike speculate that a more diverse soil community results in a more flexible soil. This means a soil that has the ability to successfully grow a number of crops, and which is resilient in drought, low nutrient conditions, and after disturbance.

In Conclusion ....

Creating a soil habitat is the first step to managing soil biological properties for long-term soil quality and productivity. This means using soil management practices that reduce soil disturbance, managing weeds and disease with crop rotation, mixed cropping, and underseeding, and using high quality compost and composted manure. For instance, unstructured soils with low organic matter content that have fine aggregates or clay within the plow layer will take between 3-5 years to build the soil biological properties necessary to improve soil structure and stability depending on climate and previous soil management. It is better to start the transition to a conservation tillage system after a perennial crop or pasture phase of 2-5 years. As an added bonus, conservation tillage and having pasture and perennial crops phases in the rotation uses less fossil fuel, and with less time on the tractor, producers have more time to consider farm management details that will improve the biological activity of soil. It is generally understood that the soil biological community benefits soil productivity, yet we know so little about the organisms that live in the soil and the functioning of the soil ecosystem. Continued research aimed at understanding the interactions between soil management practices and the soil biological, chemical and physical properties of soil will be the key to sustaining the soil, environment and our future generations.

We wrote this paper to increase awareness among producers that soils are living, breathing, and ever changing, and that the potential exists to manage and use soil properties more effectively for producing nutritious food at less environmental cost. We invite you to use the fundamental and basic information we have provided to further experiment with crop rotations, green manures, inter- and mixed- cropping, conservation tillage, and integrated livestock grazing and develop your own unique soil ecosystem.

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SALINITY DOWN UNDER

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Salts are everywhere. They're in our bodies. They're in the food we eat. They're in the soils in which we grow our food and fiber. They're in our water unless we specifically (and at great expense) treat the water to remove them.

The native concentrations of salts usually don't cause problems; indeed, some salts are required for normal biological operations. But if salts get concentrated in an area- be it our bodies or a field or an area within a field- the salts can cause problems. In this paper, we will discuss soil salinity in general terms. Individual salinity causes and effects require individual solutions but those solutions will be based on the science presented here.

Fortunately, there are management methods that can be used to reduce or eliminate the adverse effects of salinity, if salinity becomes a problem in your field. In this paper, we first will discuss how those saline soils develop. Then we will present some management methods to reduce or eliminate the detrimental effects of salinity in those areas. A very brief overview of relative responses of some crops to salinity will follow. Finally, we will briefly discuss some salinity measurement techniques. In this paper, we will address saline soils developed under two conditions- saline seeps and irrigation-induced saline soils.

DEVELOPMENT OF SALINE SOILS

Salts are moved with water. When water moves from one area of a field to another, some salts are carried with the water. If the water moves through an area of soil where the native salt concentration is high, the water will dissolve some of those salts and the salt concentration of the moving water will increase. Significant amounts of salt can also be added with irrigation water.

Whether the salts are added in the water or are present in the soils naturally, it is water moving through the soil that can move the salts. This water movement and resulting salt movement can be beneficial or detrimental. For example, water in excess of crop needs can move (leach) salts downward and out of reach of the crop roots, preventing the salts from interfering with crop root function. Conversely, water movement can cause salts to accumulate in areas where they reach high concentrations and become detrimental to a crop.

Even the process of plant roots absorbing water can make salinity problems worse. When the roots absorb water, they absorb only the water and leave behind any salts. Over time, the salts that get left behind in the root zone can accumulate to levels that interfere with crop root functions with detrimental effects on the crop.

Saline seeps are a result of the combination of geological, climatic, and management factors. Development of a seep starts at the recharge area. This is an area high in the landscape where all available water is not used by crops. Excess water drains internally downward, out of the root zone. As it moves through the soil, the water dissolves and accumulates salts. At some point in the subsoil, the water reaches a layer of very low permeability. The salt-laden water accumulates above the slowly permeable layer and forms a perched water table. Over time, the water from the perched water table will move laterally, downward in the landscape. Where the slowly permeable layer intersects the soil surface, the salt-laden water will also reach the soil surface. The water will evaporate, leaving the salts behind to accumulate and form a saline seep (Halvorson, and Black, 1974).

Instead of a slowly permeable layer, the downward-moving water might reach a more permeable horizontal layer such as lignite. The salt-laden water will then move laterally in the highly permeable layer until it reaches the soil surface (Doering and Sandoval, 1976). The water then evaporates, leaving behind the salts to accumulate.

The layer of high or low permeability doesn’t have to reach the soil surface for a saline seep to form. If the layer is near the soil surface, the salt-laden water can move to the soil surface via capillary action. Again, the water will evaporate and leave behind the salts, forming a saline seep.

In the case of irrigation-induced saline soils, the very act of irrigation is the cause for the salinity. Every irrigation event adds some salt to the soil because all irrigation waters contain some amount of salt. Some amount of leaching is required eventually to move those salts downward, out of the crop root zone. For high-quality irrigation water (with low salt concentration), small amounts of salt are added with each irrigation. For irrigation water with high salt concentration, more salt is added with each irrigation. When crop roots absorb water, they absorb only the water, leaving the salts behind in the soil. Without any water (either irrigation water or precipitation) in excess of crop needs to leach the salts downward and out of the root zone, the salts are left to accumulate in the root zone. The accumulation takes place more rapidly when the irrigation water has a high concentration of salt.

MANAGING SALINITY

Salinity management is water management.

In the case of the saline seep, the long-term solution includes controlling the water at the recharge area. Intensive, flexible cropping systems are required to reduce or eliminate the internal drainage that eventually moves and carries salts to the seep area (Black et al., 1981). More intensive cropping may require fewer or no years of fallow or growing crops that use more water in a growing season, such as alfalfa (Brun and Worcester, 1974; Halvorson and Reule, 1980). If it is not possible to reduce or eliminate recharge, then the saline water can be intercepted with an artificial drain. Proper disposal of the saline drainage water will be required.

After the recharge area is controlled or intercepted, precipitation will be required to move the salts downward at the seep area. Greater rainfall means the salts will be moved farther and more quickly.

Under irrigation, the salts are continuously being added to the soil in the irrigation water. Management of saline irrigation water must include some excess water for salt leaching. Rainfall in excess of crop water needs may provide adequate leaching, especially in the spring when crop water needs are small. In this way, the need to apply excess irrigation water for leaching might be avoided. If leaching is required during the growing season, less frequent irrigations of greater amounts will effect leaching. For example, if irrigations of 0.75 inch were formerly applied every 3 days, better salt management might be to apply 1 inch every four days or 1.25 inches every 5 days. The actual amount of leaching will depend on the salinity of the irrigation water.

If a saline water table is affecting the crop, water table management measures will be required. Such measures may include a grid artificial drainage to lower the water table or an interceptor drain if the saline water is moving laterally.

CROP RESPONSE TO SALINITY

Different crops respond differently to salinity. For example, barley, durum, triticale, and sugarbeet are listed as salinity-tolerant crops, while wheat is listed as tolerant to moderately tolerant to salinity. Rye, safflower, and oats are listed as moderately tolerant. Crops listed as moderately sensitive include corn, flax, millet, sunflower, and alfalfa. Among grasses, tolerance varies among cultivars. Wheatgrasses and wildryes are listed as tolerant to moderately tolerant. Smooth brome and blue grama are moderately sensitive to salinity. Finally, crops are generally more susceptible to salinity-induced damage in early growth stages, such as the emergence and seedling stages.

Most crop salt tolerance information was developed in California. The chemistry of salinity is different in the Northern Great Plains (sulfate-dominated salinity) so thresholds are greater and yield losses are somewhat smaller in the Northern Great Plains compared to those of California (chloride-dominated salinity), but the relative responses of different crops will be accurate.

For more specific information on crop salinity tolerance, see publications such as Maas (1986) or Tanji (1990).

Measuring salinity

The traditional method of measuring soil salinity has been to collect a soil sample, dry and grind the sample, then add water to form a paste. To measure the total salt concentration in the sample, the electrical conductivity of the paste can be measured. To determine the actual ions (salts) and their concentrations in the sample, the solution is vacuum-extracted from the paste then the concentrations of ions of interest are measured in the extracted solution. Electrical conductivity and specific ion concentrations can also be measured in irrigation water to determine the hazards of irrigating with a particular water on a particular soil. University service laboratories or commercial laboratories can perform these tests, usually for a small fee.

Instruments are now available to measure the salinity of large areas without taking soil samples. These instruments include the Geonics EM38 (http://www.geonics.com/) and Veris 3100 or 2000 XA (http://www.veristech.com/). They are particularly useful in precision farming operations where large amounts of georeferenced data are handled routinely. These instruments can be used to measure the electrical conductivity, especially relative values, over large areas in relatively little time. Some lab analyses of soil samples may still be required to establish absolute electrical conductivities.

Concluding remarks

Salinity management is water management. Because salts are either added in the water or moved with water, it is the water that must be managed to control salinity. For saline seeps, water must be used before it can leave the recharge area or intercepted before it can be discharged in a seep area. For irrigated areas, leaching and other irrigation management are required to reduce or eliminate salinity effects.

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WHAT IS IN FERTILIZER OTHER THAN NUTRIENTS?

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Commercial fertilizer is a source of plant nutrients that can be applied to soil to nourish crops when the soil cannot supply to total crop requirement. Soil testing is the predominant tool to measure plant nutrient levels. When a nutrient in the soil is low a certain amount of that nutrient is recommended to be applied to supply the total needs of the crop and yield. Fertilizer is the normal method of supplying the nutrient although animal manures and sludge may be used.

The plant nutrients are inorganic elements. Their plant available forms are:

Nitrogen (N)	NH_4^+ and NO_3^-
Phosphorus (P)	$H_2PO_4^-$ and HPO_4^{2-}
Potassium (K)	K^+
Calcium (Ca)	Ca^{2+}
Magnesium (Mg)	Mg^{2+}
Sulfur (S)	SO_4^{2-}
Zinc (Zn)	Zn^{2+} and organic complex Zn
Iron (Fe)	Fe^{2+},Fe^{3+} and organic complex Fe
Manganese (Mn)	Mn^{2+} and organic complex Mn
Copper (Cu)	Cu^{2+} and organic complex Cu
Boron (B)	H_3BO_3
Chlorine (Cl)	Cl^-
Molybdenum (Mo)	MoO_4^{2-}

Plants use these ions, sunlight, carbon dioxide, and water to grow. The point of this discussion will show that inorganic fertilizers supply nutrients in the forms used by the plant.

Nitrogen fertilizer manufacturing starts with the production of anhydrous ammonia. Anhydrous ammonia (NH_3) is made by combining nitrogen gas obtained from the atmosphere with hydrogen gas obtained from natural gas. It takes 32,000 to 38,000 cubic feet of natural gas to make 1 ton of ammonia. Over 80% of the total cost of manufacturing NH_3 is natural gas. The gases are reacted at a temperature of 930°F and 3000 to 4500 psi. The reaction is:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Phosphorus fertilizers are made from phosphoric acid. Phosphoric acid is made by treating rock phosphate with sulfuric acid. Phosphoric acid and gypsum are produced. There are a few impurities in the acid so the color is green or black. The color does not affect handling of the acid.

Almost all potassium fertilizers are obtained from potassium chloride (KCl) ore. It is mined, ground, and suspended in water, treated with a flotation agent that adheres to the KCl crystals. Potash fertilizer is colored pink to red because of iron that is not removed during processing.

I have presented the basics of fertilizer manufacturing to show the start of making fertilizer. The main nitrogen fertilizer is anhydrous ammonia. The main phosphorus fertilizer is phosphoric acid. Anhydrous ammonia is a base (alkaline) and phosphoric acid is an acid (acid). When an acid and a base are combined a salt is formed. So most fertilizer products are salts because of this combination. The only prominent exception is anhydrous ammonia.

The N, P, and K concentration are expressed as %N, %P_2O_5, and %K_2O, always in this order. This is called a fertilizer grade. Fertilizer 10-20-10 has 10% N, 20% P_2O_5, and 10% K_2O.

Anhydrous ammonia (NH_3) is 82% nitrogen and 18% hydrogen. The grade is 82-0-0.

Urea fertilizer is produced by combining anhydrous ammonia and carbon dioxide the chemical formula for urea is $CO(NH_2)_2$. Its composition is:

Carbon (C)	20%	Hydrogen (H)	6.6%
Oxygen (O)	26.7%	Nitrogen (N)	46.7%

A hardener is added to make the granules longer lasting during handling and shipping. Therefore, urea is usually 46-0-0.

Ammonium nitrate is made by mixing anhydrous ammonia and nitric acid. The compound formed is NH_4NO_3. Its composition is:

Nitrogen	35%
Oxygen	60%
Hydrogen	5%

The NH_4NO_3 granule is coated with a clay which retards moisture absorption and caking. This makes the fertilizer 34-0-0.

These are two examples of what is in fertilizer besides plant nutrients. The compound is formed when you mix an acid and a base. Note that there is no chloride or “salt” as noted by some. However, the compounds formed are salts.

UAN solution is made by combining near equal portions of ammonium nitrate and urea. The solution is 28-0-0 or 32-0-0. The 32-0-0 will "salt out" near freezing where 28-0-0 can be stored over winter. The properties are:

	28-0-0	32-0-0
% Ammonium Nitrate	38.8	44.3
% Urea	31.0	35.4
% Water	30.2	20.3

Phosphorus fertilizers are usually ammonium phosphates but some are calcium phosphate. The ammonium phosphates are produced by reacting phosphoric acid (acid) and anhydrous ammonia (base) to produce monoammonium phosphate (MAP), diammonium phosphate (DAP) and ammonium polyphosphate (liquid). The MAP compound is $NH_4H_2PO_4$. The composition of the pure compound is:

Nitrogen (N)	12%
Hydrogen (H)	5%
Oxygen (O)	56%
Phosphorus (P)	27%

Note that the phosphorus concentration is 27% P. However, in fertilizer P is expressed as P_2O_5 so P must be multiplied by 2.29 to convert it to P_2O_5. The P_2O_5 concentration in the pure compound would be 62%. The common grade for MAP is 11-52-0. There are some impurities in the phosphoric acid, which lowers the P_2O_5 to 52%. But the main ingredients of MAP are N, O, P, and H. There is no filler added to lower the grade.

The DAP compound is $(NH_4)_2$ HPO_4. The composition of the pure compound is:

Nitrogen (N)	21%
Hydrogen (H)	7%
Oxygen (O)	49%
Phosphorus (P)	23%

The P_2O_5 concentration is 53% with the impurities in the phosphoric acid the most common grade in 18-46-0. However, the main ingredients are N, H, O, and P.

I have shown the formulas for MAP and DAP. Note that the P ion is H_2PO_4 and HPO_4 respectively. These are the forms used by plants. The element P is not taken up by the plant but the ion that has H and O with the P. When P is combined with 4 O they are called orthophosphate ions.

Ammonium polyphosphates (APP) is made by reacting anhydrous ammonia, polyphosphoric acid and water. The polyphosphoric acid is made from wet-process phosphoric acid by heating to drive off water.

$$2H_3PO_4 + \text{Heat} \rightarrow H_4P_2O_7 + H_2O$$

The most common APP fertilizer is 10-34-0. Liquid 10-34-0 contains 65 to 70% polyphosphate and 30 to 35% orthophosphate. When polyphosphate is applied to the soil, moisture will add water back (hydrolyze) to the polyphosphate to form orthophosphate.

The other common phosphorus fertilizer is triple superphosphate (TSP), 0-45-0. The formula is $Ca(H_2PO_4)_2$. The P is in the orthophosphate form. Its ingredients are:

Calcium	17%
Hydrogen	2%
Oxygen	55%
Phosphorus	26%

The P_2O_5 concentration of the pure compound is 60%. Phosphoric acid is added to rock phosphate to produce TSP. The impurities in the rock phosphate reduces the P_2O_5 to about 45% P_2O_5. There is about 2% S in the fertilizer also.

Most potassium fertilizer is KCl crystals. The dry fertilizer grade is 0-0-60. The ingredients are:

Potassium (K)	52%
Chloride (Cl)	48%

Potassium (K) is expressed as K_2O in fertilizer. Multiply K by 1.2 to arrive at K_2O. So the K_2O concentration of KCl is 62%. A small amount of impurities lowers the K_2O to 60% or 0-0-60. This makes the chloride concentration 46%. Note that plants take up potassium as the K^+ ion. For fertilizer solutions a pure white KCl crystal is produced that is soluble in liquid mixtures. Its grade is 0-0-62.

This discussion shows that most of the ingredients in fertilizers, other than the plant nutrients, are ions that are components of the compound. There are some impurities in the phosphoric acid that reduces the phosphate content but no inert matter or filler is added to lower the plant nutrient content. I have demonstrated that the plant nutrient ions are present in the fertilizer and that these nutrients are available and ready for plant uptake.

These are many other fertilizers. The formulas and ingredients of a few are:

Name	**Formula**	**% per element**
Ammonium sulfate	$(NH_4)_2SO_4$	21%N, 6%H, 24%S, 49%O
Potassium sulfate	K_2SO_4	45%K, 18%S, 37%O
Potassium magnesium sulfate	$K_2SO_4 \cdot 2MgSO_4$	19%K, 23%S, 12%Mg, 46%S
Zinc sulfate	$ZnSO_4 \cdot H_2O$	36%Zn, 18%S, 45%O, 1%H
Elemental S	S	100% S (about 90% when granulated)

Zinc fertilizers should be selected carefully since some compounds are insoluble. The research indicates that zinc compounds must have water solubility greater than 40% water soluble to be beneficial to plants, especially in alkaline soils.

There are many dry and liquid blends of fertilizer products that are made from the fertilizers discussed. Knowledge of compatibility is necessary for making the blends but the ingredients of the compounds do not change.

There is one other factor of fertilizer I would like to discuss. This pertains to the salt effect. I discussed that all fertilizers except NH_3 are salts because they are compounds.

The relative salt index of fertilizer is determined by the concentration of N and K_2O. The salt index is important if you are applying fertilizer in the seed slice. Some precautions before we discuss the amount of fertilizer you can place with this seed. DO NOT APPLY BORON or AMMONIUM THIOSULFATE WITH THE SEED. Obviously NH_3 wouldn't be applied in the seed furrow either.

A higher rate of N + K_2O can be applied on a per acre basis as the row spacing narrow. There are more feet of row per acre as the row width narrows. The suggested maximum rate of fertilizer to be applied directly with the seed for corn and small grains is:

	Pounds N + K_2O per acre	
Row Spacing Inches	Med-Fine Texture Soil	Sandy & Dry Soil
40	6	4
30	8	6
20	12	8
15	16	11
10	24	17
6-8	30	21
From "Crop Nutrient Management Guide", Agrilliance LLC, Kansas City, MO		

For sorghum and sunflowers, reduce the salt rates 30%. Do not apply fertilizer with soybean or dry bean seed.

PLANT-SOIL-MICROBE N RELATIONSHIPS IN HIGH RESIDUE MANAGEMENT SYSTEMS

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INTRODUCTION

The importance of supplying nitrogen (N) to optimize crop production has been known for over 150 years. The use of legumes in crop rotations was the only practical method of rebuilding soil-N supplies for row crops until the advent of industrial N fertilizer production following WWII. Much research has been conducted over the past century on the topic of N fertility for agronomic crops. Many studies concentrated on rates of applied N to optimize economic yield in conventional tillage, while fewer studies focused on understanding of the complex cycle of N in the soil environment. Only in relatively recent times have research studies investigated N cycling within native prairie and no-till soils. Although some important relationships have been discovered in these experiments, much remains to be learned.

Tilled and no-till soils can vary dramatically in carbon (C), oxygen (O_2), water content and temperature because of the tillage process. Tillage breaks bonds between soil particles and mixes air and plant residues throughout the tilled zone. This increases soil temperature, evaporative losses, and the amount of available oxygen. The overall effect of tillage is a soil environment that stimulates aerobic microbial activity, eventually leading to increased decomposition rates of plant residue-C and accelerated cycling of soil-N compared with no-till and native prairie soils. We will briefly describe how plant residues and soil microbes interact and their effects on soil-N, and provide some recommendations on how to manage N for no-till crop production.

PLANT RESIDUE AND MICROBIAL INTERACTIONS

Tillage affects plant residues and N cycling in soils because plant tissue is a primary source and sink for C and N. Normally, when plant residues with C:N ratios greater than approximately 20 parts C to one part N are added to the soil available N is immobilized during the first few weeks of decomposition (Sinha et al., 1977; Doran and Smith, 1991; Somda et al., 1991; Green and Blackmer, 1995). Green et al. (1995) observed that incorporation of corn stover into soil resulted in rapid immobilization of all available inorganic N during the rapid decomposition period. This occurred because the microbial population decomposing the plant residue had increased exponentially in response to the C source and tillage, essentially needing the N much like cattle require protein in a balanced feed ration. If N immobilization occurs when a crop needs N for growth and development, the growth and yield may be reduced. Eventually, as residue decomposition proceeds, the C:N ratio will begin to approach that of soil organic matter (~10 or 12 to 1), microbial populations will decrease, and N from plant residues that was taken up by the microbes will once again be released into the soil. However, if temperature, water content, or other factors slow the residue decomposition process, N may not be released from the plant residue or microbes until the primary crop has matured and stopped assimilating N. In a Nebraska study, Varvel and Peterson (1990) determined that in continuous corn production 80% of the applied N fertilizer was still immobilized in crop residues, soil organic matter, and microbial biomass at the end of the growing season. This emphasizes the importance of understanding all the factors affecting plant residue decomposition along with fertilizer additions and how they might be manipulated to reduce losses of N without decreasing availability of N to the primary crop, or adversely affecting the soil C and N pools.

Incorporation of shoot residues by tillage can significantly increase the decomposition rates (Douglas et al., 1980; Doran, 1987; Holland and Coleman, 1987; Aulakh et al., 1991). Root residues, however, may respond differently to tillage or disturbance than shoot residues. For example, Martin (1989) observed that decomposition of root residues was more rapid and more complete when they were left undisturbed in the soil than when air-dried roots were mixed with moist or air-dried soil.

Even in the absence of disturbance, root and shoot residues appear to have inherent differences in decomposition rates. In a laboratory simulated no-till experiment, Gale and Cambardella (2000) found differences in the partitioned amounts of shoot-derived C and root-derived C during decomposition. They concluded that accrual of soil organic C associated with no-till is primarily due to the increased retention of root-derived C in the soil and that shoot-derived C did not have much of an effect. This is largely due to shoot residue remaining on the surface with no-till and that this simulation did not include earthworm activity.

The increased amount of plant residues at the surface and within the soil with no-till creates an environment that is wetter, cooler (during the growing season) and less aerobic than tilled soils (Allmaras et al., 1964). The greater amount of available C with no-till may lead to N limited conditions for plants even though the no-till soil has more total N than tilled. Soil organic matter (SOM) content is greater in no-till despite having higher microbial populations because the cooler early season soil temperatures and a more anaerobic soil condition results in reduced microbial activity and SOM decomposition. During the period of increasing SOM content (i.e., first few years after conversion from tillage to no-till), the soil's C content increases and the N cycle is shifted towards inorganic N being immobilized into organic N. At this stage the timing, placement and rate of N applications are critical to minimize the risk of N deficiencies for the crop. Once the SOM level comes to a new equilibrium, N immobilization and mineralization processes become more balanced. This results in a reduced crop response to N additions and N fertilization rates may be able to be reduced without diminishing economic yields.

TIMING AND PLACEMENT OF N FERTILIZER FOR NO-TILL

Due to the accelerated decomposition rates with tillage, fall and early spring tillage may lead to mineralization of residue- and microbial-N before the crop is able to assimilate the N. The mineralized N is then vulnerable to loss from leaching and denitrification. In contrast, no-till often delays decomposition and mineralization, and residue-N may not be mineralized fast enough nor soon enough to optimize crop production.

The challenge with any tillage or no-tillage system is to manipulate N availability before, during, and after peak crop demand. If N fertilizer is applied long before the crop is actively growing and taking up N from the soil profile, the N can be lost through leaching, denitrification, volatilization, or immobilization processes. The same is true for residual N remaining in soil after crop senescence (Magdoff, 1991; Karlen et al., 1998), especially in years that do not produce optimal yields (Power et al., 1998). A key factor to increasing N use efficiency and reducing nitrate (NO_3) leaching potential is to limit the amount of inorganic N within the soil at the end of the crop growing season and before the next crop has established a root system extensive enough to efficiently scavenge plant-available N from the soil profile. Therefore, timing and placement of N application and accounting for mineralizable soil-N are important for improving N management, whether one tills or no-tills.

Typical N fertilizer application for corn production in the sub-humid Midwest currently consists of a single pre-plant application, usually done in autumn prior to the year when corn is planted. This management practice was promoted by agricultural experts because the potential for soil compaction following harvest is generally less, labor is often more available, the window of opportunity for the operation is generally more favorable, and fertilizer prices are frequently lower than in the spring. However, fall application places the applied N in the soil several months before the crop needs it and thus increases the potential for leaching or other losses. Sanchez and Blackmer (1988) conducted a study of fall-applied N efficiency and found that 49 to 64% of the fall-applied fertilizer N was lost from the upper 1.5 m of the soil profile through pathways other than plant uptake.

Changing the timing of a single pre-plant fertilizer application from fall to spring could significantly decrease N loss and increase fertilizer use efficiency. This was demonstrated for southern Minnesota (Randall et al., 1992; Randall, 1997) where studies showed N use efficiency was improved by over 20% through spring rather than fall N application. Although fall strip tillage offers soil physical benefits for spring planting and deep placement of phosphorus and potassium, potential N losses with this operation can still be severe. Some farmers choose to apply most or all of their annual N fertilizer in a liquid form with their pre-plant herbicides, which may perform reasonably well as long as adequate rainfall occurs soon after application. However, a starter fertilizer application at planting followed by in-season application(s) tends to be most efficient.

Starter fertilizer application is more important for no-till than tilled conditions due to no-till's slower N mineralization in early season and tendency for N to be immobilized during the early years of conversion from tillage (Brouder, 1998). A starter fertilizer that supplies a form of N readily plant-available (such as nitrate-N) and is placed two to three inches away from the seed at the same depth of planting serves well in preventing seedling N stress. It is important to not place the starter fertilizer too far from the seed because cool early season soil temperatures limit the growth of seedling roots. In addition, it is important to not apply too high a rate of starter fertilizer because of the risk of salt damage to the seedling. The safe rate limits will vary upon soil type, but in general, lower rates should be used as the closer the starter fertilizer is placed to the seed and the coarser the soil texture (Brouder, 1998).

Rate recommendations for in-season N applications can be determined by monitoring N mineralization to better synchronize N availability with crop uptake using either a pre-sidedress soil nitrate test (PSNT) (Magdoff et al., 1984; Fox et al., 1989; Magdoff et al., 1990) or modifications such as the late-spring nitrate test (LSNT) (Blackmer et al., 1997). These tests are often implemented by sampling the soil after planting and are used to help account for the net effects of mineralization, leaching and other potential losses that may have occurred since the last crop was harvested. However, an in-season N application does not need to use a soil test to determine the applied N rate. An in-season rate may simply be chosen, much like any pre-plant application rate, by experience with one's own production system or guided by previous end-of-season stalk nitrate tests (Blackmer and Mallarino, 1994). But a PSNT test does allow a farmer to track plant available-N supplies in their no-till soil given the season's climate, which can be valuable management information in the future.

Placement of in-season N fertilizer application for no-till, like all other no-till N applications, is most efficient if it is knifed or injected. Broadcast applications tend to be the most inefficient, surface banded is better, but knife or injection performs best at minimizing N losses due to volatilization and immobilization by microbes on surface residues. Because a substantial amount of surface residues can accumulate on the soil surface, surface immobilization of N is more of a concern than in tilled soils. Knifing or injecting N fertilizer separates the N from the surface residues and reduces the risk of the added N being immobilized. Again, a readily plant-available form of N fertilizer (i.e., urea-ammonium nitrate as opposed to anhydrous ammonia) would likely perform best because the crop is actively growing and is near peak demand for N.

SUMMARY

No-till soils vary dramatically from tilled soils in C content, O_2 status, water content and temperature. Understanding that these and other factors affect the soil-N cycle can help to manage N fertilizer by accounting for the effects of high levels of surface residues on no-till's N mineralization and immobilization processes. With cool early season soil temperatures, the timing and placement of N fertilizer for no-till corn is critical. Readily plant-available N starter fertilizer placed near the seed at planting, and an additional in-season application, can provide an effective no-till N program.

Also, because of high surface residue levels, knifing or injecting of N fertilizer is more effective than surface applications.

Improving N fertilizer use efficiency provides benefits not only to the environment, but also for farm economics. Historically, many farmers used rates of N greater than they perceived their corn crop required to maximize yield because the cost of N fertilizer made this practice a relatively cheap form of yield insurance in the event of excessive precipitation. However, with N fertilizer prices nearly doubling within the past year, there is now adequate economic pressure to minimize N fertilizer costs and make efforts to make one's crop production program as efficient as possible. Because much remains to be learned about the N cycle in no-till environments, it is very important for the no-till farmer to keep up-to-date on new knowledge and technologies from the soil sciences to improve their N management and farm profitability.

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NO-TILL AND NITROGEN FIXING INOCULANTS

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Nitrogen fixation is the utilization of the free gaseous nitrogen in the air by soil bacteria to produce a form of nitrogen that plants can use. Nitrogen fixing Inoculants provide the 'Rhizobia' bacteria necessary for this process in legume plants. The name for the Rhizobia that are necessary for soybeans is Bradyrhizobium japonicum. These Rhizobia bacteria form a symbiotic relationship with the soybean plant in which the bacteria supply 'fixed' (useable) nitrogen to the plant while the plant provides photosynthates (sugars) to the bacteria as a source of energy. This process occurs in the nodules located on the soybean roots.

The specifics of this process has been known for slightly more than 100 years, and 'Inoculants' for legumes have been available almost as long. Inoculation is the application of Rhizobia bacteria (Inoculant) directly onto legume seed or into the furrow while planting the seed. If all goes well, the Rhizobia bacteria in the Inoculant infects the developing soybean root and forms nodules on the root where the bacteria proliferate and start 'fixing' nitrogen. Inoculants should be used when there is reason to believe that soil populations of the necessary Rhizobia bacteria are low. This situation will exist when cleared land is brought into production, the legume has not been grown on the soil for several years (more than 4), when the pH is low, or after severe drought or flooding.

'No-till' or 'conservation tillage' is used for soybean production in many areas. These reduced tillage practices save moisture, soil, and fuel; but these same practices can generate problems involving planting in cool, wet soil (disease and emergence problems), soil compaction, and weed control.

RECOMMENDATIONS:

The question Inoculant manufacturers often are asked is how Inoculation fits into the no-till picture. Very generally, our answer is that Inoculation is needed and that our standard rules for Inoculation apply: Remember that Inoculants (be they in the granular form, or the liquid or humus seed-applied form) are biological and thus must be treated differently than are chemicals or fertilizer. Specifically, some things to do in this regard are:

a. store in a cool place.
b. check expiration dates and package labels -- especially with regard to getting the proper Inoculant for the specific legume being planted.
c. check manufacturer's compatibility recommendations with regard to mixing with pesticides like fungicides; and use the suggested application rates and techniques.
d. Remember the general rule that 'in-furrow' Inoculants will have a greater

chance of success in stress conditions and thus are the first choice, followed by double rates of Inoculants using a liquid product as the sticker for a humus-based product, with the third choice being a single rate of a liquid or humus-based product. All these methods work equally well in optimum planting and growing conditions -- though 'optimum' is seldom seen.

PROBLEMS:

Since much of no-till ground is in areas of low annual precipitation, and since such areas are considered stress areas for biological N-fixing Inoculants, potential problems are abundant:

Examples:

1. The general no-till suggestion is to plant soybeans early and shallow. This can place a seed-applied Inoculant close to the soil surface exposed to the sun and drying winds. Also, early-planted soils often are more moist soils that can easily be compacted. Compaction not only makes it difficult for the soybean to emerge, but also it makes it difficult for air to get to the nodule and thus provide the gaseous nitrogen needed for the Nitrogen Fixation process. Further, it has been observed in some cases that compaction can result in decreased nodule number.

2. Often seed treatment fungicides are recommended for early plantings and thus fungicide/Inoculant compatibilities can be a problem – i.e. just as fungicides kill biological disease organisms in the soil, they can kill the Rhizobia bacteria in the Inoculant or in the soil. The level of toxicity depends on the active ingredient in the fungicide, and on the formulation of the active ingredient.

3. In some areas, pH can be a problem. Especially in areas where wheat has been continuously grown for a long time. The pH optimum for growing wheat may be below or close to 6.0 while the optimum for soybeans is closer to 6.5. A low pH kills the Rhizobia bacteria in the Inoculant and/or prevents the bacteria from surviving and growing in the soil.

4. Many no-till farmers use starter fertilizer with soybeans because of low initial nitrogen levels. If too much nitrogen is used, the soybean roots may not pick up the Rhizobia early when the bacteria are readily available; and then when the soil N is totally depleted by normal plant growth, the Inoculant Rhizobia bacteria are dead or not available. Also, direct contact between starter fertilizer and the Inoculant bacteria can kill the bacteria in some cases (usually because of low pH fertilizer.)

5. Drought! Drought shuts down plant growth as everyone knows. One of the initial things a soybean plant does in a drought stress is to redirect photosynthate from the nodule to the root tips -- most likely to help the

roots grow and explore for more water. When the Rhizobia bacteria in the nodule don't receive the photosynthate energy source from the plant, they stop fixing nitrogen.

There is not a lot a farmer can do about drought and some of these other factors, but it is important to understand their effect on the soybean plant and on the process of Nitrogen Fixation. Inoculants are not super fertilizers or magic bullets but rather just provide the living bacteria (Rhizobia) to soybean roots so that the plant can use the free nitrogen in the air. Both the bacteria and the soybean plant must be in good health for this symbiotic process to develop and work efficiently.

The Nitrogen Fixation process will not be initiated if: a) the plant does not have all the macro and micro nutrients needed besides nitrogen, b) the soil is compacted, c) a fungicide toxic to Rhizobia is mixed directly with the Inoculant, d) the pH is too low, or e) the Inoculant bacteria are not alive as the soybean root starts to grow. Consequently the plant will be starved for nitrogen. Therefore, use Inoculants wisely remembering that the Rhizobia bacteria in these Inoculants are biological, living entities that needed to be treated as such.

BENEFITS:

Properly nodulated legumes can leave from 50 to 300 pounds of nitrogen in the soil for the succeeding crops. [Table I] The exact amount depends on effectiveness of the Nitrogen Fixation process, type of legume, length of time the legume is grown, soil nutrient levels, moisture levels, and nitrogen already available in the soil. A general rule of thumb for the amount of nitrogen left by soybeans for the next year's crop is one lb. of nitrogen for every bushel of soybeans harvested.

TABLE I

NITROGEN FIXED BY LEGUMES

Type of Legume	lb. N fixed/acre/year
Alfalfa	110 – 300
Red Clover	75 – 170
Pea	70 – 135
Soybean	55 – 100
Vetch	80 – 140

[From: Soil Microbiology by Dr. Martin Alexander]

TYPES OF INOCULANT (WHAT TO USE?):

Table II shows the forms of Inoculant available to the Farmer along with the advantages and disadvantages of each.

TABLE II

FORM OF INOCULANT	ADVANTAGES	DISADVANTAGES
Humus based:		
1. Granular in-furrow	No treatment of seed is required. Granular herbicide or insecticide equipment can be used	Requires more Inoculant material. Produced and sold in 40 pound bags.
2. Seed applied Humus based:	Good bacterial survival. Can be sterilized to eliminate background contamination and/or made with extra adhesives.	Can have high level of contamination. Can adversely affect seed flow in planter
Water based:		
1. 'Ready to Use' - seed applied	No background contamination. Good seed coverage	Lots of volume to ship and store.
2. 'Concentrates' (frozen)	Little background contamination. High concentration	Higher shipping costs. Special storage required.

The goal of any Nitrogen Fixing Inoculant is to provide the proper specific strains of Rhizobia in large numbers. An important secondary goal is to produce an Inoculant which coats the seed well or can be introduced into the soil in a precise manner via methods that are convenient and efficient. Thus, Inoculants are like different types of equipment or different formulations of fertilizer. Certain types of equipment work best for certain crops, and different types of fertilizers (bulk, anhydrous ammonia, liquid slurry, dry starter, etc.) work best according to the crop and management scheme. Similarly, different Inoculant carriers or forms work best with different types of seed, soil, or planting equipment.

EVALUATION:

After using Inoculants, it is good to evaluate the resultant nodulation. The late vegetative stage is a good time to dig up a few soybean plants to look at the root structure and to evaluate nodulation. Use a garden spade or shovel rather than jerking the plant out of the ground. Soaking the plants in a bucket of water will help remove excess soil clods without removing nodules.

On crops such as soybean that have been planted in the Spring, there should be from 5 to 15 spherical shaped nodules located on or around the taproot. The total root system may have up to 50 or more nodules. For alfalfa and clovers that have been growing for a year or two, the nodules will appear on the lateral roots and be long and slender in shape. When evaluating nodules, keep in mind you are looking for overall nodule mass not just quantity. For example, 4 large nodules with a weight of 50 grams will be as effective as 10 small nodules with a weight of 50 grams.

Next, slice open a few nodules and check the color. Nodules actively 'fixing' free atmospheric nitrogen to usable ammonia will range in color from pink to bright red. If the nodules are white, they are ineffective or may not be developed yet to a stage at which they can fix nitrogen. To check if white nodules are immature or ineffective, examine the plant roots again a week later. This will usually give enough time for young nodules to mature into pink or red colored N-fixing nodules. If nodules are green and soft, they are past their prime and have already contributed to the plant's nitrogen economy. In soybeans, this 'green' stage will be observed in August and September after the plants are well into the pod filling stage of growth.

The final evaluation, of course, is yield.

SUMMARY:

There are several specific factors that adversely affect Rhizobial survival in the soil:

1. Acid or alkaline soils
2. Very wet or very dry soils
3. Soil treatment or seed treatment chemicals
4. High soil temperatures
5. Soils low in organic matter

Keep these things in mind as well as the fact that Nitrogen Fixing Inoculants for legumes contain a biological living entity that must remain alive in order to be effective. Biological Inoculants have requirements necessary for successful use that chemicals and fertilizers don't have. There are specific and important rules for handling Nitrogen Fixing Inoculants that must be followed for the Inoculant to work.

On the positive side of the ledger, when you successfully establish Rhizobia bacteria in your soils, you can harvest the benefits of higher legume yields with lower inputs, fertilizer savings, and residual soil nitrogen for succeeding non-legume crops.

SOIL HEALTH: PERCEPTIONS OF THE PAST, DIRECTIONS FOR THE FUTURE

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INTRODUCTION

Soil health is defined as the capacity of soil to function. Functions of soil include sustaining biological productivity, regulating water flow, storing and cycling nutrients, and filtering, buffering, and transforming organic and inorganic materials. Soil also functions as a habitat and genetic reserve for numerous organisms. Consequently, management strategies that optimize multiple soil functions have a greater potential for improving soil health over management strategies that focus on a single function.

PERCEPTIONS OF THE PAST

Soil health is not a new concept. Greek and Roman philosophers were aware of the importance of soil health to agricultural prosperity over 2000 years ago, and reflected this awareness in their treatises on farm management. As the science of agriculture developed, plant nutrients were identified as essential components of soil health, at least with respect to sustaining biological productivity. This resulted in a paradigm of plant nutrition and soil management that relied heavily on the use of artificial fertilizers and intensive tillage.

Increasing concern over agriculture's impact on the environment has created renewed interest in soil health. Efforts to define soil health in the context of multiple soil functions began in 1977 (Warkentin and Fletcher, 1977), and were followed by more formalized definitions (Larson and Pierce, 1991; Karlen et al., 1997), selection of indicators (Doran and Parkin, 1994), and specific strategies to enhance soil health (Doran et al., 1996).

Recent efforts to quantify soil health have resulted in the development of tools to evaluate the impact of management on the soil and environment. The soil quality test kit (reviewed by Cramer, 1994) and soil health scorecard (USDA-NRCS-SQI, 1999) are two examples of tools that provide users with a means to quickly evaluate soil properties and processes with minimal equipment and expertise. These tools, along with numerous extension-oriented presentations by USDA and university personnel, have increased awareness among producers, conservationists, scientists, and policy makers regarding the importance of soil to agricultural and natural resource sustainability.

DIRECTIONS FOR THE FUTURE

While much has been accomplished in the area of soil health, much more needs to be done. Research efforts to monitor and index indicators of soil health need to be balanced with efforts to clearly define relationships between the status of indicators and specific soil functions. In doing so, there is a need to consider the simultaneity of diverse and occasionally conflicting soil functions and their soil property requirements (Sojka and Upchurch, 1999). Greater relevance to these efforts may be achieved by adopting a broader perspective of soil health; a perspective that establishes strategies for agricultural and natural resource sustainability up front, and then uses indicators encompassing all aspects of agroecosystem performance.

Sustainable agriculture is one that, over the long-term, enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fiber needs, is economically viable, and enhances the quality of life of farmers and society as a whole (Schaller, 1990). This definition, and others like it, can be used as a starting point to develop specific strategies for agricultural and natural resource sustainability. To make strategies amenable for assessment, however, they need to be organized into measurable categories, as there is no single, summary indicator for sustainability.

The performance of every farm and ranch can be expressed through economic, environmental, and social indicators. Indicators chosen from these categories should be a reflection of producer success and/or natural resource conservation. Indicators should also be relatively easy to measure and simple to interpret. Examples of indicators meeting these criteria include crop yield, profit, risk of crop failure, soil organic matter content, soil depth, percent soil cover, leachable salts (especially NO_3-N), and energy use (Table 1).

Table 1. Proposed indicators for a simplified approach for on-farm assessment of agricultural and natural resource sustainability (after Doran, 2001).

PRODUCER AND SOCIETY NEEDS	RESOURCE AND ENVIRONMENTAL CONSERVATION
YIELDS relative to locale, climate, and soil type.	**SOIL ORGANIC MATTER** change with time, relative to local potential.
PROFITS relative to net returns and degree of subsidization.	**SOIL DEPTH** of topsoil and rooting relative to local potential.
RISK / STABILITY of net returns over time.	**SOIL PROTECTIVE COVER** effective as continuous or stratified.
INPUT / OUTPUT RATIO of energy (renewable and non-renewable) and costs.	**LEACHABLE SALTS (NO_3-N)** at planting and post-harvest.

General management strategies considered to enhance agricultural and natural resource sustainability include crop rotation (for tighter cycling of nutrients), reduction in soil disturbance (to maintain soil organic matter and reduce erosion), and use of renewable biological resources (to reduce auxiliary energy requirements). For these management strategies to be successful, however, it will likely be necessary to make better use of the diversity and resiliency of the biological community in soil.

CONCLUSIONS

1. The concept of soil health has increased awareness among agriculturists regarding the importance of soil in maintaining plant productivity and environmental quality over the long-term.
2. There is a need to better understand relationships between the status of soil health indicators and soil functions, and to consider the occasionally conflicting nature of soil functions and their soil property requirements.
3. The best application of soil health may be under a broader context that first defines strategies to enhance agricultural and natural resource sustainability, and then uses indicators encompassing all aspects of agroecosystem performance.

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SYSTEMS APPROACH TO NO-TILL IN THE FUTURE

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INTRODUCTION

The presentations I make are normally focus strongly on techniques used to improve crop rotations and other components of diverse no-till systems. In reality, all of this material can be found at our web site. Readers interested in this important material are encouraged to visit that site. I am often questioned as to why the Dakota Lakes Research Farm has put so much emphasis on developing the systems approach and what it tells us about the future. In this paper we will attempt to share some of our thoughts.

The track record of meteorologists and stock pickers in the last year demonstrates the danger of prognostication. Consequently, readers should interpret the contents of this paper with a great deal of skepticism. The author reserves the right to be wrong (and hopes you forget). He also hopes to have the ability to gloat if some of this material is prophetic.

THE SYSTEMS APPROACH

The terms system, systems approach, holistic management, etc. have become quite popular during the last few years. This signifies there is increasing awareness that management decisions and policy techniques need to be based on a broader perspective than has been common in the past. This awareness has developed as the result of continued frustration when seemingly good management decisions and sound policy lead to totally unexpected consequences. The logic is that, if seemingly good decisions consistently lead to bad or unanticipated consequences, either the decision and policy makers are incredibly stupid or the techniques used are flawed. Maybe there is a little of both involved.

Being aware that the approaches being used in the past have problems does not provide solutions to these problems or even indicate where they were flawed. Simply espousing the need to use a systems or holistic approach does not indicate how it should be done. Similarly, when it is stated that a systems approach has been used it does not mean that it has been used correctly.

The validity of decisions made using a systems approach must by definition be based on evaluation of the impacts these decisions have on the components of the system and the system as a whole. There are several excellent texts that outline this way of thinking and how it is developed and implemented. This paper will not try to compete with them in providing the basics. However, since most of these have not specifically focused on issues surrounding crop production or no-till, we will attempt to apply some systems analysis techniques to predicting what the future holds in store.

BASIC PREMUSES

Before making any predictions it is important to outline some basic "principles" upon which they will be based. Obviously, if these are not correct the predictions will be flawed.

PERCEPTION IS REALITY

It is not certain that the "real truth" ever triumphed over "perceived truth" other than in old movies. There is no reason to expect that to change in the future. In fact, as the complexity of issues increases (global warming/carbon sequestration) it becomes difficult for even well intentioned individuals to agree on what is the truth. (See the papers on global warming in these proceedings). This is complicated even more by the willingness and ability of special interest groups to impact public perceptions. Consequently, even when the truth is known, it isn't important unless efforts are made to assure perception is the same.

NO ONE HAS YOUR BEST INTERESTS IN MIND EXCEPT YOU

It is very common for politicians, bankers, personnel from government agencies (CES, NRCS, USDA-ARS, and ABS), and company representatives to infer that they have your best interest in mind. They (including me) lie. They (we) have your best interests in mind only if they happen to coincide with ours. This should not surprise you. It does not make them immoral or unethical. Their first responsibility is, as it should be, to themselves and their organization. Your first responsibility should be to yourself and your family or organization. How many times have you bought ag. chemicals, fertilizers, or machinery because it would be good for John Deere, Monsanto, or the Co-op? Never. Why should they be any different?

IT'S THE ECONOMY STUPID

The laws of economics, like the laws of nature, work exceptionally well. Economic systems, like natural systems, will shift to relieve or offset a stimulus applied to them in a consistent and predictable manner. Agricultural subsidies and import tariffs eventually become capitalized into the price of land and other agricultural inputs. They then become subsidies to landowners and major corporations not to crop producers. If (when) the subsidy or tariff is removed, the producers find themselves in dire economic straights until land and input prices respond to the new reality (sugar beet producers are an example). Similarly, excessive taxes and regulation eventually lead to lower costs for other production inputs.

Improved methods or new technologies are only an economic advantage until the increased efficiency provided is capitalized into the price of land and other production inputs. After this happens the new techniques become necessities. No-till has raised (or will raise) the price of land in South Dakota to a point higher than it would be without this technique. Established farmers who own a substantial land base can continue to operate and even expand without using no-till because they do not have to pay full land costs on all their acres. New producers will not be able to cash flow land purchases without using no-till or some other production system that gives them an advantage over traditional techniques.

Similarly, developing an improved product that commands a higher price from the buyer is only important until others also develop the same or similar products. Then it becomes a necessity to provide the improved product (it is not possible to sell the unimproved product). An analogy can be made with farm machinery. How many people would buy a tractor without power steering? A few of us remember when power steering, cabs, air conditioners, etc. were innovations.

To the Consumer Quality, Consistency, Convenience, and Credibility Count-Cost Doesn't

The ultimate consumer of agricultural products is becoming increasingly less concerned about the cost of the finished product and more interested in perceived value. If you don't believe this go shopping with my wife. Convenience, food safety, wholesomeness, and other factors have become much more important than price. Processors of agricultural goods are interested in buying quality raw materials (inputs) as cheaply as possible so they can maximize their profits. You do the same thing. When is the last time you offered to pay more than the co-op was asking for fertilizer in order to assure they were making enough money? Owning processing capability will only be important if you create a "valuable" product from raw material produced in an economic manner. In other words, farmer owned processors must be as efficient as privately owned ones. This means obtaining the raw material at competitive prices. Trying to make up production deficiencies by adding value in processing will not work.

There Are No Miracles

We are not going to get rich producing drugs and pharmaceuticals. The quantity needed is too small. The requirements will be too high. And the value will be capitalized into land costs in the area where the companies choose to grow the product.

Carbon sequestration payments present more potential problems than promises. Even if other countries agree to allow use of this approach, the only people who will make substantial amounts of money from it will be lawyers, bureaucrats, and land owners. It will become another subsidy. It will be almost impossible to administer fairly. It will focus attention on other greenhouse gasses in agriculture (Ammonia, nitrous oxides, etc.). It will produce more regulation. We will have difficulty being competitive with other areas of the world (and US) in sequestering carbon.

AGRICULTURAL PRODUCTION ISN'T IMPORTANT

Politicians (including those that run farm organizations and lobbying groups) like to tell farmers they are important because they feed and clothe the world. That is true, but nobody cares. If you didn't do it someone else would be happy to take your place. From an economic standpoint, production of raw agricultural products is almost irrelevant. Bill Gates's net worth exceeds the total value of agricultural production in the United States many times over. It is not as many times today as it was a year ago, but it still is many times.

Agriculture is important economically in terms of the amount of value generated by the final product, not the raw material. Agriculture is important on how it impacts the environment. This is not as obvious in sparsely populated South Dakota but the fact that Amendment E was passed more on environmental grounds than social and economic ones should serve as a wake-up call to us also.

THE FUTURE

TECHNOLOGY WILL BE A TOOL, NOT A SOLUTION

Technology has often been used to treat symptoms that should not occur in properly designed agricultural systems. In other words it has been used to replace management and cultural practices rather than augmenting them. In the future, technology will become more expensive both in economic costs but also from a public relations capital standpoint. This does not mean that it will not be used, but rather that it will become increasingly important to be sure that it is used appropriately to increase the value of the product to the consumer not to reduce the cost. Remember the cost is not important to the consumer.

The technology that will probably have the largest impact on agriculture may be in the electronic sector not the biological sciences. This does not mean that biological technology will not be important but rather that the ability to market directly to consumers using the web, the capability to manage inputs accurately on a site-specific basis, and other electronically based technologies may allow us to utilize the biological technology to its full potential.

COMMODITIES VERSUS PRODUCTS

Some farmers will continue to produce commodities. Producing these commodities at the lowest possible price will continue to be the driving force for these people. This will mean they need to be extremely efficient. Appropriate farm size, crop diversity, technology, etc. all play a role in that equation. Others will focus on making products that have enhanced value to the targeted consumer. This value will be gained as much by how the raw material is produced as how it is processed. Organic farmers have done an excellent job of convincing some consumers that their method of production is better for the environment and results in a healthier product. Both of these perceptions are wrong, but since perception is reality, they can command a higher price for their products. No-till farmers need to capitalize on the environmental benefits provided by using diverse no-till systems by selling that value to the consumer. Carbon sequestration could be part of this value. This approach means the grower gathers the increased value because it is gained by management and salesmanship not by blanket subsidy.

FARMERS NEED TO TAKE CONTROL

The bottom line is that farmers need to take control of their own destiny rather than waiting for others to create this destiny for them. Value added co-ops are a small step in that direction. They are not an end but a means. They provide sufficient critical mass to allow producers to compete with large multi-national corporations. This does not mean they allow producers to use inefficient production practices. If production is not efficient the raw material will cost too much and the co-op will not be competitive. Producing products designed to sell into a subsidized market (sugar, ethanol, etc) contains substantial risks.

Farmers need to take a larger role in funding research. Research conducted by private industry is designed to serve their interests. Research at public institutions is designed to serve the public good. What is perceived as public good may not be good for the producer. Similarly, research funded by commodity groups (corn, soybean, wheat, etc.) is important from a commodity basis, but it in general is not focused on systems impacts. Getting the research you need may mean funding or doing it yourself.

CONCLUSION

THE LAWS OF NATURE AND ECONOMICS WILL NOT CHANGE

This is the prediction that I know will be true. Economic and natural laws will not change. In the past much effort has been put into trying to change these laws rather than on spending time in understanding how they work and how we can use this to our advantage. If we continue to try to change how these laws work through technology and legislation we will continue to fail. If, on the other hand, we concede that we (and our farming operations) are not independent entities but rather only a part of the system. Then we can begin the process of developing a niche for our operation. Not every organism in a system occupies the same niche. Quite the contrary they all strive to find the thing they can do better than other organisms. No-till farmers need to do that. I do not have to list the things we do better. Other speakers at this conference have done that. What we need to do is to focus on taking advantages of those strengths. The probable increase in environmental awareness, escalating energy and fertilizer prices, etc. position us very well to take advantage of the power presented by sound no-till systems.