Healthier Soils
Producing Healthier Plants
For Healthier people

A report for

Nuffield Canada

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Introduction

Our population relies on healthy soils to sustain life. Great civilizations like the Romans, Egyptians, Greeks, and Mayans were built and flourished near fertile soil. When soils were not properly managed, erosion and degradation of soil, lead to the decline of these great empires. Around 360 B.C., the philosopher Plato attributed the demise of the Greek power to land degradation: "[in earlier days] Attica yielded far more abundant produce. In comparison of what then was, there are remaining only the bones of the wasted body; all the richer and softer parts of the soil having fallen away, and the mere skeleton of the land being left." Are we immune to the fate of declining soils causing hunger and higher frequencies of disease in the twenty first century? Like the old adage, 'history repeats itself' as the lessons of the past are forgotten. One would wonder how that could happen in today's modern world of technological advances compared to that of ancient civilizations.

Battling nature is an ever uphill road, especially when nature is needed to feed the population. Trillions of dollars are spent in an arms race between the pesticide companies of the world and the ever evolving insects and diseases. In stark contrast to this image is native prairie. Even without the use of pesticides insect and disease plagues do not devour native prairies and heavy rains do not drown out large areas in the prairies. In this study I set out to learn how natural processes can improve soil and plant health, reducing the injection of margin limiting cash for pesticides. With crop selection and soil management, I hope to pass the farm on to the next generation with healthier soils than I stated with.

One of the aims of this study is to learn to grow food working with and not against nature. Some pesticides, compaction, erosion, salinization, and mismanagement of fertilizer are all current threats to maintaining healthy soil.

To become more informed I spoke with organic, conventional, and no-till farmers. I discussed general concepts and farming practices that generate sustainable productive soils and then reviewed existing literature on the concepts discussed to get more detail and a better grasp of the information. Though the information in this report is not exhaustive, I feel good about sharing some of the farming practices I have learned that grow equivalent yields with less input costs, producing food with higher nutritional value, and have less environmental impact. I am currently implementing some of these practices on my farm and am excited to try others to round out my farming program. I have always tried to be a good steward of the land and it is a proud moment in my day when somebody asks me what I am doing to achieve sustainability. This gives me the opportunity to describe some good environmental farming practices we are engaged in and hopefully strikes up a conversation where both parties are able to gain knowledge.

My land sustainability practices have been learned through tours, courses, winter reading and observation of the growing crop. My Nuffield experience greatly enhanced this flow of information by providing a network of resource people. In this paper I will elaborate on what I see as the next step in land sustainability. This step involves knowing your own soils, how to select soil labs and interpret soil tests, and having the tools to grow a crop closer to its maximum potential. I hope that at this stage a farmer can rely less on crop consultants as he will be more informed to make soil management decisions backed up with effective field measurement tools.

I will discuss the advantages and disadvantages of the three farming methods mentioned and how they affect soil life and the properties of soil. Surprisingly in many cases I found criticism or apathy from farmers toward opposing farming methods. Getting more of these farmers speaking to one another would be a step in the right direction for improved sustainability.

The soils physical, chemical, and biological balance needs to be taken into consideration with all farming passes over the soil. Generally agriculture has been concerned with just soil chemistry in the past. There has been recent success for agriculturists who are attentive toward harmony in all three soil properties and consider how management decisions will affect all three.

Nobody fertilized the rainforests to make them what they are today. With adequate water and heat, look what symbiotic relationships and nutrient cycling between soil organisms, the air and the plants and trees of the rainforest are able to accomplish! Mycorrhizal fungi, rhizobium bacteria and free living nitrogen fixing bacteria are just a few of the soil microorganism that have a nutrient cycling relationship with plants. These microorganisms provide more nutrients to the plant than their roots would be able to accomplish on their own. Discovering how to enhance these relationships to produce healthier soil and plants with higher nutrient values year after year was the aim of my study. I will be sharing the farming and soil management methods I have learned from the farmers and consultants in my travels, which have had positive results with soil health. Soil management needs to be a major focus in farming. Jill Clapperton's, a respected soil scientist, writes [Farm Journal, November2000,] "Someday farmers will manage the animals in their soil as intensively as their above-ground livestock, producing crops with less risk to the environment" (2002)

Background

I was born in Lethbridge, Alberta, Canada where I still farm today. Along with my wife and three children, I farm in a partnership with my brother and his family and my parents. We each have our own corporations with our own assets. Working together has enabled us to have more time to pursue goals in life beyond farming. We farm 1150 acres of process potatoes that are used for Frito Lay chips and McCain French fries as well as three hundred acres of peas for a frozen pea product for Lucerne. We are using compost and microbial inoculants to enhance our soil structure. My interest in soil health has led to my involvement with Nuffield and to this study topic specifically. I am very grateful for the network of people around the world and knowledge I have gained. My association with Nuffield will help me produce healthier crops with less environmental impact and enable me to help others by sharing my knowledge and resources.

The Organisms in the Soil and Their Functions

Did you know that in a square meter of healthy soil you can have up to 10 trillion bacteria, 10 billion protozoa, 5 million nematodes, 100000 mites, 50000 springtails, 10000 rotafiers and tardigades, 5000 insects and arachnids, 500 worms, 100 snails and slugs, and up to 10 kilometres of fungi hyphae. The metabolic activity of that number of bacteria in the top six inches of an acre of healthy soil would exceed that of 50000 people. "Life in the Soil" Nardi 2007

Nitrogen and carbon can be grown or sequestered from the atmosphere. All other nutrients need to be added to the soil as nutrients are hauled off the field with the crops. Bacteria can be used to fix atmospheric nitrogen, which is in a form plants are unable to use, into ammonium NH4 which plants can use.

<u>Bacteria</u>

Bacteria that fix atmospheric nitrogen into the soil can be;

- Free living atmospheric nitrogen fixers. Perform this task without symbiotic associations with plant.
- Bacteria that make a symbiotic association with the plant.
  Here are a few examples
  (1) Legume plants and the bacteria Rhizobia
  (2) Certain trees have a symbiotic relation with Frankia bacteria
  (3) Certain grasses have a symbiotic relation with azosprillium

In healthy soils, legume plants with sufficient Rhizobia inoculation can supply all nitrogen needs to the host plant and in most cases supply nitrogen needs for the following crop. This is a great savings to the farmer and the environment, as nitrogen produced for agriculture is one of the largest energy consumers of all agriculture inputs. This is one of many reasons to have a good crop rotation plan. There is bacteria inoculation for sale to ensure healthy populations in your crops. The plants or soil can be tested by a lab to make sure the inoculation application was successful.

There is a large diversity of bacteria in your soil. Listed here are just a few of the many tasks they perform;

- As the plant root grows, it sloughs off dead cells that the bacteria feed on and in turn the root feeds on the dead bodies of bacteria.
- They stabilize and cycle nutrients.
- Food for other organisms in the soil food web.
- Largest biomass of all living things on earth.
- Anaerobic digestion of organic material

Fungi

There is a large diversity of fungi in the soil performing many different roles most of which are beneficial to plants. Mycorrhizae fungi (meaning fungus roots), are an extremely important fungi to agriculture. One of the most beneficial is Vesicular Arbuscular Mycorrhizae (VAM). VAM form symbiotic associations with most agricultural plants, with a few exceptions (e.g. lupines and canola), Vesicules are structures formed inside the cell wall of the plant. They connect to the hyphae which after repeated branching form arbuscules which grow through the soil on their own. Arbuscules are believed to be the major site where carbon from the plant and nutrients from the VAM exchange takes place. The hyphae explore the soil for nutrients, transport them back to the host plant, and help bind soil particles into aggregates. The hyphae form networks between neighbouring soil particles, between roots and soil particles, between roots on the same plant, and roots of different plants (even different types of plants). They also form networks inside the roots they colonize (These networks of hyphae are also referred to as mycelium). The University of Western Australia newsletter. Mycorrhizae fungi can increase the plants nutrient and water uptake capacity of the roots by three times, exploring much more soil than the plant would be able to do with its own root system. For further information, including photographs, explanations visit the University of Western Australia mycorrhizae website.

Legumes grow better with healthy levels of mycorrhizae as Phosphate provided by the mycorrhizae is an essential nutrient for transporting all other nutrients in the plant.

When too much phosphate fertilizer is present in the soil plants do not need the mycorrhizae fungi, for an important role they perform for the plant is making phosphate in the soil available through biological activity. When there is sufficient available phosphorous in the soil the plant does not feed the mycorrhizae slowing or halting their symbiosis. Without this association between plant and fungi all other benefits are lost.

A very important role of the mycorrhizal fungal group Glomus is to produce glomalin. An exciting article by Mike Amaranthus, a professor at Oregon State University, states. “Organic glue, the glomalin molecule is made up of 30% to 40 % carbon and can represent up to an astonishing 30 % of the carbon in soil. Glomalin acts to bind organic matter in mineral particles in the soil. It also forms soil clumps – aggregates – that improve soil structure and deposit carbon on the surface of soil particles. Glomalin is a relatively stable carbon deposit found in the soils lasting from seven to 42 years.” 2008, Acres USA.

To get the benefits from the soil organisms mentioned above we need a healthy habitat for soil organisms including proper proportions of soil air and water and as little contamination as possible e.g. some types of pesticides, fertilizers and nutrient applications that put soils further out of balance. Salt, the carrier for most synthetic fertilizer is unhealthy for soil biology as it sucks the moisture out of the organisms. Cultivation and compaction also negatively affect soil life. This idea goes back to Jill Clapperton prediction that one day we would farm the organisms in the soil as intensively as we farm the crop on top. When a chemical is used that wilts or yellows the crop we call the chemical representative and want answers for this occurrence. If a chemical or fertilizer kills the beneficial soil organisms we should be just as concerned. There are many soil amendments that will steer soil health in the proper direction. There are labs that will test soil biomass, current theory correlates greater biomass created each year with healthier soil. Other labs are able to test populations of specific species of organisms. The technology is at a fledgling stage. As we learn more about the organisms in the soil and their benefits, this technology will be an excellent tool for farmers.

Carbon Cycle: From Sun and Air to Earth

On our earth we have billions of acres of nature's solar panels in plants. This is the start of biology's energy cycle on earth. The first group of organisms to share in the photosynthetic energy generated by the plant are the symbiotic microorganisms on the plant and its roots. The symbiotic microorganisms receive sugars and exudates from the plant in exchange for nutrients. The healthier the plant is the more energy it can supply to the organisms. In turn the organisms can grow further in to the soil or multiply more times, supplying greater amounts of nutrients back to the plant. To live comfortably, plants and soil organisms need to have a good home. Air is essential, and with a good diversity and balance of organisms the carbon and nutrients can be recycled up the food chain, potentially from the plant, to bacteria or fungi, to amoeba, to protozoa, to nematode, to springtails, to mites, and to earthworms. The secretions or castings from these organisms form larger soil aggregates as you go up the food chain creating larger pore air space. The plant roots and the hyphae from fungi are penetrating soil compaction and hard pan layers, searching for more nutrients. When these roots and hyphae die, there are tunnels left creating air space and food stored in dead plant and animal matter. Food and water are important. There are stable nutrients available in the dead bodies and secretions of soil organisms in the soil food web. When biological activity is thriving, organic material is being decomposed into organic matter or humus at an optimum rate, increasing percent soil organic matter (SOM). SOM or humus is comprised of about 50% carbon, another way to increase the carbon content of soil. Another benefit of a biologically active soil is the amount of carbon that gets fed to the symbiotic organisms in plant exudates, becoming part of their bodies and entering the nutrient cycling chain of the soil food web.   There are many holding sites for nutrients on humus; humus can hold up to nine times its volume in water increasing the water holding capacity of the field.

Chemical, Physical, and Biological Soil Properties

When soil is driven on it will compact, affecting the physical property by reducing the porosity and water holding capacity. The chemistry of the soil is altered oxidizing nutrients into the atmosphere. Biologically, as you reduce the porosity, the microorganisms and plant roots run out of air and space to live. The outcome is a less healthy plant. This plant is unable to adequately feed the symbiotic organisms in the soil with plant exudates that were generated through photosynthesis.   When the microorganism's nutrient supply from the plant is reduced, their growth is limited and they are not able to supply the plant with optimal nutrients for plant growth. Ultimately, plant yields decrease and maximum sequestration of different carbon forms into the soil from the air through photosynthesis does not take place. Optimum levels of soil organic matter (SOM) therefore are not generated. High inputs of salty fertilizers, soil fumigation and over watering have similar negative impacts on soil balance. Today there are soil and plant tools like penetrometers and refractometers for farmers to use to help them make educated decisions when managing the soil.

Tight soils will begin to loosen with correct nutrient balancing. When clay colloids have the correct nutrient balance soils become more flocculated and the clay colloids will also have more holding sites available for a balance of cation nutrients required by the plans.

A good level of biological activity and proper management of physical and chemical properties of soil will loosen the hardpan and compaction layers, increasing porosity, creating a better infiltration rate.

This can be measured with a penetrometer, a probe that measures PSI as you push it through the soil profile. The harder the push the more compacted the soil, the easier the push the more flocculated the soil. A rule of thumb for healthy soil is: 25% air space, 25% water, 45% soil particles, and 5% organic matter.

A large precipitation event is a good test to see if soils are well flocculated. If proper management has eliminated the hardpan, excess water can flow through the soil profile once field capacity is met. When water can flow through the soil, an anaerobic situation in the soil will be lessened or avoided, keeping plants and soil organisms from suffocation. The nutrients that are biologically recycled will be stable and will not leach out of the root zone.

When the soil is at this stage of health, higher humus content and porosity increase soil water holding capacity, enabling plants to withstand longer droughts. When the soil begins to dry up, the capillary action of soil and humus will be able to pull the water up from below. Because of a good infiltration rate, this water is also brought to the surface with the gravitational pull of the moon just like tides in the soil. (Gerald Weibe, 2008, personal communication, a respected Canadian organic farmer)

Farming Methods

No-till

No-till farming has early roots on Carlos Crovetto's farm in Chile. Carlos Crovetto (aka "the grandfather of no-till") has taken a farm that soil erosion nearly put out of business 50 years ago and turned it into a productive farming operation. When he started no-tilling he slowed down the soil erosion, all the while keeping very good records and watching his farm become profitable. It is currently a show piece for no-till farmers. The following table displays some of his progress.

Management	Depth / cm	OM %	CEC meq/100g
1959	0-5	1.42	11.00
Beginning of	5-10	1.24	11.00
No-tillage in pastures	10-20	1.00	11.00
1978	0-5	4.56	16.00
Beginning of	5-10	1.92	10.00
No-tillage in grains	10-20	1.14	10.00
2001	0-5	6.53	23.20
After 23 years	5-10	2.14	18.80
No-tillage	10-20	2.76	18.50

Conditions of soil organic matter levels (SOM) and cation exchange capacity (CEC)
In Chequen soils after 42 years of no tillage. Carlos Crovetto

Significant in the chart above is the increase in SOM and CEC, SOM holds nutrients from leaching maintaining their availability for plant absorption. Increased

CEC means the humus and clay have greater negative charge sites available, which is good for the basic cation nutrients which have a positive charge; Ca^{++}, Mg^{++}, K^{+}, Na^{+}, and NH_4^{+}

I spoke with Carlos Crovetto as well as Cesar Belloso, a farmer and consultant from Argentina, who shared with me the concepts of no-till. Both were members of Aapresid (an acronym in Spanish for Argentina no-till farmer Association). This association is farmer-based and was set up for the exchange of knowledge between farmers. Aapresid is a very well run, respected, and very effective association. Jill Clapperton, a soil scientist from Alberta, was asked to speak at an Aapresid function and was so impressed she assisted in getting a sister association going in Southern Alberta. Several no-till farmers I spoke with on my Nuffield tour were well on their way to improving their soil quality.

There are three stages of no-till before your soil is producing at optimum levels. Stage 1: (3-5 years) there is a large build up of trash as macro organisms (the trash shredders) are getting back to native soil populations. These populations are much higher than tilled land as tillage kills and destroys the macro organism's habitat. Macro shredders are worms, mites, and arthropods. The slower break down of trash and nutrient cycling can cause nitrogen to be tied up and may create a need for higher nitrogen applications in the first 3-5 years. Porosity is increasing as the old roots decay and leave tunnels for larger soil organisms to travel deeper into the soil and recycle larger amounts of nutrients, creating better soil aggregation.

Stage 2: (5- 10 even 15 years), this is the intermediate stage, when organisms are beginning to harmonize into a more balanced ratio for nutrient cycling. Fungi to bacteria ratio increases. Conventional tilled fields are too low in fungal numbers. Fungi perform numerous beneficial functions in the soil from decomposing organic matter to assisting the crops in a symbiotic relationship to increase nutrient uptake as well as secrete glomalin and other compounds which adds stable carbon to the soil and improves soil structure.

At this stage the porosity has continued to increase allowing roots and organism at greater depths access to air, which is necessary for survival. The organisms being more balanced to one another and just more numerous are able to do a better job of shredding trash and subsequently turn the trash into a stable organic substance with nutrients attached to different sites on the organic compounds in a stable form (nutrient cycling) .

Stage 3: The last and ongoing stage, (15 to 20 years plus), is the consolidation stage. At this stage the soil should be close to its native population and balance of organisms according to rotation, with higher populations and greater diversity than the first two stages. The porosity is close to optimal and has a good air, water, and soil particle ratio. With proper management of chemicals and fertilizer so the organisms can do the job of breaking up the hard pan, the infiltration properties of the soil will be near optimum allowing larger rain events to flow through the soil profile once moisture field capacity is met. In turn, moisture should be able to flow back up to the surface with capillary action and the gravity of the moon as the soil surface dries up, depending on the soil texture of the bottom layers of the soil horizons.

The thin layers of decomposing trash that are converting to organic matter right on top of the soil surface are very important. As the amount of undisturbed layers increase, they build a soil habitat in which nutrient exchange between plants, soil, and soil organisms can thrive in increasing SOM. (Carlos Crovetto, 2008, personal conversation)

In the Argentine Pampas agricultural region farmers say “nobody debates whether to till or not to till it is just known that no-till is the best practice.” Some negative consequences of no-till are resistant perennial weeds, and in Argentina, slugs. Benefits of no-till, aside from those listed above, include reduced capital costs i.e. no tillage equipment, time, labour, and fuel saving of less passes over the field generating less green house gasses. In Argentina, the current research supports keeping the ground covered with a growing crop whenever possible.

Conventional Tillage

Conventional tillage has been a major contributing factor in soil erosion over the years, beginning when the oxen or horse pulled a plough through the soils. Some soils are much more at risk for erosion than others, so well managed tillage is always important.

Reasons for tillage are:

- Incorporation of trash or crop inputs; fertilizer, compost, pesticides, and green manures.
- Managing compaction and getting air into soil profile.
- Breaking up a hard pan in the soil profile.
- Creating a seed bed for future crops.
- Controlling clods - some vegetable harvesters use of rotatillers or power hillers
- Planting and harvesting of deep seeded crops.
- Preventing nutrient stratification in the soil profile.
- Ploughing in underground drip irrigation.

Soil textures, percent soil organic matter, and whether the soil sees a freeze thaw in winter will affect decisions to till or not to till. If heavy clays are farmed when the soil is wet, compaction will be a concern. If the soil is not in good health, tillage may be necessary to allow air into the soil. If soil organic matter is under 6%, soils are not as spongy and more susceptible to compaction. If soils go through a freeze thaw cycle over the winter and have sufficient moisture content, compaction created from equipment from previous years may break up with the 9% expansion of water turning to ice. If there is a chemical or biological imbalance creating the compaction problem then freeze thaw may or may not remedy the problem. A healthy soil should have about: 25% air, 25% water, 5% Organic matter, and 45% soil particles depending on precipitation events.

To neutralize the carbon that oxidizes into the air from tilling the soil, it is recommended that the rotational crop puts back the equivalent amount or more of the burned off carbon in crop residue. This carbon returned to the soil can be measured in the amount of humus, which is decomposed trash now in a stable form, returned to the soil. Also to be measured and added to the total humus generated by the crop is the humus created by any soil organism that had a symbiotic relationship with that plant. Equivalent or greater amounts of manure or compost, measured in the stable humus form can also be added to neutralize the carbon burned off from tillage. New studies have found healthy plants, assisted by soil biology, can sequester large amounts of stable soil carbon.

The table below measures the tons per hectare per year of carbon lost from the soil to the atmosphere with different crop practices. Water stable aggregates prevent soil erosion and are a sign of better soil tilth as well as an indication of increased porosity.

Crop practices	% water stable aggregates >15 mm	Erosion rate t/ha/year
Traditional spring ploughing	14	15
Traditional autumn ploughing	25	8
Spring minimum tillage	30	7
Spring chisel	34	6
Autumn chisel	53	3
Autumn minimum tillage	55	3
Winter no-tillage	77	1

Different tillage implements on stable aggregates and soil erosion in clay soils, typical of the south central coast mountain range in Chile. (Ellies, 2000 in Carlos Crovetto No tillage, 2006 pg. 71)

There are steep slopes in Chile which will exaggerate the tons of erosion per year in this chart but it is good to see, for the same thing is happening on land with less slope just at a slower rate. Using tillage to correct stratification problems means that nutrients with different molecular weights settle out into different layers in the soil profile. Tillage can redistribute these nutrients in the root zone.

Don Schriefer's, six tillage commandments; author of *Agriculture in transition*

- A tillage system must not be allowed to place limits on crop yields.
- A tillage system must address the problems of spring compaction, with the ultimate goal of eliminating most spring pre-plant operations.
- A tillage system must guarantee a conditioned seedbed that will provide the environment for a good start, rapid root expansion, and uniform emergence and stands every year.
- A tillage system must either directly or indirectly manage soil aeration, soil water and crop residue in a manner that will nurture soil life and conserve and build the soil system.
- Every tillage operation within the tillage system must be done with the purpose of removing one or more yield limiting factors.
- A tillage system must address the potential problem of nutrient stratification and contain safeguards to evaluate and prevent this condition from becoming yield- limiting.

Disadvantages to tillage are:

- Carbon lost to the atmosphere from soil and exhaust.
- Compaction and hard pan layers.
- The expense of equipment and extra passes across field.
- Destruction of soil organisms.
- Temperature of soil surface too hot when black in some cases.
- Soil erosion and leaching of nutrients.
- Generally poorer infiltration rates.

Organic Matter and Carbon in Our Soils

An acre of soil measured to a depth of one foot weighs approximately 4 million pounds, which means that 1 percent organic matter in the soil would weigh about 40000 pounds per acre and contain roughly 20000 pounds of carbon. Since it takes at least 10 pounds of organic material to decompose to 1 pound of organic matter, roughly it takes 400000 pounds (200 tons) of organic material applied or returned to the soil to add 1 percent stable organic matter (40000 pounds) under favourable conditions.

How much has been lost? Research indicates that organic matter content in the prairie regions of the United States and Canada have declined between 50 and 90 percent since the land was first cultivated. Let us look at an example. Because organic matter converts to carbon dioxide, the organic matter in the top foot of soil on a conventionally managed Iowa cornfield has decreased from 10 percent to 5 percent. How much soil carbon has been lost? How much CO2 has been released into the atmosphere? A reduction of 5 percent organic matter equals 50 tons of soil carbon (100000 pounds) lost to the atmosphere. When oxidized, these 50 tons of carbon are equivalent to over 180 tons of atmospheric carbon dioxide released from a single acre! There are millions of acres of farm land in the United States, Canada and other countries of the world that have seen a five percent decline in total soil organic matter content due to conventional tillage practices. Mike Amaranthus, Acres USA, 2008.

If indeed tilling is essential (even no-tillers need to cut the soil to put the seeds in the ground) and carbon is the basis of all organic life on earth, then one should consider sequestering the CO_2 that comes out of the smoke stack on tractors as food for soil organisms. That is just what Gary Lewis, the founder behind N/C Quest has done. With each pass over the field Gary and now I put down 5% CO_2 some NOX, NOX2, NOX3 and oxidized minerals and oxidized heavy metals. To date Gary has been charging a $15,000.00 license and proprietary fee for his idea. He can set a tractor and tillage implement up with a cooler and fan system with pipes on the shanks to deliver the exhaust to the soil in a form that will not gas off but adhere to the soil. If the exhaust is not cooled down it will gas off and not have any affect. The whole system today will cost about 30 to 40 thousand dollars on an air seeder and is justified with soil health and reduced fertilizer costs. Other parameters in the soil must be met to make sure the soil is healthy when deciding how much fertilizer to cut. The system has had different results with different soils. Some positive results have had base saturation increases in calcium and available phosphate increase as well.

Drilling oil from the ground and burning it into the atmosphere is causing a build up of CO_2, a significant green house gas. Sara Wright, a scientist from the University of California at Riverside, did a three year study on a semi arid shrub and a six year study on grasslands with controlled CO_2 levels at 670ppm CO_2 (the predicted atmospheric level for the mid to late 21 century). Mycorrhizae hyphae grew three times as long and produced 5 times as much glomalin as fungi at today's ambient level of 370ppm in the atmosphere. If carbon is the basis for all life and the population keeps growing at the current rate. We may need that carbon out of the ground and sequestered by healthy biologically active soils to grow healthier, more nutritious plants to feed the population.

According to the International Food Policy Research Institute, an estimated 10 million hectares of cropland worldwide are abandoned due to soil erosion and diminished production caused by erosion. They estimate another 10 million hectares are critically damaged each year by salinization, in large part because of irrigation.
The above statement answers my earlier question about declining soils and health in the 21st century. We have depleted our carbon bank account in the soil. It is possible to turn around the trend of decreasing organic matter. No-till farmers have already recorded increases in organic matter. During a full growing season in Ontario a hectare (2.47 ac) of corn removes about 22 tons of CO_2 from the air. (chemcorp,1992)http://www.ontariocorn.org/envt/envclim.html.

Farms that have vegetables in the rotation that need to be mechanically lifted from the soil or organic farmers that need to control the weeds in the rotation have a greater need for tillage. Farms with ample rain or irrigation see less effects of tillage but could save money and carbon by going to no-till. These farms might need to manage the rotation with legumes for nitrogen needs and excessive trash concerns. Proponents of tillage argue that only dry land and certain soil types are appropriate for no-till, but most reasons for tillage are remedied over time with no-till and proper rotation while saving money. After being in Argentina and Chile and experiencing the confidence and evidence in no-till, were I not growing potatoes, I would gear my farm and rotation up for no-till. Unfortunately with our 4 year rotation we and all the farmers we trade land with get put back to the beginning stage of no-till farming every four years when we till the land for potatoes, which we plant 6 inches deep and then lift all soil above those 6 inches to harvest the potatoes.

Organic and Biological Farming

Organic farming is the production of food without any synthetic fertilizers or pesticides, genetically modified organisms, or the residues of these in the soil. For produce to be labelled organic it must be certified by a government recognized organization. Biological farming uses the same principles as organic farming but may not have met all the criteria to be certified organic. Organic and biological farming use the natural potential of plants and soils to try to optimize production. Many of the methods used here can also be used in conventional and no-till farming. The table below illustrates how different farming practices and soil amendments increase soil carbon content.

Soil Carbon Sequestration Estimates

(Data Projected from Rodale Long-term Trials & Literature Values)

Practice	Soil Carbon Sequestration (lbs./acre)
Compost	890 to 1780
Cover Crop	715 to 1070
No-till	90 to 450
Rotation	0 to 180
Manure	0 to 180
Cover + Rotation	800 to 1250
Comp. + Cover + Rotation + No-till Proj.	1800 to 3600

Carbon Sequestration & emissions under Three Systems

(Pounds / acre / year)

Parameters	Conventional No-Till (1)	Cover Crops Till (2)	Biological No-Till (3)
Gross Carbon Sequestration	+294	+891	+1185
Carbon Emissions	-132	-70	-53
New Carbon Sequestration	+162	+832	+1132
Gross C-seq. Ratio	1	~3	~4
Net C-seq. Ratio	1	~5	~7

(1) Meta-analysis of conventional no-till west and Marland, 2002.
(2) Hepperly, 2003, Pimentel, et al. 2005, Teasdale, et al. 2007 and Veenstra, et al. 2006
(3) Value projected using on additive model for carbon sequestration and input adjustments based on the system requirements.

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The above tables display that through management decisions and soil amendments we can increase stable carbon in the soil (carbon comprises 50 % of soil organic matter on average). The top table shows, in the bottom column, how a medley of composting, cover crops, rotation, and no-till can be very effective in ultimately increasing soil organic matter levels.

On an acre foot of soil, 1 percent organic matter is comprised of about 5 percent nitrogen, equalling 900 pounds per acre. This equates to 20 to 30 pounds of nitrogen per year that becomes available to the plant as well as 4 to 7 pounds of phosphorus and 2 to 3 pounds of sulphate.

http://www.noble.org/Ag/soils/OrganicMatter/Index.html.

Numerous consultants will describe the soil organic matter as the farmer's bank account. This bank account has subtle transactions. The withdrawals (depletion of carbon) take years to notice. If more money is spent on fertilizer due to lack of SOM and yield is the measurement, there is probably no difference. If SOM levels are 10 percent there should be 200 to 300 pounds of available N, 40 to 70 pounds of P, and 20 to 30 pounds of sulphate. That is a good fertility starting point for most crops.

The Reams nutrient chart is commonly used by organic farmers as a starting point for soil management. There are some key ratios to observe: at least 7: 1 calcium to magnesium ratio is important for plant health, reduction in soil compaction, and nitrogen availability. A less than 2: 1 ratio of phosphate to potash for row crops and a 4: 1 for forage crops is desired for maximum crop production, crop vigour and a suppression of broad leaf weeds, insect, and disease pressure. These recommended ratios are a guide and may need tweaking to fit certain soils. Having the chemistry balanced in the soil is a sound foundation to start to propagate desired biology.

Carey Reams suggests the following for a minimally balanced soil:

- Calcium 2000 – 4000 Lbs.
- Magnesium 285 – 570 Lbs.
- Phosphate 400 Lbs.
- Potash 200 Lbs.
- Nitrate nitrogen 40 Lbs.
- Ammonium nitrogen 40 Lbs.
- Sulfate 200 Lbs.
- ERGS 200 – 600 micromhos
- pH 6-7
- Sodium 20-70 ppm

The test method to measure the soil nutrients in the chart above, developed by Carey Reams is the lamotte testing kit and the Morgan procedure.

Here is a brief explanation of ERGS and pH. ERGS is energy released per gram of soil, ERGS relates to electric conductivity of the soil. Carey Reams developed a graph that shows where plants ERGS should be during the growing season (Dr. Arden B. Andersen 2000).

pH is the negative log of hydrogen (H+) activity in an aqueous solution. To put this into perspective a 6 pH soil has 10 times more hydrogen ions than a soil with a pH of

7 and a soil with a pH of 5 have 100 times more hydrogen ions than a soil with pH of 7. Hydrogen activity increases as pH decreases. The greatest amount of nutrient exchange is able to take place at a 6 to 7 pH. Obviously, many farming areas do not have soils in this PH range, but the rhizosphere (the plant's root growing zone), creates its own pH with plant exudates and soil organism secretions.

Compost

Compost can come from countless different sources (manure, yard wastes, phone books, straw, fish, saw dust, leaves, dead animals—anything that once grew and is now dead). Any of these sources, properly managed, can end up as a beneficial soil amendment (Midwest Biosystems manual, 2006). I took a 3 day composting course with Midwest Biosystems which was based upon the Luptke composting method. This composting method measures the amount of CO_2, temperature, and moisture to see when and how often your compost row should be turned using a special compost turner that adds air while turning and moves product without pulverizing the compost. An inoculant is added for each of the three stages of composting. The first stage involves breakdown of organic matter where ammonia (NH_4) is converted to nitrites and then nitrates. In the second stage or "humus build up stage", the simple compounds from the organic matter breakdown and are re-synthesized into short molecular chain humic substances. The third or stabilization stage, short molecular chain humic substances extend to become long chain varieties, volatile substances are stabilized and the microbial population expands.

The reason to measure the CO_2 in the pile is to ensure the pile has not gone anaerobic, killing the organisms necessary to carry out the three stages discussed. The temperature is measured and kept between 130 and 150 F – too hot and the microbes necessary to stabilize compost will be killed off and not warm enough will allow weed seeds and pathogens to survive.

Adding minerals and nutrients to compost can increase the availability of that mineral or nutrient to the plant by 5 to 100 times compared to directly applying the mineral or nutrient to the soil. When the compost is stabilized, minerals and nutrients bonded to sites on these long humic chains prevents the minerals and nutrients from leaching through the soil, gassing off into the atmosphere, and tying up with one another or other molecules that could render them unavailable. From a chemical standpoint this is beneficial to the plants, as the plant can access these nutrients by creating the right chemistry in the soil through plant exudates and the promotion of helpful soil microorganisms. Humus's nutrient holding sites are great for plant availability. This organic form of mineral availability is much better for the plant than petroleum based fertilizers as it is self governing, you can have large amounts of mineral in an organic form that will not burn crops for it will not be available until the plant decides to exude the proper substrates from its roots to get the biology working to make that nutrient available. This nutrient form is an advantage over some forms of inorganic fertilizer, as they can burn plants in too high a dose and if not used by the plant can be leached from the soil or evaporate into the air causing pollution. The compost method of nutrient delivery brings Base Saturation levels into balance, which, in turn, positively impacts the chemical structure of the soil. Humus substances also exert magnetic forces that expand clay colloids, increasing soil porosity.

A compost analysis is important to measure what amounts of nutrients are added to the soil. If the compost is high in a nutrient that is already too high in the soil the imbalance could make other nutrients in the soil unavailable. Compost is a great way to introduce biology to the soil with food sources for the organisms and plants.

Compost Teas and Compost Extracts

Organic farmers also use compost teas, and compost extracts as foliar food sprays and soil amendments. A compost tea is the brewing of a small amount of selected ingredients, one usually being high grade compost, in an aerobic water solution for 12 to 30 hours with the intent of propagating beneficial fungi, bacteria, and amoeba.

Compost tea can be difficult to brew. If the batch goes anaerobic it is no good, plenty of air and a perfectly cleaned tank is required to start with. Because of the time necessary to brew a batch it would be time consuming to cover large farms. A benefit of compost teas is being able to grow large amounts of organisms for your crops and soil from an inexpensive blend.

Compost extract is the act of forcing large amounts of aerated water through an inexpensive blend similar to the compost tea. The difference being, there is less brewing time involved. The purpose of the extract is to allow the selected organisms to multiply on their own once they have been flushed out of your blend and hit the soil. If they are unable to survive in the soil it does not matter how many are distributed on the plants or soil, if they cannot reproduce in that environment there is little fertility advantage. Both teas and extracts try to get beneficial fungi into the soil or on the leaf as fungi to bacteria ratios in agricultural soils are usually low.

Organic fertilizers

Some other fertilizers that organic growers use are:

- Sugars to stabilize liquid fertilizers and add an energy source for soil microbes.
- Liquid fish providing food for microbes, especially fungi.
- Vitamin C1, B6, B1, B2, PP, and B12.
- Kelp - a good mineral and is microbial food.
- Minute amounts of concentrated ocean water for minerals.
- Biochar – Terra Preta soil, low oxygen high heat charcoal from most organic sources – incredible soil building for poor soils.

Green Manure

Green manure is another way to fertilize and incorporate life into the soil.

Green manures can be grown to:

- Select for desired organisms in the rhizosphere and suppress others.
- Add fertility to the soil with root exudates and symbiotic relations with soil organisms.
- Control weeds through competition and allelopathy.
- Feed soil organisms with easily digestible green decaying plant material.
- Fertilize the next crop in rotation.
- Sequester carbon through photosynthesis to the soil from plant and soil organism metabolites.
- Increase biological activity.

Allelopathy refers to any process involving secondary metabolites produced by plants (plant exudates), microorganisms, viruses, and fungi that influence the growth and development of agriculture and biological systems. (International Allelopathy society, 1996). In laymen terms allelopathy is when a plant or animals excretions affect the growth of another plant for better or worse. An example would be mustard plant root exudates retarding the growth of nematodes in the soil.

Some disadvantages to green manure are; nutrients are easily leachable until they are stabilized by soil organism cycling and nutrients can gas off to the atmosphere during and after incorporation.

Cover Crops

Cover crops can be grown in any farming method. It is recommended to have crops growing on soil whenever soil moisture and weather conditions are favourable in order to steadily build biomass and SOM in the soil.

Reasons for growing a cover crop:

- Weed control.
- Increase biological activity and biomass in the soil.
- Desired allelopathy affect towards other plants and soil organisms.
- Generate fertility through photosynthesis and symbiotic relations with soil organisms.
- Aerate soil with decaying roots, increasing infiltration rates.
- Flocculate soils through photosynthesis and symbiotic relations with soil organisms and plant exudates creating better and larger aggregation.
- If the cover crop is desiccated it can serve as a weed carpet limiting weed growth for next crop and prevent moisture loss.

Organic farmers need to make optimal use of the natural systems to generate and maintain adequate fertility in the soil. All research efforts in agriculture were concentrated in this area until the discovery of synthetic fertilizer. There was a gap of about 40 years with little research done on soil organisms as most research energy was diverted to the synthetic fertilizers. Research into organic methods was revived because people became concerned about synthetic fertilizer and pesticide residuals and their side effects. Organic farming is not new as generations before had no options except for organic agriculture, so lessons from the past are being rediscovered.

Organic farmers that farm by neglect, that is switch to organic farming by just planting and harvesting with no inputs, have traditionally done poorly or failed. Without replacing the nutrients supplied by synthetic fertilizers, organic farmers will not be able to compete with today's conventional farms which have set a continually higher bar in yield production over the years. Organic farmers, farming by neglect, have generally been weeded out or are making poor returns not to mention the nutrient values of food produced are usually less then conventionally grown produce.

The outcome of this led to an innovative group of organic and biological farmers, people who understand the soil properties and biology well enough to compete at the new standard of production set in agriculture. The organic farmers of the late twentieth century had to do most of the research on their own as the mainstream crop products researched were not organic and could not be used. These trail blazing organic farmers have come a long way in a short time. New lab testing techniques, electron microscopes, new tools to use in the field, and proven practices have resulted in good yields and mineral content of the food.

Tools to Measure Good Soil Health

A refractometer is widely used in organic agriculture. A refractometer reading is accomplished by squeezing plant juice from the plant onto a small prism on the refractometer and closing a glass flap lid over top of the prism. Looking through the eye piece displays how the light refracts as it goes through the plant juice giving a good indication of the percent sucrose in the sap or degree of Brix (juice solids). For reference, pure water has a reading of “0”. Within a given species of plant, the crop with the higher refractive index will have higher sugar content, higher mineral content, higher protein content, and a greater specific gravity or density. This adds up to a sweeter tasting, more minerally nutritious food with a lower nitrate and water content and better storage characteristics. It will produce more alcohol from fermented sugars and be more resistant to insects, resulting in decreased insecticide usage. Crops with higher sugar content will have a lower freezing point and therefore be less prone to frost damage. Soil fertility needs may also be ascertained from this reading (Dr. Arden B. Andersen, 2000).

The refractometer can be used to test the effectiveness of all sprays and cultivations in the growing season to see how they impact your crop negatively or beneficially! Arden Andersen recommends spraying a test plot in the field prior to a large-scale application.

Testing the sprayed plot against the rest of the field with the refractometer will indicate if the spray increased the plant's brix reading, which is the mineral content and general plant health. Arden Andersen's book Science in Agriculture has charts that will inform you on minimum brix degrees reading needed for different crops to be healthy. When the crop is in the excellent range, most diseases will not affect it and insects will be uninterested unless a last resort and even then will not flourish.

Unfortunately, use of the refractometer is not an exact science. During the day time around 1:00 to 2:00 PM, a large amount of energy is in the leaves as photosynthesis is taking place and the brix reading is higher than at night when the plant is taking that energy down to the roots and feeding the soil organisms. The brix reading in the leaves will also be lower if it is a cloudy day. Taking all that into consideration to insure a healthy plant with proper nutrient flow the roots and stems should also be tested. The brix reading is just a snap shot in time. If the plant is weaker for a few days then disease or insects can set in and plant health becomes a downward spiral. Therefore, the plant should be tested throughout the growing season to track plant health. Knowledge of seasonal growth trends in brix readings and what nutrients are needed to keep the plant healthy is the key.

Biochar

In Brazil along the Amazon River, soil enthusiasts discovered dark soils which produced far better crops than the common tropic soils in the area. Researchers have discovered that tribes, dating back to seven thousand years ago, used to practice the burning of organic material in kilns at very low oxygen levels and very high heat, 400 to 500 degrees Fahrenheit. The product they were creating was biochar. The soils have kept the high yielding capabilities instilled by these tribes for thousands of years which is very exciting and promising for researchers and farmers alike. This substance is high in energy and carbon with lots of nutrient holding sites and very porous. There is a buzz of excitement around the world as different countries are trying to simulate or repeat this practice. So far Japan, Australia and Brazil lead the way with results between 10% and 330% yield increases. The Alberta Research council is working on creating biochar as well and the product they have made costs around $250.00/ ton. The current recommended application rate is 1 ½ tons per acre. If you search Google or YouTube for biochar there are some incredible visuals of what a difference it makes in some of the test plots in plant growth.

Conclusions

That is a brief overview of three types of farming methods. A trend I noticed on my trip and in general was the unwillingness of the different farming camps (farming methods) to learn from one another. I observed more than once conventional and no-till farmers who had their minds made up about organic farming before these words even left a person's mouth. In many cases the different farming camps seem to look for one or two reasons why another method would not work on their farm and then could go back to being comfortably content in their ignorance. To learn about and try new methods of farming is a paradigm shift and may mean leaving a comfort zone and talking about things that are new. No doubt, there will be several farming colleagues who will relentlessly question your intelligence.

The organic farmers are not exempt from this mind set. In Argentina Cesar Belloso tried to speak to the organic committee about working with no till farming and some of its benefits and they shrugged him off because of GMOs. A working relationship in this case could be just the exchange of knowledge, a bridge to something in the future that could be mutually beneficial. The organic industry often speaks ill of the big pesticide companies in the farming industry. Again burning a bridge here could squash the organic farmer's chance, at for, e.g. a pharmaceutical need for their crop or a market that the corporations can get produce in to. I know that the person who has read this far in my paper is not like that of course. But hypothetically speaking if next time one hears the word organic, instead of tuning out and only hearing bla bla bla coming out of that person's mouth open your mind and listen to what they have to say. On the other hand, if one is anti large corporation in farming try not to think of all the negatives as soon as a big corporation gets brought up in conversation. Try instead to think of the positive things one of these corporations can accomplish in the future. Lastly, if one sees no reason to try another method of farming inform oneself on one thing that you could incorporate to your method of farming. I know these methods of farming are not as black and white as I have painted them, there is overlap. I wanted my point to be effective, hopefully giving readers enough momentum to be ready for a paradigm shift if need be, ultimately, cultivating healthier soils for healthier food for a healthier population.

Food with higher nutrient density is clearly healthier for the population. Food with higher nutrient density tastes better and satisfies the body's nutrient needs with less food. When the body is being served fillers and foods with too few nutrients to supply its demand, the hunger signal will continue, adding to the obesity health problem we are faced with today.

I think many farmers have a quality farming program and are increasing their soil health. Hopefully these farmers can spread their knowledge and cut back on the millions of acres being lost to erosion and salinization. I am excited to see what we can accomplish in agriculture in the upcoming years.

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Interesting titles to search on Google and youtube

Sara Wright mycorrhizae glomalin

University of Western Australia mycorrhizae

Biochar Terra Preta

Exhaust sequestration, N/C Quest

World soil erosion rates per year

Brix testing and plant health

Contacts

People that have benefitted my Nuffield study.

Gerald Weibe	Successful organic farmer with good yields – consultant - organic fertilizer sales - Manitoba Canada
Edwin Blosser	compost course- company Midwest Bio systems - Brodhead Wisconsin
Larry Kawchuck	Microbiologist - Lethbridge research station - Developing phages a Biological control to control BBR in potatoes
Dr. Frank Larney	Compost research at Lethbridge research Station – Concentrating on feedlot manure
Howard Leffers	switching from conventional to organic farming – composting
Mark Benson	Organic farming and store – Lethbridge – Compost tea, Kelp

Jill Clapperton	Soil Microbiologist – No-till seminars – Mycorrhizae specialist, Montana
Gary Lewis	N/C Quest diesel exhaust injected into soil – CO2Xchange Carbon credits – pincher creek Alberta
Dr. Kathy Harvey	Biological farmer and vet organic dairy herd – fellow Nuffielder – Tauwitchere Narrung SA
Gustavo Gonzalez	seed Inoculants and coatings – Company Rizobacter – PHD on mycorrhizae Pergamino Argentina
Cesar Belloso	Pioneer no-till farmer – consultant – past chair Argentina no-till farmers – Part owner Don Mario – Pergamino Argentina
Fernando &George	Rogamoli - Grain elevating and storage _ on farm conference room – past Chair Argentina no-till farmers - Companion cropping Cordoba Argentina
Jim McCarthy	farms 3 9000 acre farms in Argentina which his companies in Ireland own – Past chair of Nuffield World.
Hernan Echeverria	inta gov. Ar - soluble P levels and mycorrhizae – works with N reflection tools of plant leaves – Balcarce Argentina
Daniel Caldiz	McCain Agronomist – farmers don't store potatoes McCain does Balcarce Argentina
Walter Hermandes	Frito lay grower sprays Boron-phos, Calcium Phos Manganese phos 3 x South American wrestling champion and Race car driver Mar Del Plata
Carlos Crovetto	Grandfather of No-till - show piece No-till farm wrote two books on no-till - is set up to do large tours – Chequen, Concepcion, Chile