SOIL HEALTH TECH BULLETIN II

FACT SHEET

BIOLOGICAL SOIL HEALTH TEST:

Microbial diversity is an excellent indicator of soil health (Nielsen and Winding 2002). They report that variation in microbial population or activities precede changes that can be noticed in some cases as early signs of soil degradation or amelioration. Water and nutrient supply from soil, particularly N and P, determine the plant growth both in natural and agro-ecosystems. It is important to understand that the above ground vegetation is the ultimate source of C for the microbes in the rhizosphere that, in turn, support the macro-fauna. Thus, it is important to understand that ***the above ground vegetation influences the below ground microbial community structure and soil properties*** (Orwin and Wardale 2005). A&L Biologicals research has shown that microbial populations require certain carbon sources that the plant must provide and maintain in the rhizosphere in order to sustain healthy beneficial populations of microorganisms. A&L's soil health test is designed to measure the important nutrient levels that are needed to support the plants ability to provide these essential carbon sources to feed the soil biome.

From the past few years of study on unravelling the interaction of soil & plant physical, chemical and microbial parameters on soil & plant health through agricultural innovation program research, we found some interesting interactions of microbes on soil health, overall fertility and yield. The total microbial population in the soil, root, and rhizosphere measured through plating on selective nutritional media did not show any contribution to the yield or the overall fertility. When we dissected these microbiome in subgroups such as Gram negative and positives we found some interesting facts. Gram negative bacteria such as *Pseudomonas, Rhizobium, Azospirillum* showed a strong positive correlation with the high productivity and the general fertility of the soil; thereby higher yield. Gram positive bacterial populations such as *Bacillus* species have strong positive correlation with the low productivity of the soil; thereby lower yield. Based on the in depth tests on several related aspects and findings, we developed a simple, fast, and affordable test to identify the indicators of soil health by measuring the key components. This biological test will complement the other physical and chemical soil tests to arrive at complete soil health information and for effective soil management and sustainability.

The following soil parameters influence the soil biome and from our research have a strong correlation to the relationship to the population of the indicator organisms that have a positive or negative influence on crop performance. By increasing or reducing any of these indicators based on the ranges that have been established in our field research a grower can have a direct influence on the population of these organisms in both the bulk soil and the rhizosphere. Although other cultural practices such as crop rotation and addition of organics have a strong relationship to soil quality it still requires a good balance of nutrients available to the plant to provide the proper carbon source to attract and maintain these organisms.

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SOIL HEALTH TECH BULLETIN II

In our research, we have measured the difference in these parameters in the bulk soil and the rhizosphere over the growing season when nutrients are in balance and available to the plant. This demonstrates the degree of the activity of these organisms on mineralizing nutrients in the rhizosphere making nutrients more available for plant uptake.

INTERPRETATION OF A&L SOIL HEALTH TEST

CEC

Cation Exchange capacity is a property of the soil much like pH, and is an indicator of the soils sand silt and clay content. The higher the CEC the greater the clay content of that soil. Cation Exchange capacity is also an indicator of the soils ability to hold and exchange nutrients for plant growth.

K:Mg Ratio

The ratio of potassium to magnesium comes from over 25 years of research at A&L in field crop production. Our findings over the years is that this ratio other than pH on the soil test correlates to field performance better than any other parameter on the test other then of course the general fertility index which K:Mg and pH are part of. In 2007 A&L in cooperation with Ag Canada published a paper on scab control in potato and how K:Mg in milliequivalents, relationship was the main contributor to this corrective treatment in the field. (*Edophic Soil Levels of Mineral Nutrients, pH, Cation Exchange Capacity in the Geocaulosphere Associated with Potato Common Scab Dr. George Lazarovits, Jacquelyn Hill, Greg Patterosn, Kenneth L. Conn, and Nigel s. Crump. Phytopathology 2007, 97:1071-10820*). A&L Biologicals soil health research has done extensive research on the soil microbiome and analyzing the relationship between plants and microorganisms in the rhizosphere. A&L Biologicals research has shown that beneficial organisms in soils also show a strong correlation to the K:Mg and is one of the main indicators for corrective treatment on this test to increase soil Health through beneficial microbial activity. The optimum level of K:Mg in milliequivalents is .25 - .35 for most crops and .30- .40 for potato.

GFI (A&L's General Fertility Index)

The General Fertility Index is an index algorithm developed through A&L research that is an overall calculation of field fertility based on a number of soil algorithms of the soil nutrient optimum level based on soil type. The General Fertility correlates very strong to yield and performance in fields and is used in a number of variable rate nitrogen formula algorithms developed by A&L's precision Ag group. In our Soil Health research A&L biologicals findings is that the beneficial soil organisms also correlate very strong both in the rhizosphere and bulk soil to GFI. Anything that increases the overall GFI increases the population of the beneficial microbes in the rhizosphere. The ranges of GFI Index are VL 0-35, L 35-55, M 55-65, G 65-80, H> 80

% Saturation of the Cations

Maintaining the % saturation of the cations in the optimum range for that soil type insures a better coefficient of diffusion for that element making it more available for plant uptake. The optimum % saturation of the cations is one of the factors that makes up the GFI. In our research potassium shows as an important nutrient in plant signaling and increase in population of the beneficial organisms in the rhizosphere.

SOIL HEALTH TECH BULLETIN II

Soil pH

The relationship between soil pH and the microbes:

The soil is a heterogeneous matrix with a vast diversity of physical, chemical and biological characteristics, which lead to a wide range of different niches that can sustain a large microbial diversity. Microbial communities in the soil play a significant role in soil health by regulating major biogeochemical cycles thereby controlling the major ecosystem function. Agriculture is one of the most impacting anthropogenic activities that affect soil properties and consequently their function. Soil pH is the one of the main factors, largely affected by chemical crop inputs which influence the nutritional availability, crop growth and microbial diversity. There is a unique pH range where different microbes selectively colonize and multiply in soil. Bacteria prefers (pH 5-9), Actinomycetes (pH 6.5 - 9.5), Fungi (pH 2-7), Blue green bacteria (pH 6-9). In the same way, pathogenic microbes are dominant in certain pH range. In general, lower pH favors the fungi and higher pH favors the majority of the bacteria, the increase/ decrease of the fungal or bacterial density is fivefold in the lower or higher pH respectively. Among the bacteria, Gram positives the “Actinobacteria” (*Actinomyces, Bacillus, Enterococcus, Streptomyces*) are stronger, have bigger cells, have thicker cell walls, have the capacity to produce endospores and survives in wider a pH range, drought, water stress and metal toxicity conditions. But Gram negatives the “Proteobacteria” (*Acetobacter, Azospirillum, Burkholderia, Enterobacter, Flavobacterium, Klebsiella, Nitrobacter, Pseudomonas, Pantoea, Rhizobium, Rahnella, Serratia, Thiobacter*) are the majority of the beneficial soil bacteria, are small and sensitive to extreme conditions, survive near neutral pH, which is vastly replaced by resilient “bad bugs”. Quick changes in pH in any medium, will significantly affect the “good bugs”. By providing conducive environment for the “good bugs” thereby building up its abundance and diversity, one can keep the pathogenic organism under suppressive condition, conserve nutrients from wastage and enhance soil health & sustainable productivity.

EC, ms/cm

Soluble salts are the total dissolved salts in the root substrate (root medium) at any given time and is measured by electrical conductivity (EC). Most fertilizer materials, except urea, contribute to the EC content of the medium, and the most common are nitrates (NO_3), ammonium (NH_4), phosphates (P_2O_4), potassium (K), calcium (Ca), Magnesium (Mg), sulfates (SO_4), sodium (Na), bicarbonate (HCO_3) and chlorides (Cl). Organic materials (i.e. urea) also contribute to the EC content after they have been changed from an insoluble to soluble form. In some areas, irrigation water can elevate substrate EC levels. One must be aware of substrate EC levels because excess salts can accumulate when leaching during irrigation when too much fertilizer is applied or when the irrigation water contains a high amount of dissolved elements. Excessively high EC readings are associated with poor plant growth. If the soil is allowed to dry down, plants may exhibit wilting symptoms because of root tip dieback due to salt injury. When substrate EC is too low, plant growth may be also effected from lack of fertilizer.

SOIL HEALTH TECH BULLETIN II

Sodium (%Na)

Sodium is part of the total salts and is very harmful to plants. On the soil report we want sodium to be low and less than 1% saturation. Sodium background levels for soils is 0.5% and at this level causes no problem for plant growth, plants can tolerate up to 1% in soil or media. Above 1% sodium starts to create problems with germination and growth of plants. Some plants can tolerate higher level of sodium but in general sodium greater than 1% becomes a problem with growth. Sodium levels can be at a level that creates production issues, tightens up soils, reduces plant growth and usually results in more weed pressure but EC levels are still OK. These two parameters should be evaluated separately.

Saturation of %P *–(see A&L's tech bulletin 565 on %P)*

In all life processes uptake and conversion of phosphorus is a driving force to cell energy and functioning. Soils with low phosphorus saturation have also shown to have more weed persistence and where potassium levels are high increased herbicide resistant weeds will prevalent. The %P is the relationship to the amount of phosphorus that is in the soil and how much is available for plant uptake. This indicator is based on over 18 years of research work done by researchers in North America which A&L has participated. The latest work on %P *"Determination of some key factors for Ontario soil P index and effectiveness of manure application practices for mitigating risk to water resource"* was published in (*Relationships between various soil extractable phosphorus and phosphorus saturation estimations and their indications on soil P losses. Wang, Y.T., T.Q.Zhang, I. O'Halloran, Q.C.Hu, C.S. Tan, K. Reid, D. Speranzini, I, Macdonald, and G. Patterson, published in 2009*).

Saturation of %AL^{3+}

The degree of Al^{3+} in the soil has a marked effect on overall plant growth as well as interfering with phosphorus uptake. Al^{3+}, impacts the root cap directly and has a major effect on the mucigel secretion from the root tip which also influences the make up of the compounds redeposited in the rhizosphere that feeds the microbiome. Some plants are tolerant to Al^{3+} but in all cases Al^{3+} above 1% on the exchange complex effects root growth and interferes with phosphorus availability.

Micronutrients in Soil

The micronutrients in soil although required in smaller amounts than major and macro nutrients are just as important for plant growth. In our A&L Biological research it was also demonstrated that they have an impact on soil microbial activity and although the correlation for most was not as high as some of the other parameters it was partly due to the data set we have so far. Zinc and copper for the most part where low in the sample set and did not show strong correlation and Iron and Manganese both showed optimum levels in the data set and no differences between data points so it was difficult to establish any degree of differences in microbial activity from this data. However, Boron did show a strong correlation in our research in particular to Rhizobium bacteria both in legume and non legume plants. This has also been found in other research on the role that boron plays in signaling for Rhizobium and the maintenance of Rhizobium in both the rhizosphere and in the plant (*Boron deficiency results in induction of pathogenesis-related proteins from the PR-10 family during the legume-rhizobia interaction, Maria Reguera, Ildefonso Bonilla, Luis Bolanos, Journal of Plant Physiology 167 (2010)*).

SOIL HEALTH TECH BULLETIN II

Chloride, ppm

Chloride for a long time has been confused with Chlorine in production agriculture and has got a bad rap. Chlorine is a very hazardous compound to plants, soil microbes and humans alike however Chloride is an essential plant nutrient and required for optimum growth. Chloride soil levels should be greater than 12 ppm and in the case of cereals the critical level is 15 ppm. Cereals will respond to up to 30 ppm of chlorides in soil and it will have a substantial impact on the reduction of leaf rust in cereals. Levels for Chlorides in soils are Very Low 0-7, Low 8-15, Medium 16-22, High 22+.

Nitrogen

Nitrogen is necessary for life on earth to continue and the nitrogen cycle is one of the most important nutrient cycles in terrestrial ecosystems. Everything that lives needs nitrogen; it is required for the manufacture of complex molecules such as chlorophyll, proteins and DNA, and the production of enzymes necessary for growth, reproduction and other vital functions. However, when present in excess, nitrogen poses risks both to the environment and human health. A&L Biological research on soil health shows a direct correlation to available N in the soil.

Total N: This number is the total N from the water extract from your soil (in ppm). It contains both inorganic N and organic N sources from your soil.

Inorganic N: This is the combined amount of plant available forms of inorganic N (NO_3-N plus NH_4-N). NO_3-N is the form of N that is easily lost from soil through surface runoff, subsurface leaching, erosion, and in water logged conditions it can revert back to a gas. NH4-H is usually quickly converted to NO_3-N by soil microbes but is less susceptible to leaching. The majority of inorganic soil N is in the NO_3-N form.

Organic N: Organic N is the total water extractable N minus the total water extractable inorganic N in ppm. This form of N should be easily broken down by soil microbes and released to the growing plant providing minimal chance of loss since the N is bound in large organic molecules. This pool represents the amount of potentially mineralizable N in your soil.

Water Extractable Organic Carbon and Water Extractable Organic Nitrogen

We have been talking about carbon in the soil for quite some time now and it only makes sense to come up with a good way to measure it. In our A&L's new Soil Health Test we are also offering a water extractable carbon and nitrogen test. The combination of this with the organic matter percentage will not only tell us the potential carbon in the soil but also the quality of that carbon. A large percentage of organic matter in the soil is just not enough. You need quality organic matter for biological activity.

Water extractable organic N (WEON): This number is the amount of the total water extractable N minus the inorganic N (NH_4-N + NO_3-N). This N pool is highly related to the water extractable organic C pool and will be easily broken down by soil microbes and released to the soil in inorganic N forms that are readily plant available.

SOIL HEALTH TECH BULLETIN II

Water extractable organic C (WEOC): This number (in ppm) is the amount of organic C extracted from your soil with water. This C pool is roughly 80 times smaller than the total soil organic C pool (% Organic Matter) and reflects the energy source feeding soil microbes. A soil with 3% soil organic matter when measured with the same method (combustion) at a 0-3 inch sampling depth produces a 20,000 ppm C concentration. When we analyze the water extract from the same soil, that number typically ranges from 100-300 ppm C. The water extractable organic C reflects the quality of the C in your soil and is highly related to the microbial activity. On the other hand, % SOM is about the quantity of organic C. In other words, soil organic matter is the house that microbes live in, but what we are measuring is the food they eat (WEOC and WEON).

Organic C:Organic N Ratio: This number is the ratio of organic C from the water extract to the amount of organic N in the water extract. This C:N ratio is a critical component of the nutrient cycle. Soil organic C and soil organic N are highly related to each other as well as the water extractable organic C and organic N pools. Therefore, we use the organic C: N ratio of the water extract since this is the ratio the soil microbes have readily available to them and is a more sensitive indicator than the soil C:N ratio. A soil C:N ratio above 20:1 generally indicates that no net N and P mineralization will occur, meaning the N and P are "tied up" within the microbial cell until the ratio drops below 20:1. As the ratio decreases, more N and P are released to the soil solution which can be taken up by growing plants. We apply this same mechanism to the water extract, as the C:N falls; we credit more N and P mineralization on a sliding scale. We like to see this number between 8:1 and 15:1. The C:N ratio is also used in calculating the Soil Health number.

Solvita ® 1-day CO_2-C:

This number in ppm is the amount of CO_2-C released in 24 hours from soil microbes after your soil has been dried and rewetted (as occurs naturally in the field). This is a measure of the microbial activity in the soil and is highly related to soil fertility. In most cases, the higher the number, the more fertile the soil.

Microbes exist in soil in great abundance. They are highly adaptable to their environment and their composition. Adaptability, and structure are a result of the environment they inhabit. They have adapted to the temperature, moisture levels, soil structure, crop and management inputs, as well as soil nutrient content. In short, they are a product of their environment. If this were not true they most likely would have died out long ago, but they didn't. Since soil microbes are highly adaptive and are driven by their need to reproduce and by their need for acquiring C, N, and P in a ratio of 100:10:1 (C:N:P), it is safe to assume that soil microbes are a dependable indicator of soil health. Every organism on this planet requires Phosphorus to produce ATP which is the driving force of all living cells. It is clear carbon is the driver of the soil nutrient-microbial recycling system and much of this carbon that these microbes depend on comes from the redeposition of carbon into the rhizosphere from plants. This consistent need sets the stage for a standardized, universal measurement of soil microbial activity. Since most soil microbes take in oxygen and release CO_2, we can couple this mechanism to their activity. It follows that soil microbial activity is a response to the level of soil quality/fertility in which they find themselves.

SOIL HEALTH TECH BULLETIN II

Potential Mineralizable Nitrogen (PMN)

Nitrogen is one of the most important nutrients that beneficial microbes make available to plants. The PMN test isolates those microbes that transform nitrogen from the organic form to plant available ammonium and nitrate (mineral) forms. This potential mineralizable nitrogen (PMN) by the Solvita CO_2 Burst test results assesses how this previously unmeasured organically bound N pool can help decrease fertilizer costs by more efficient understanding of this Nitrogen pool. This is only a gauge of your soil's potential to release nitrogen in a plant available form. It does not take into account, the many ways nitrogen can be lost from your soil during the growing season. This is also a measurement of organic matter quality in terms of nitrogen content and carbon/nitrogen balance, both of which affect nitrogen release characteristics of your soil.

Reactive or Active Carbon

Active Carbon also known as Reactive Carbon is more complex than the Labile Carbon in that its composed of all the dead and actively decomposing organic matter plus all the living soil microbial community that will eventually die and begin decomposing. For example, the hyphae of mycorrhizae only live about 5 to 7 days before they die and start to decompose, while the fungus organism itself may live far longer.

Many soil functions are strongly influenced by organic matter and, due to its association with total organic carbon and microbial biomass, are likely to be related to reactive carbon as well. Soil climatic conditions for example soil moisture and temperature have a pronounce effect on the mineralization rates of organic carbon and the accumulation or decline of the quantity of reactive carbon in soil organic matter. Poor drainage creates an anaerobic condition that favours the formation of methane inducing a loss of carbon and decline in total organic carbon and reactive carbon. Reactive carbon is linked to a number of soil processes, including microbial biomass growth and activity and nutrient cycling.

Reactive carbon changes in soils can happen very quickly and a significant decrease in reactive carbon may signal a decline in soil organic matter and indicate the deterioration of physical, chemical, and biological properties and processes related to soil organic matter. The adverse effects caused by the decline in reactive carbon include reduced aggregate stability, increased bulk density, and reduced water infiltration, water-holding capacity, microbial activity, and nutrient availability.

Reactive Carbon ranges based on the Cornell Assessment of Soil Health in ppm of Active Carbon for a medium Textured soil are Very Low 0-400, Low 400-500, Medium 500-600, High 600-700 and Very High >700.

Microbial Active Carbon

%MAC – microbial active carbon is a measurement of how efficiently your soil microbes are using the carbon you are providing and can track the effects of changes in management and the impact of crop rotation and cover crops plus other soil amendments.
%MAC = (Solvita 1 day burst CO_2/Organic Carbon) x 100

SOIL HEALTH TECH BULLETIN II

Soil Health Index

The soil health Index which is an algorithm that has been developed by A&L Canada and is a scale from 0 – 60.

Soil Health Score as calculated by NRCS-(USDA -National Resources Conservation Services

This score as determined by NRCS includes the 24 hour Solvita CO_2 Busrt, the water extractable organic carbon, and the water extractable organic Nitrogen in an equation as follows.

1) Solvita (CO_2 Burst)/C:N + WEOC/100 + WEON/10 = Soil Health Score
   68.6/10 + 210/100 + 14/10 = 10.36 (NRCS Soil Health Scores are from 0 – 50) Soil health Score should be greater than 10.
2) Solvita CO_2-C/C:N should be greater than 4
3) Organic Carbon:Organic Nitrogen ratio; This is a unitless result comparing the amount of water extractable carbon to water extractable organic nitrogen (C:N ratio). The ratio is important in microbial activity in the mineralization of nitrogen and phosphorus. The optimal ratio is between 8:1 and 15:1. As with other nutrient analysis in our A&L Biological research available nitrogen in the rhizosphere also showed a strong correlation to beneficial microbial activity.

Residual Soil Chemistry Index

This index is a measurement of the residual soil chemistry that could have an effect on the biological activity in the bulk soil and the rhizosphere. This index has been developed by A&L Canada based on the findings of our field research and the relationship that certain residual chemistry has on the soil biome. The use of this index is so that the grower can evaluate pesticide use practices and analyze if the product choice and rotation of compounds is effective. Residual chemistry may also be due to pH being too low or too high for the products being used. A&L's findings have also shown that soil microorganisms are very resilient and can withstand almost any amount of residual chemistry if the Soil Health Index is in the high range.

This index however is not a measurement of carry over chemistry that could cause crop injury due to the amount of product remaining in the soil. If there are concerns over crop sensitivity to residual chemistry for crop rotation A&L can perform specific analysis to determine the crop safety factor.