THE SENSITIVE SIDE OF OUR SOILS

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Soil is a sensitive and living natural resource linked to everything around us. Microorganisms are found in extremely high numbers in soil habitats, with bacteria reaching numbers of 10^6-10^9 per gram of soil. Indigenous soil microorganisms are present in unique microenvironments favouring their optimal survival and nutrient cycling. With an increasing demand to grow more food on soils that have been mismanaged for millennia, it is clear that the responsibility lies with us to look after our soils.

Air, water and soil is our continent's most valuable natural resources, but soil is the only non-renewable resource. With the natural formation rate of approximately 6-8 cm of fertile soil over a period of 2,000 years, this is not surprising.

Paradigm shift

Traditionally, soil has always been seen/treated as a "dead" medium with the sole purpose of keeping our planted maize, wheat, leguminous crops, and vegetables upright. What very few people realize, is that soils also filter out pollutants from water, as the water filters down to underground water-tables. Soils can even store up to 9,000 tons of water in a 0.4 hectare piece of land (https://www.quickcrop.co.uk/blog/top-10-interesting-facts-about-soil/). Our precious soils have been subjected to annual planting of the same crop on the same piece of land, continuously ploughed, and crop residue either removed by cattle, or burned after harvesting. These practices have left valuable topsoil bare and unprotected – vulnerable to being blown away by windstorms and carried away during rainstorms. Keeping in mind that 10 tons of topsoil spread evenly over one hectare is only 2.35 mm thick, it is astounding to realize how much topsoil is actually lost; consequently leading to huge crop losses due to unproductive soils.

The Green Revolution of the late 1960's, aimed at increasing global agricultural production resulted in increased use of pesticides, herbicides and fertilizers. The increased use of chemicals may have saved billions of people from starvation, but today, the quality of our soils have declined to such a state of "fertilizer addiction", that it cannot function properly without the addition of more fertilizer. As a result, declining crop yields are accompanied by increasingly resistant soil borne plant diseases and pests. Fortunately, unproductive soils can be rehabilitated through the adoption and implementation of the three interlinked principles of Conservation Agriculture (CA) in Africa: no or minimum soil disturbance, permanent soil mulch cover, and crop diversification. From an agroecological perspective, healthy soils form the foundation of food production in successful agriculture.

The soil's living component

Healthy soils are composed of countless living creatures. Unfortunately, we are only familiar with the pests and diseases destroying their crops. What we fail to realize, is that a healthy soil contains both good and bad organisms – all co-existing in a very fine balance. Some of these organisms, such as earthworms, can be seen with the naked eye, but the biggest living component of the soil can only be seen through a microscope and are called microorganisms. This microscopic component consists of bacteria, fungi, yeasts, nematodes and several other kinds of organisms. Each of these soil organisms, big and small, has to fulfil its own specific and very critical role in the functioning of the soil. As soon as this balance is disturbed through tillage, monocropping, use of agrochemicals, and overgrazing, the functioning of the soil's ecosystem is impacted negatively.

Were you aware that eight teaspoons of healthy soil may contain more bacteria than there are currently people on the earth? Besides the approximate 5,000 different kinds of bacteria found in one gram of soil, there are also almost 1,600 meters of fungi-threads ("fungal hyphae") in a teaspoon full of soil. Although bacteria cannot be seen with the naked eye, the weight of all the bacteria in a 0.4 hectare patch of soil can be equal to the weight of one or even two cows!

Functioning of the soil

A healthy soil consists of 45% minerals, 25% air, 25% water, and 5% organic material per volume of soil. This composition of elements, if maintained, can provide adequate nutrients to plants and other life in the soil ecosystem. As we know, CA is an environmentally friendly approach aiming to restore the natural balance in soil which will ultimately increase and sustain high crop yields.

So, what is meant by "to restore the natural balance in soil"? As mentioned earlier, good (beneficial) and bad (pathogenic) soil (micro-) organisms co-exist and collaborate in a very fine balance in the soil ecosystem. In a healthy and well-balanced soil, the beneficial microorganisms maintain the amount of pathogens below a dangerous/infectious level. As soon as this fine balance is disrupted through agricultural practices such as soil tillage, monocropping, and the excessive use of fertilizers, herbicides and pesticides, the beneficial microorganisms are usually suppressed, while the pathogens then dominate the soils, resulting in high levels of plant diseases.

The effect of CA practices on soil microorganisms

Soil microorganisms do not only obtain their nutrients from decomposing plant material, but also from plant root exudates. These exudates contain various amounts of different carboxylic acids, carbohydrates, amino acids, etc., depending on the type of plant, growth stage, and even the cultivar. Since soil microorganisms are very energy-efficient, different microorganisms will be attracted to different carbon sources that they are well-adapted to utilize rapidly. By implication, as the carbon sources change, so will the composition of the microbial community – influencing the diversity of the microbial community, as well as the nutrient cycling process. Therefore, by planting a wider variety of crops as part of a rotation or intercropping system, a more diverse microbial community is stimulated to conduct more functions simultaneously in the soil ecosystem. Apart from the decomposition of plant material, various microorganisms have the ability to produce chemical compounds, such as antibiotics and other anti-microbial chemicals, to inhibit pathogens and favour beneficial microorganisms, while others produce chemical compounds to stimulate plant root growth. Monocropping/monoculture, unfortunately, has the opposite effect. Since the same crop is planted annually on the same piece of land, the microbial communities lose their diversity and become highly specialized due to the continuous supply of the same carbon sources. As a result, some of the microorganisms with the ability to produce the anti-microbial compounds are absent, creating the perfect environment for pathogens to thrive without competing with other microorganisms for the same food supply. Through crop rotation, this disease cycle is broken, since the food source that the pathogen was used to, is suddenly absent, and replaced by a totally different food source that the pathogen is not used to, and it is suppressed – either by anti-microbial compounds produced by the new set of microorganisms being stimulated by the new food source, or the pathogens are simply out-competed.

Figure 1. Wheat monoculture under conventional soil disturbance. Note the absence of plant material on the soil

Figure 2. Wheat monoculture without soil disturbance. Note the presence of plant material on the soil surface

Soil structure is also improved by planting different crops with different root systems and structures that "break up" the soil structure as it grows through the various soil layers. Root exudates are consequently available in the deeper soil layers, thus increasing soil fertility by

Figure 3. Crop diversification: medic-clover mixture rotated with wheat under no soil disturbance. Note the presence of plant material.

Figure 4. Maize-cowpea intercropping under minimum soil disturbance

attracting soil microorganisms to increase nutrient cycling. The topsoil is kept cool by sustaining a soil surface cover with mulch, thus reducing evaporation to a minimum. Under these favourable conditions, the growth of fungi (mainly) and bacteria responsible for decomposition, are stimulated. As plant material is shredded into smaller pieces by ants, termites and other insects, the shredded pieces are then carried into the deeper layers of the soil profile by the same insects, as well as by earthworms. Fungi and bacteria are mainly responsible for decomposition of plant material, thus breaking the complex molecules of the plant material into smaller simple elements which are more easily utilized by microorganisms as a food source. In this way, the soil microbial communities are responsible for the mineralization process in soil ecosystems by unlocking the nutrients in organic matter and releasing it into the soil in plant-accessible forms.

It is thus obvious that the soil ecosystem is finely integrated and working harmoniously to ensure the optimal functioning of this "underground factory". Unfortunately, by ploughing the soil, this whole "factory" is significantly disrupted. With this physical process of overturning the soil, the microorganisms working optimally in the deeper soil layers under conditions of limited oxygen and sunlight, are suddenly exposed to conditions abundant in oxygen and sunlight. Similarly, microorganisms working optimally in the topsoil under conditions of sufficient oxygen and sunlight, suddenly have to survive under conditions of limited oxygen and sunlight. In the human world, it is similar to taking an experienced fisherman who is used to spending days on a boat on the wide open waters of the ocean, and forcing him/her to become a farmer who has to work daily with lots of soil and dust and very little water. Fungi, responsible for decomposition of plant material after harvesting, are destroyed during tillage, thus slowing the decomposition process. Earthworm tunnels, that allow oxygen and nutrients to flow into the deeper soil layers, are destroyed, and functioning microbial communities are completely disrupted. Consequently, it is going to take some time for the microorganisms to re-organize themselves to function optimally again.

How is soil health/fertility determined?

For decades, soil physical-chemical analyses have been used to determine the health/fertility status of soils. Although this practice is not incorrect, it does make more sense to rather look at the more sensitive indicators such as the soil microorganism, due to their extreme sensitivity to any disruptions/changes in the soil environment. When we, as humans, feel unwell, we would like the doctor to test our most vital signs first to look for something wrong, isn't it? We don't want them to test our bone density if we have the flu – they should test our temperature and heart rate first, since these are more sensitive indicators of flu infections. When a doctor is uncertain of the nature of the illness, he/she cannot conduct only a single test to determine the nature of the illness; he/she has to conduct a whole set of tests/analyses! The same applies to soil microbial tests/analyses: it is impossible to determine the health/fertility status of a soil by conducting a single analysis. It is strongly recommended that soil samples are sent at least two to three times a season over a period of at least five years for microbial analyses. Since a healthy soil is characterized by a high diversity of soil microorganisms that are actively busy cycling nutrients, soil microbial analyses will determine the changes in diversity and activity of soil microbial communities over time, providing an indication of improving or declining soil fertility. Frequent analyses of samples collected over an extended period of time will minimize the influence of seasonal fluctuations on microbial data, and enable the soil microbiologist to attain a more complete reflection that the various agricultural practices might have on soil microorganisms as indicators of soil fertility and health.

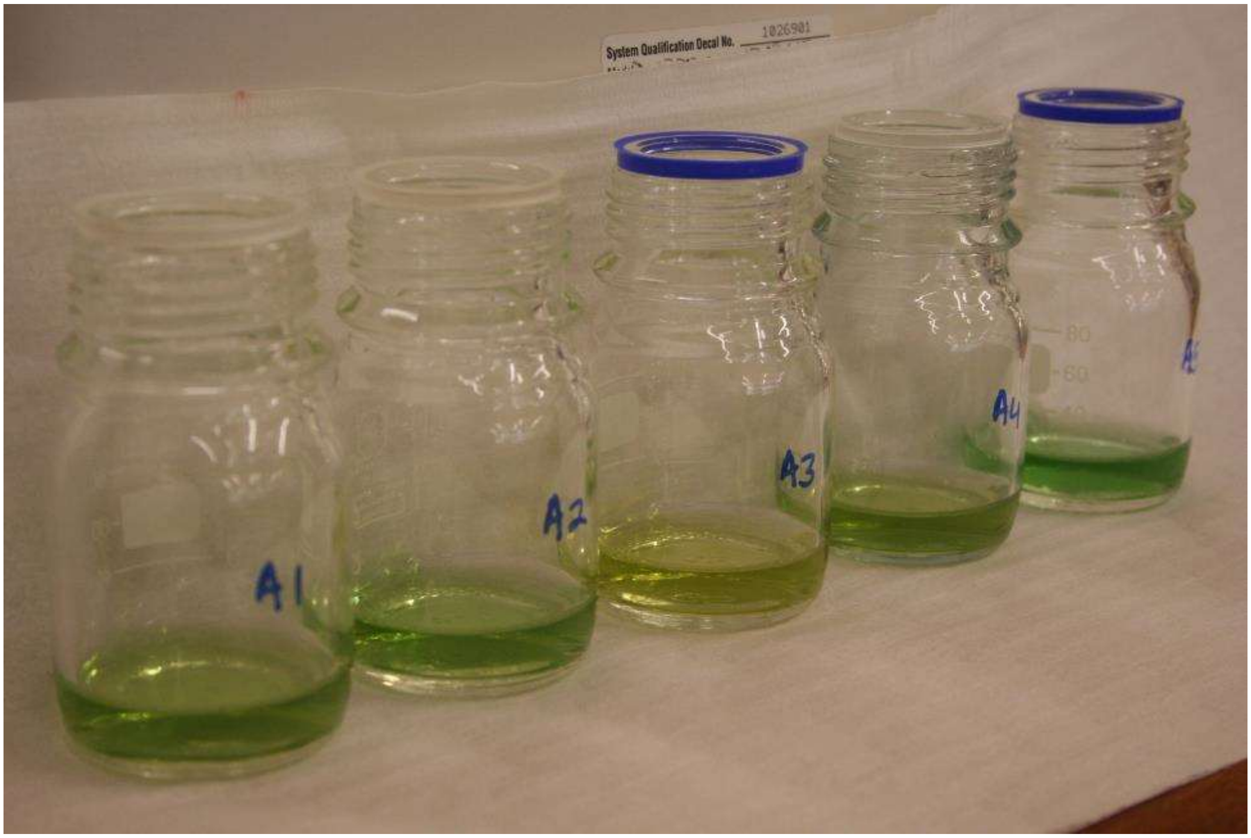

Figure 5. A laboratory analyses to determine soil fertility. The darker the colour, the more active the soil microorganisms

The Soil Microbiology Laboratory at the Agricultural Research Council's Plant Protection Research Institute in Pretoria, South Africa, is adequately equipped with facilities and knowledge to analyse soil microbial communities as indicators of soil health due to their sensitivity to changes in the soil environment. These services are available to anyone concerned about their soils. We have been appointed as curators of our soils – let's own that responsibility, because without healthy soils, there can be no farmers, no agriculture, no life.