Farming the CO_2 Factor

by WILL BRINTON

In a rare moment in an early Rover reconnaissance mission to Mars, carbon dioxide (CO_2) was released from a soil sample during a scientific test and was thought to indicate the presence of microbes. Excitement quickly faded to puzzlement, then dismay, as it was realized that a glitch in the expensive on-board lab had produced inorganic CO_2. Chemicals used for the soil extract triggered release of inorganic CO_2, perhaps from the ubiquitous magnesite ($MgCO_3$) found in Martian soil.

On Earth, the release of carbon dioxide from moist soil due to microbial activity is so pervasive that it is difficult not to observe it. We don't have the problem they do on Mars trying to distinguish biological CO_2, in an atmosphere containing 96 percent CO_2, from non-living sources. In science we call this dilemma "distinguishing small differences between large numbers." Here on Earth, CO_2 in the atmosphere is only 0.04 percent, and climbing just barely perceptibly, making it relatively easy to distinguish biological CO_2. Curiously, almost nobody is doing it.

PHOTO BY SARAH TROIS/PA NO-TILL ALLIANCE

Will Brinton (Woods End/Solvita) and Odette Menard (MAPAQ Quebec) speak at an on-farm event in Pennsylvania as part of the No-Till Alliance Field Days 2014.

BORROWING FROM THE PAST

I learned about soil CO_2 respiration working on a graduate program in Sweden investigating fertilizer and crop effects on soil biology. Agronomists in the 1950s set up farm plots and maintained them for decades, enabling later researchers such as myself to observe the long-term effects of differing soil management. In the process, I discovered a trove of even earlier Swedish work on soil respiration.

The legacy of this soil biology work traces to soil scientist Henrik Lundegårdh (pronounced Lun-de-gourd) who, in the 1920s, established an essential framework for understanding the biology of crop productivity. Lundegårdh was concerned about the early rush into inorganic chemical farming based on the new discoveries of mineral plant nutrition. In his view, soil biological functioning should be part of routine soil fertility assessment. He selected soil CO_2 respiration since it reveals the all-inclusive metabolic activities of soil bacteria, fungi, arthropods and plant roots. He labeled this indicator "the CO_2 factor."

It's possible that Lundegårdh built the first farm CO_2-flux chambers. He set up as many as 42 in farm fields and nearby forests running year-round under differing soil and crop regimes. This kind of approach is only now coming into vogue to understand the potential of CO_2-driven climate change. Lundegårdh already grasped the significance of the global

Figure 1: Past and Present Approaches to Soil Fertility

Past View	Emerging View
Soil is the basis to support plants; nutrients and minerals must be added and balanced according to limiting factors and crop removal	Soils function as self-structuring systems; biology regulates crop growth, delivery of nutrients and soil physical integrity
Lab Tools Supporting the View	
"Soil Chemical Analysis" Short-term chemical extractions; calibration of soil liquid extracts to relative crop yield; balancing extracted soil mineral levels, precision grid nutrient mapping	"Soil Health Test" Soil CO_2 respiration, soil earthworm counts, bacteria and fungi mass, soil organic matter; water soluble carbon, humus amino-N
Actions/Results of Applying this Approach	
Increased use of mineral supplementation; high costs of nutrient-mineral inputs; lower net profit of yield; increased digitalization of fertilization; increased soil compaction; salinization; loss of organic matter; decrease in soil biology, unreliability of collapse of yields	Reduced expenditure on fertilizers; less nitrate-leaching; increased carbon-sequestration; increased use of soil building inter-crops; inclusion of animals due to positive soil effects; reduction in soil tillage; improved soil structure, improved yield reliability

carbon cycle at the time, but more importantly, saw an enormous upside to CO_2 in the context of quantifying "healthy soils."

From this effort Lundegårdh reached several astonishing conclusions. He was a systems researcher in the best sense, and to make a point about the relevancy of soil CO_2, he adjusted soil profiles with microbe-rich manure until steady CO_2 rates were attained. Next, he grew wheat, oats and sugar beets and monitored their nutrient and carbohydrate assimilation. From this he demonstrated a significant connection of soil respiration to plant photosynthesis. Considering the thoroughness of these studies and their dissemination in published literature of the time, it is hard to understand how such excellent work escaped further attention.

I have confirmed many of Lundegårdh's measurements and calculations. The essence of the discovery is that plants obtain the CO_2 they need not from the atmosphere per se, but from soil respiration. Lundegårdh showed that if soil respiration fails to furnish a sufficient quantity of CO_2, the supply from the atmosphere is furnished too slowly to prevent a CO_2 deficit in the leaves, and thus a partial starving occurs. This can be intuitively grasped as a basis of truly biological-oriented farming.

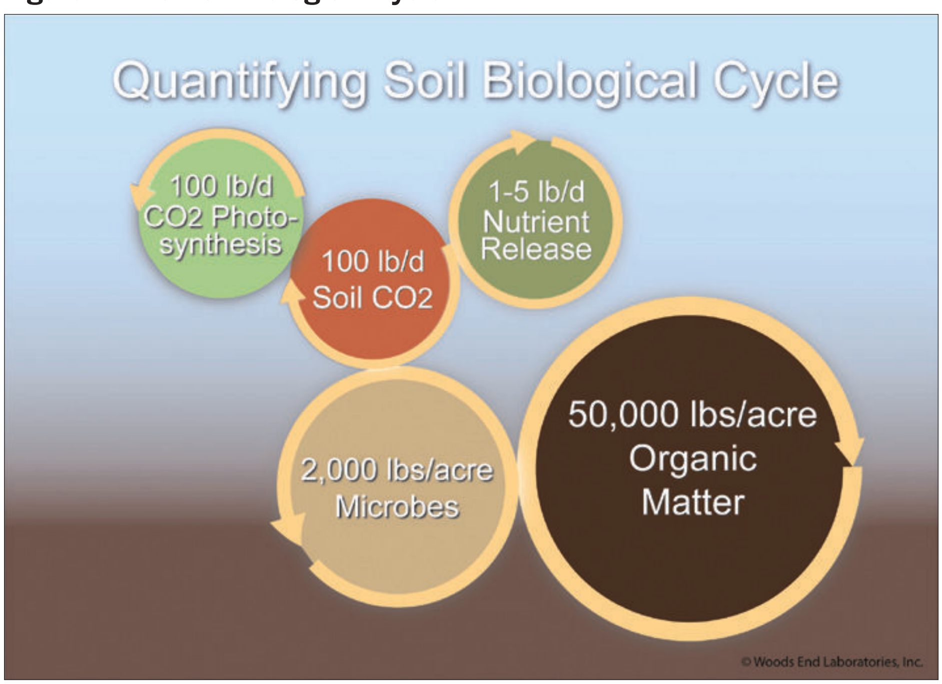
Some very recent studies on forest canopies in ecological journals confirm that in highly functioning ecosystems the cycle of CO_2 (and O_2) between plants and the soil is nearly completely closed. In this regard Lundegårdh was a pioneer showing that we cannot separate living soil from high-yielding crops. This is a far cry from where we stand in the present, and this is unfortunate.

Lundegårdh outlined the biological pathways that directly contribute to crop productivity, including:

1. mineralization of organic nitrogen to nitrates (due to microbial activity);
2. extraction and buffering of the soil solution (due to dissolved carbonic acid from microbial activity);
3. soil aggregate formation (due to microbial activity) and
4. furnishing plants with CO_2 for photosynthetic assimilation, also due to soil respiration.

The implications of Lundegårdh's discoveries were largely ignored. Lundegårdh was aware of the conflict with prevailing mineral-theory views. Writing a commentary in the journal *Soil Science* in April 1926 he voiced his concern: "The direct action of mineral fertilizers on increasing plant growth is the only one attention is being paid to in agriculture."

Figure 2: The Soil Biological Cycle



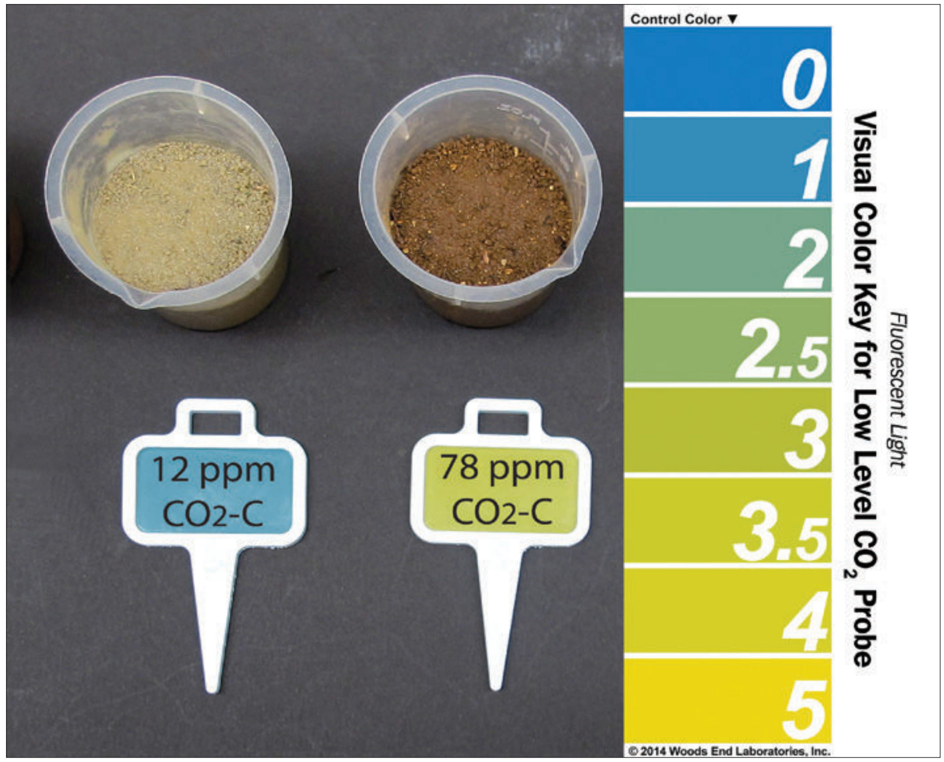
The daily carbon and nutrient release rates in relation to the mass of microbes and soil organic matter.

DOMINATION OF MINERAL VIEW

Lundegårdh's remark in which he regrets the narrow focus on mineral nutrition of plants is certainly as true today as it was then – or even more so. Europeans in Lundegårdh's time witnessed the explosive growth of the inorganic fertilizer industry and its integration into farming, sweeping away centuries of old customs. The founding of our Land Grant University system grew out of this turbulent era, a result of political fears that Europeans would gain an advantage over the United States with the new mineral theories applied in agriculture to attain stupendous crop yields.

Today, if you operate a soil lab as I do, virtually all the equipment and technology is tasked for testing inorganic minerals. The basics were laid down a century ago. Advances in technology have largely focused on making it easier to measure *more* minerals *faster*. Harsh soil extracts are designed to pull the nutrients from soil as rapidly as possible. We combine this with mathematical equations formulated in the late 19th century by German chemists Liebig and Mitscherlich to "calibrate" extracted minerals to crop response.

Figure 3: Soil Comparison



Fertility Comparison of two soils. Left: truck farm continuously tilled soil, NC, Solvita 12 ppm CO_2-C. Right: Virgin Prairie Soil, NE, Solvita 78 ppm CO_2-C

This chemistry-mathematical approach is also very convenient: it is directly tied to applying inorganic fertilizers keyed to soil analysis, a business model that catapulted the mineral industry into becoming the cornerstone of modern farming. As the damage from a century of one-sided practices comes more into focus, some are asking: was the compelling post-war business opportunity of industrialization, more than the science itself, the real impetus for these agricultural changes? Some caution that we are being too critical of these early advancements or not appreciating the extraordinary amount of early scientific work that went into the new protocols. The problem is, all that work was done *before* the field of soil biology was even recognized.

Lundegårdh could well have been an organic science pioneer, but the movement was yet to be born. He did something that was highly significant by drawing attention to the shortsightedness of the new chemistry discoveries, and he tied the best science to measurements in soil biology. Lundegårdh was not opposed to inorganic nutrients. He pointed out that in some circumstances increasing inorganic fertilizers also increased soil biology and CO_2 respiration due to greater root mass and more crop residues. His approach clearly fits current concepts of soil health (the connection of soil-respiration to carbohydrate assimilation certainly belongs in the soil health arena). The point is, we have been trained for over a century to overlook soil biology with the best excuse being that it takes care of itself (which is partly true), and the somber threat that without inorganic fertilizers the world's populations will starve.

A recent scientific survey from Richard Mulvaney (Univ. Illinois/Urbana) examining soil tests nationwide found that in spite of increased soil mineral applications, soils are steadily declining in organic nitrogen, the key indicator of soil vitality. I believe this proves that there is no connection between mineral fertilizers and soil improvement. The inescapable conclusion is that soil degradation – despite our best efforts – is likely to continue unabated. Aside from erosion and salinization, the central crisis is depletion of soil biological capital, or Lundegårdh's "CO_2 factor." In fact, it is possible that we are approaching, for the first time, a new low-water mark in soil fertility, for which Lundegårdh's studies are a harbinger and warning. But without new testing tools, no one will notice it.

CRISIS TO NEW ACTION

There is nothing like impending crisis to trigger new experimentation. Part of the exciting turning point is seen in efforts by progressive farmers who appear to be training the government and the Land Grant researchers. Private soil labs have jumped into the fray to evolve new indexes for biological fertility. Underlying this is the age-old axiom that you can't manage what you cannot measure. It explains our laboratory's introduction of a new type of soil test called "Solvita," making measuring soil CO_2 factor respiration practical and cost-effective within the infrastructure of soil labs and crop consultants, who are starting to see the connections.

A transition era is upon us and is captured in Figure 1, showing the prevailing and new views.

PUTTING NUMBERS TO CO_2

The basis for biological functioning related to soil CO_2 starts with calculations anyone can perform. Take your entire dry matter crop yield and multiply by 50 percent to get your approximate carbon yield per acre. Divide this into 60 (the most active carbon assimilation days) and you have the carbon factor per day, which multiplied by 3.7 gets you to the CO_2 factor. This was Lundegårdh's basis in comparing soil respiration to crop carbohydrate assimilation. These two sets of numbers – the plant uptake and the soil respiration of CO_2 – can be found to be roughly comparable, in a healthy system. Crop CO_2 needs such as in corn can be as high as 450 pounds per day per acre during the active period (as pure carbon this is 125 pounds per day). It turns out that nature has designed redundant biological systems in soil to furnish adequate amounts of CO_2 to keep plants in top shape, while the biology itself regulates the commensurate supply of nutrients and maintains soil structural integrity.

The cycle can be quantified, using an example of a soil moderate organic content as follows (Figure 2).

By more accurately quantifying the CO_2 respiration rate we get closer to the mass of microbes and the potential nutrient supply to plants. Over time these measurements will be interpreted with greater precision. In the following example we show relative CO_2 rates with the Solvita 24hr CO_2-Burst test, used by Soil Health Tool labs (see note at end for a soil map showing labs offering this soil biology test).

In the example, given the "dead soil" on the left, a continuously cropped (truck farm) soil from North Carolina, had very low (12 ppm) daily CO_2 rates. This is depletion farming (mineral test levels in the same soil were adequate and did not reveal the extent of the problem). For comparison we tested a virgin prairie soil from Nebraska which showed almost seven times more biological activity. That system has accumulated biological capital. Associated with such a rich soil is a potentially high organic nutrient cycle. Modern mineral soil tests just do not show this.

GETTING TO THE CO_2 FACTOR

We need to alter the way we measure yield response in soil testing by paying attention to the capability of soil to produce CO_2, an integrated measure of all soil biota. In time, we will learn more about relationships of the biota to each other (fungi, bacteria, mycorrhiza) and to organic nitrogen fertility. It is well known that these have been factored out of calibration studies used in soil interpretation. Correcting this omission is a challenge and is critical to assuring soil health and high-yielding crops and to fixing soil testing from being all about minerals to including biology. Perhaps the 2015 International Year of Soils is a good time to address this issue. Incidentally, we may rediscover mineral nutrition of soil from a new perspective: creating the optimal balance to foster microbial activity and diversity according to the edict: feed the soil. This work is only beginning today.

It is noteworthy that soil mineral theory is a self-fulfilling prophecy – not focusing on biology leads to emphasis on minerals, this in turn fosters management practices that ignore biology; this leads to increased dependency on inorganic fertilizers: the cycle repeats.

INCLUDING SOIL LABS IN THE BIOLOGY TRANSITION

We need to foster the independent relationship of grower to soil lab, with the new biology standing in for mineral theory. Growers interested in soil biology should contact their soil labs. A new open-source methodology integrating soil biology with common nutrient tests, called the Soil Health Tool, originated with support from USDA-ARS and is available to any lab. More than 30 labs around the world now offer the Solvita biology test. At least five U.S. laboratories offering the soil health tool and more this year include: Ward Labs, Brookside Labs, Midwest Labs, A&L Memphis and A&L Canada and Woods End Labs. The success of the transition depends not on a new era of "expertism" of the sort that brought us the chemical mineral revolution, but by on-farm efforts comparing yield stability and quality with soil biology. Therein may lie the key to breaking the 150-year-old N-P-K spell.

NEED MORE INFORMATION?
For more information, visit the interactive soil map to locate soil biology labs at *www.solvita.com/soil/map*.

The author dedicates this article to the memory of Jerry Brunetti, a pioneer in soil care.

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