Managing Carbon: Do You C What I C?

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Managing Carbon: If I were to ask a class of University Agronomy Students "What essential nutrient element is taken up in largest quantities by plants?", the response given by most of them would be "nitrogen". That same answer would probably also be given by most scientists and farmers. In reality the answer is carbon. Carbon, hydrogen, and oxygen constitute the vast majority of the atoms (and the mass) contained in plant dry matter. Carbon is the nutrient element taken up in largest quantities by plants.
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Some of the leading books on plant nutrition (Mengel and Kirkby; Tisdale and Nelson; or Stanley Barber) mention carbon, hydrogen, and oxygen only briefly as being essential elements. The Tisdale and Nelson book goes on to state that little or nothing can be done by man to directly impact the supply of carbon dioxide to a plant. Cook and Veseth make a similar statement in their "Wheat Health Management" publication. I believe they are wrong. I further believe that the lack of attention to carbon as a plant nutrient will be viewed as a major shortcoming of the practice of agronomy in the 20th century. **I reserve the right to be proven wrong, but there is something happening on long-term no-till fields that is not easily explained.**

Carbon chemistry is the basis of life as we know it. The search for life on other planets begins with a search for water and carbon containing compounds. Carbon has some very unique chemical properties. In its lowest energy level it has the electron distribution of 1s2, 2s2, 2p2. This would lead us to believe that it would form the most stable compounds when it has a valence of +2. In fact, carbon forms its most stable compounds when it has a valence of +4. This is the result of the promotion of one of the paired 2s level electrons to the empty 2p orbital (there are two half-filled p orbitals and one that is empty). This is subsequently followed by the formation of 4 hybrid sp^3 orbitals when bonding occurs. These hybrid orbitals are the basis for the tetrahedral shape that gives diamond its hardness. This property also allows carbon to form rings and long chains with carbon bonded to carbon as the skeleton. Carbon forms more compounds than any other element except hydrogen. The fact that an entire field of chemistry (organic chemistry) is devoted exclusively to compounds of carbon is a testament to the importance this element holds for science.

Most agronomists and farmers recognize that soils high in organic matter differ in their characteristics relative to others that have lower levels of organic matter. Most farmers for centuries had utilized manure as fertilizer. It was valued for adding nutrients like nitrogen and phosphorus and for making the soil easier to till and capable of holding more water. Soil scientist even developed methods of classifying soils that were heavily influenced by the amount of organic matter present. The system still being used in Canada classes soils based on color (brown, black, dark brown, grey). These colors are caused by differing amounts of organic matter. Scientists like Hans Jenny spent a lifetime studying the climatic factors that led to soils in different areas developing different organic matter contents.

Scientist did determine that tillage based farming systems reduced organic matter levels of soils and made them less productive over time. Crops that produce low levels of residue (cotton, soybean, etc.) speeded the rate of organic matter loss as compared to crops with higher residue levels (more carbon). Raising perennial grass pastures and alfalfa on a piece of land increased organic matter levels relative to when it was used exclusively for tillage based cropping.

The introduction of European style tillage based farming over large expanses of formerly undisturbed lands in North and South America, Australia, and Eastern Europe during the late 1800's and early 1900's is a prime example of wholesale mining of stored nutrients. The "homesteaders" were searching for the stored nitrogen and other nutrients and were willing to waste organic carbon in the process. It is not uncommon for organic matter levels in the Pampas and the Great Plains or Prairies to have been reduced to less than one-half the amount present before settlement by Europeans. (If this reduction was from 4% to 2% organic matter, the amount of carbon dioxide released would be equivalent to burning 20 tones of coal per acre (44 tonnes per hectare). Obviously, the soil was out of balance relative to what it had been in its native condition.

Even though everyone was aware of organic matter and realized it was valuable, no one paid much attention to the carbon part of the carbon cycle. Carbon dioxide was given off to the atmosphere as organic material decayed and released "valuable" fertilizer nutrients like nitrogen. That attitude changed when scientists noticed the concentration of carbon dioxide (partial pressure of carbon dioxide) in the atmosphere was increasing relative to historic levels. A massive amount of effort has been expended trying to quantify the amount of change that has occurred and predict the potential impact that might have. Reasons for this change have been attributed to natural causes, deforestation, use of fossil fuels, etc. Some of it is also due to the impact of tillage on the organic matter in the soil. There were now incentives and funds available that encouraged scientists to look at all parts of the carbon cycle.

Scientists like Don Reicosky began to study the carbon system in the soil. He found that there was a large "flush" or release of carbon dioxide in the 3 to 4 days immediately following a tillage operation. On land that remained untilled and had been in grass for several years (after many years of farming) less carbon was released during the season and the release happened later in the year when the weather warmed. Don is most concerned with how and why carbon enters and exits the soil. He really does not care what happens to it after it leaves the soil. But we are intensely interested because our crop needs to find carbon. The more carbon it can find the better.

Let us look at the immobilization side of the carbon cycle. Much of what we know about the impact differences in carbon dioxide partial pressures have on plant growth comes from studies dealing with the greenhouse effect. These data suggest that plants have higher water use efficiencies when grown under elevated carbon dioxide levels. The phenomenon is attributed to the fact that these plants do not have to open their stomata as widely to attain the carbon dioxide they need. Consequently, less water vapor “leaks” out. Many greenhouse operators actually enhance the carbon dioxide partial pressure in the greenhouse atmosphere to reduce water vapor loss from plants. Reducing transpiration cuts down on water condensation on the ceiling and walls. Commercial greenhouses also use carbon dioxide enhancement to promote growth during periods of low light and short days. For example, ADM raises ambient carbon dioxide levels to 1,200 ppm during the depth of winter in the northern United States. Lower levels of enhancement are used at other times of the year.

Similarly plants grown in higher carbon dioxide environments are also better able to attain adequate carbon under water stress conditions when stomatal closure occurs for substantial periods of time during the day. The reason for this is related to the use of enhancement in greenhouses. Higher carbon dioxide concentration allows more photosynthesis to take place during periods of the day when light intensity is low. In addition since the carbon dioxide in the air that enters the plant when the stomata are open is greater, more total carbon should be fixed before the concentration falls to levels where fixation stops. These impacts should be most pronounced on C_3 plants as compared to those with the C_4 pathway. The C_3 pathway is not as efficient as the $C_{4.}$

The best way to understand how something should work is to examine it in a natural system or several natural systems. If we look at carbon cycling in the rainforest, the bush or the prairies, the system was in equilibrium. The same amount of carbon entered and left the soil each year (on average). Carbon dioxide was formed as dead plant residue, soil organic matter, and dead animals decayed and as living organisms breathed. Warm-blooded animals are breathing throughout the year but the microbes that mediate most of the decay process operate best when the temperatures are neither too hot nor too cold. They also like the proper moisture. That means that the “flush” of carbon dioxide associated with microbial activity (on the American Prairies) occurs after soils warm in the spring and increases when moisture is adequate. This is coincident with the time of peak vegetative growth of most species native to these regions. This is most likely an evolutionary adaptation because most other fertilizer elements are associated with (bound within) the organic material that is decomposing. If it did not decompose, there would be less nitrogen, sulfur, zinc, etc. for the next generation to use. If organic material decomposed before the period of maximum plant growth, there would be a high probability that many nutrients would be lost from the system (perhaps permanently). Most interesting to this discussion is the fact that carbon dioxide evolution coincides almost exactly with the maximum demand for carbon dioxide by plants. It is easy to visualize the dense canopy of a tall-grass prairie serving as a trap for preventing carbon dioxide from leaving an area until it can be used by the plants forming the canopy.

The rainforest operates in much the same manner other than it does not have its reserves of nutrients stored as soil organic matter. It does not need storage because the nutrients (and carbon) are stored in living materials that cycle quickly. In the prairie most of the biological activity occurs in the soil or near the soil surface. In the rain forest, most of the biology is above the soil. Soil scientists have traditionally thought of rainforest soils as being “poor’. They are poor if you look only at the soil. The rainforest ecosystem consisting of the soil plus the plants and animals is not poor.

When farming first came to these areas, there was little understanding of plant nutrition. In the rainforest it was advantageous to cut down the vegetation and burn it (slash and burn agriculture). This released the nutrients being stored in the vegetation so they could be used (mined) by the farmer’s crop. Making all of the nutrients available at once and at a time well before the crop would use it, led to loss of most of the nutrients. There were enough nutrients remaining to raise the small crop of annual plants for a few years. Soil degradation did not seem important since there were many hectares of forest and very few people, more land could be found.

The process was similar for the Pampas and Prairies. In these ecosystems, many of the nutrients were “locked up” in the soil organic matter. Burning the above-ground vegetation did not have the same effect. Tillage on the other hand was tremendously efficient at “burning” the stored organic matter and releasing nutrients for use by the crop. The benefits and problems are almost identical to the slash and burn system of the rain forest. The nutrients became available for use by annual crops but they were available too early and therefore prone to loss. It just looked less destructive because there was no visible fire. There was burning going on just the same. The land degraded after some years of doing this. Productivity declined. Nutrients leached or leaked from the system into water sources. But it didn’t cause concern because there was lots of unexploited land and very few people. Once a parcel was degraded, the farmer simply moved to another one. Agriculture’s success was being subsidized by degradation of the ecosystem.

There are exceptions that occurred. One of the most interesting involves the Amazonian Dark Earths (search these terms on the internet for more details). It appears that instead of slashing and burning the rainforest, early inhabitants had slashed and charcoaled the plant material. This process created dark (high carbon) soils that have maintained higher productivity to this day.

At first blush, most practicing farmers probably think this has little to do with their operations today. In areas where the supply of new land became limited, farming practices evolved to include strategies designed to help slow the rate of productivity loss. Mineral fertilizers have allowed raising the content of many elements to levels equal or greater than in the native system, although these nutrients continue leaking from the system. Cheap energy and good transportations systems allow then to be replaced. Even with this technology, the productivity of land with a long history of farming is not as good as “new” land. The most striking characteristic of old land is that the level of carbon in the system remains well below that in the native system. This form of agriculture was subsidized by cheap energy and degradation of the ecosystem.

Most scientist believe that soils with more organic carbon in the system are more productive because of improved soil properties like water-holding capacity enhancement, better structure, and more cation-exchange capacity. These benefits undoubtedly play a major role. Still almost no-one has considered that there might be direct impacts on carbon dioxide partial pressures in the crop canopy as well. In tilled systems, where most carbon dioxide cycling is going to occur soon after the tillage operation, the farmer has no ability to manage his carbon to better suit the plants needs That may not be true for no-till farmers where carbon cycles later in the season, similar to what it does under natural conditions.

The good news about the recent emphasis on understanding global warming and the carbon cycle includes results like the following taken directly from an annual report submitted by Hatfield and others doing work at Ames, Iowa under no-till conditions.

> **Single Most Significant Accomplishment during FY 2002**: Carbon dioxide and water vapor exchanges measured within a corn canopy during the summer of 2001 revealed that distributions with height varied throughout the day. Concentrations of carbon dioxide in the lower canopy increased to levels near 900 ppm during the night and then rapidly decreased as solar radiation began to penetrate into the canopy during the early morning. Mid-afternoon concentrations were less than 300 ppm indicating that carbon dioxide values may be limiting crop growth. Examination of the patterns of carbon dioxide and water vapor suggested that the soil may be a significant source of carbon dioxide when the canopies completely cover the soil surface. Combining the gas measurements with the biomass estimates of carbon stored in the canopy and the patterns in the above canopy measurements indicates that the soil release of carbon dioxide during the growing season may contribute up to 40% of the carbon stored in the corn crop.

It is conceivable that carbon cycling could be manipulated through rotation choice, residue management techniques, cover-crop use, nitrogen application methods, etc., with the goal of raising carbon dioxide partial pressures in the crop canopy at the time when the crop needs more carbon. This may sound silly until you consider that it is possible (probable) that C cycling effects are partially responsible for the fact that soils with high organic matter content normally produce higher yields than those with less organic matter. Similarly, fields that have recently been converted from perennial crops or from sod into crop production might produce superior yields for the same reason.   Almost every seasoned no-till farmer has had instances where a crop yielded much better than expected based on the water saving aspects of no-till alone. Something else had made a contribution.

Perhaps no-till and crop rotations are not ends but rather the best means or tools we have available to manage the carbon cycle in our cropping systems. This conference is called the C connection because its goal is to explore several aspects of carbon. If C cycling is to be controlled, low-disturbance no-till now becomes the only option in terms of tillage choice. The focus then turns to optimizing the no-till system and managing it in a truly sustainable way

We have set the following goal for the Dakota Lakes Research Farm in the next 20 years.

"Take all net geologic carbon use out of the system by the year 2026". In other words there can be no net loss of organic matter and we must produce a sufficient amount of energy or biofuel to replace the fossil fuel used to manufacture, promote and transport ALL crop inputs and outputs including those used by the family and farm workers. A corollary goal is to stop all nutrient leakage from the land (recycle all that is not sold and replace what is sold). Once these goals are accepted, we can finally get over this need to compare tillage systems. Its not about the tillage practice, it is about managing the ecosystem. Tillage removes our ability to manage the system.

If C cycling is an overriding factor, then questions surrounding the use of crop residues for energy production must be approached much differently than if maintaining the current rate of degradation is the goal. Clearly, using perennial crops with their massive root systems and associative N fixation is a much better option that using crop residues generated by a farming system that has and is degrading the soil and the ecosystem. There are those that claim removing "some" residue cannot be proven to cause loss of productivity. BUT THE SYSTEM IS ALREADY DEGRADED. THE GOAL NEEDS TO BE RESTORING IT TO ITS ORIGINAL PRODUCTIVITY NOT MAINTAINING IT IN ITS DEGRADED STATE.

On previous presentations to this group we have stressed the need to diversify rotations and reduce disturbance for the purpose of improved weed control. We have recommended utilizing cover crops to attempt to minimize the leakage of water and nutrients and to mitigate wet soil issues during seeding and harvesting. We have always stressed the need to cycle nutrients and water in a manner similar to the native vegetation. Nothing has changed this time other than we expanded the subject matter to include thinking of carbon as one of the nutrients that cycle.

Animals are an integral part of the natural ecosystem. They must be an integral part of sustainable farming systems. Problems associated with the keeping of livestock are not the fault of the livestock. They do not control how they are managed. Livestock will make it easier to diversify the crop rotation and cycle water and nutrients properly. Developing methods to better manage the carbon in the system will lead to better management of the other nutrients as well.

I encourage readers to visit our web site www.dakotalakes.com for further information.