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Carbon Farming - The Global Carbon Cycle.

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November 2008

Hardly a week goes by now without several news stories about global climate change and the need to reduce the "human carbon footprint" on our environment. The link between rising atmospheric carbon dioxide (CO_2) levels, generally increasing temperatures and human activities is now sufficiently well accepted that legislation to reduce net CO_2 emissions in the U.S. seems inevitable. The European Economic Union has already established economic protocols to reduce their CO_2 emissions and individual states within the United States have formed groups, such as the Western Climate Initiative[2], to follow their lead. A formal carbon market, The Chicago Climate Exchange[1], and more recently, a carbon futures market, The NYMEX Green Exchange[3] have been established as brokers rush to secure positions in what appears to be the early stages of a "carbon rush" similar to past gold rushes familiar to us in the western U.S. Such well known corporate giants as Schlumberger[4], JP Morgan Chase[5], and Citigroup[6] have all entered the carbon trading business. Contract "Aggregators" are actively talking with land owners about selling carbon sequestration rights to their lands. So, is land management designed to sequester carbon, sometimes called "carbon farming", a viable way for U.S. farmers, ranchers, agroforesters and foresters to gain income while helping the environment? To answer this question, we need to understand the global carbon cycle, what carbon markets currently exist, and how carbon markets are likely to operate if legislation regulating CO_2 emissions in the U.S. is enacted in the future. The following article describes the general global carbon cycle and how land management actions are likely to affect it. Carbon trading will be the subject of a separate follow-on article.

The Global Carbon Cycle

Carbon is the basic building block of life on our planet. It is also a basic product of oxidation of organic matter to yield energy. This is equally true if the energy comes from you digesting a biscuit or from a power plant burning coal. As with all subjects, the carbon cycle can be as complicated or as simple as one chooses to make it. For our purposes, we can afford to take a rather simplistic view. This is good because much of what we actually "know" about carbon cycling is useful for making generalizations, but may not be entirely accurate for specific places and situations. As we will see later, this can pose some problems for selling carbon contracts on specific parcels of land. Many of the numbers presented in discussing carbon cycling are our best guess. Different people will often have slightly different numbers. The numbers are not meant to be literally true, but their relative size gives some idea of their importance in our discussion.

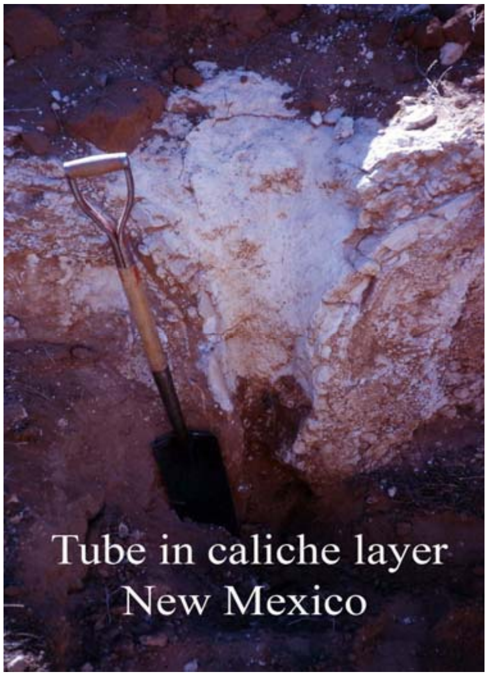
The total amount of carbon present on planet earth varies little over time. However, the chemical form that it is in, can and has varied over time. Carbon occurs naturally both as a gas and as a solid. Carbon dioxide (CO_2) is probably the most common gaseous form of carbon. It is approximately 27% carbon and 73% oxygen by weight. So, a ton of C is equal to 3.67 tons of CO_2. Methane (CH^4) together with CO_2 are principle green house gases that trap the sun's energy beneath earth's atmosphere. In moderation, this "greenhouse effect" is critical to maintaining the warmth that makes life on earth possible. When CO_2 levels become too great, however, extra heat is retained and "global warning" may result. So, our discussion of carbon cycling will focus on CO_2. Although most CO_2 is an atmospheric gas, it is soluble in water and a considerable amount of it at any point in time is dissolved in our oceans where it moves with ocean currents. Since cold water can hold more dissolved gas than warm water (the fizzy can of warm beer effect), CO_2 generally moves south in cold water currents from the polar regions to lower latitudes where it is released as the water surfaces and warms[7].

Table 1. World Carbon Storage

[Billions of Metric Tons]

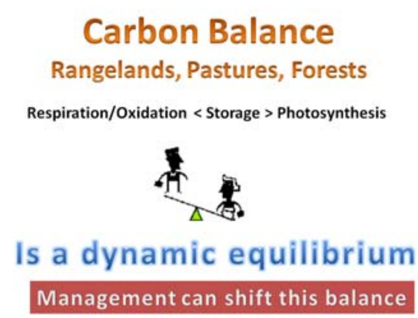
Compartment		Amount
Atmosphere		766
Soil Organic Matter		1600
Ocean		40,000
Rocks		66,000,000
Terrestrial Plants		600
Fossil Fuels		5000
	Coal	4000
	Oil	500
	Natural gas	500

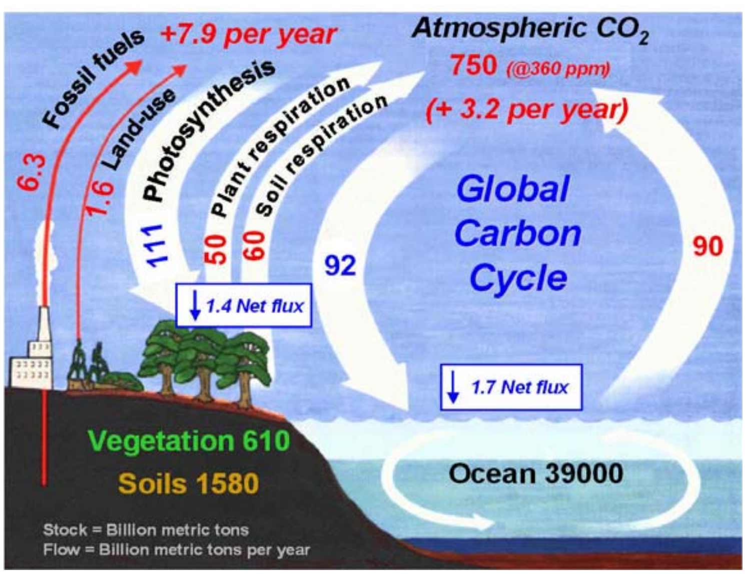
Most solid carbon is found as either carbonates (rocks, sea shells), or as organic materials (from plants or animals). To understand mineral cycling, scientists like to look at where things are (storage compartments) and the rate at which they move from place to place or from state to state (transfers). Table 1 presents a rough inventory of world carbon storage.



Several properties become immediately obvious from this inventory. Atmospheric CO_2 is actually a relatively small part of total world carbon. By far the greatest storage area for carbon is in carbonate rocks and sediments. Those of us who have lived in arid or semi-arid areas where the soil is underlain by a thick layer of caliche (calcium carbonate rock), can easily identify with this observation. The geologic processes which govern movement of carbon into and out of rock are relatively difficult for us to manage in a meaningful time frame. Organic matter, such as terrestrial plants and soil organic matter are much easier for us to manipulate. Organic matter is roughly half carbon. The other half is oxygen, hydrogen, nitrogen, and other elements. Together, ocean and terrestrial organic matter contains several times more carbon than does the atmosphere, giving us hope that we might really be able to effect atmospheric CO_2 levels by managing organic matter. In terrestrial systems, most organic matter is stored in soils rather than in plants or in animal tissue. Fossil fuels, such as coal or oil, are just ancient below ground organic matter. It is interesting to note that although much recent attention has been focused upon scarcity of oil and natural gas, most of the earth's fossil fuel energy is coal. Coal fired plants are major point source emitters of CO_2 and likely targets for carbon reduction or mitigation strategies. Oregon, for instance, requires that all new carbon burning power plants mitigate 15% of their CO_2 emissions. However, the Pacific Northwest gets relatively little of its energy from burning coal, because of its abundance of hydro-power. Most of its fossil fuel use is natural gas and motor fuels (gasoline and diesel oil).

The amount of organic matter present at any moment in time is the net effect of processes that add vs. processes that remove it from that place. Photosynthesis is the single most important source of organic matter. Plants, ranging from simple ocean phytoplankton to large complex terrestrial vegetation, extract CO_2 from the air or water and combine it with water, using the sun's energy to produce chains of carbon (carbohydrates) that are then employed to build tissue and storage compounds (such as sugars and starches). The process of photosynthesis requires a considerable amount of energy. This stored chemical energy can be released by decomposing the organic matter through oxidation reactions. Two common oxidation reactions are respiration and fire. Both of these reactions essentially undo photosynthesis by converting organic materials back into CO_2, water, and energy along with any minerals present. Most animals derive their energy from respiration (oxidation of organic compounds) which releases previously stored CO_2. Animals are by their nature, therefore, generally sources of CO_2. Plants also get their energy from respiration. In the daytime, photosynthesis often exceeds respiration and we see a net increase in stored carbon, some of which is later consumed by respiration during the night. In balance, plants generally fix more carbon than they use and the surplus is either consumed by animals or is stored in plant tissue, soil organic matter, fossil fuels, or other organic matter.





This stored surplus of "sequestered carbon" is about 3 billion tons per year[8], compared to about 8 billion tons released by human activities. So, the system seems to be out of balance by about 5 billion tons of carbon per year, and atmospheric CO_2 levels should continue to rise at about 3.2 ppm per year unless something changes. Logically, balance can be restored by reducing human-induced CO_2 release and by promoting net organic matter storage, through either increased photosynthesis or reduced respiration. It is unclear how rising atmospheric CO_2 levels and gradually increasing world temperatures will affect the balance of photosynthesis and respiration. Photosynthesis is often limited by CO_2 availability within the leaf, so increasing atmospheric CO_2 level tends to increase photosynthesis. On the other hand, respiration rates increase with increasing temperature, so higher environmental temperatures tend to increase CO_2 released by respiration. Potential effects relating to vegetation change caused by climate shifts add another dimension of complexity. In general, cool season growing (C3) plants have more shallow root systems, are less fibrous, and decompose more rapidly than do warm season growing (C4) plants. A possible shift from C3 to C4 plants, favored by higher average global temperatures, could increase carbon stored in soil organic matter. In any event, deforestation, soil erosion, plowing of agricultural fields and other human land use contributes only about 20% of global carbon release, compared to 80% by burning of fossil fuels. So, it will be difficult to use land use changes alone to offset fossil fuel use. Even if all net carbon release from land management ceased, net carbon surplus (photosynthesis – respiration) from ocean and land ecosystems would have to double to offset current fossil fuel burning. Changes in management of terrestrial and ocean ecosystems to favor increased net carbon storage are potentially very helpful. However, they are not seriously proposed by most experts as the sole solution to global carbon imbalance. Any practical solution will also have to address energy use and how energy is obtained (generated) in a more holistic way than merely trying to mitigate the emissions of current fossil fuel use.

Biological Carbon Sequestration Projects

Oceans cover approximately 70% of the planet's surface and have an important geologic carbon sequestering mechanism that terrestrial systems largely lack. They contain organisms such as corrals, mollusks, zooplankton, and other animals that extract carbon and combine it with calcium to form carbonates which ultimately contribute to sedimentary and metamorphic rocks such as limestone, marble, etc. Under specific conditions (dry climates and plentiful calcium in the soil) calcium carbonate can be formed in place from bicarbonates produces by plant respiration, however this process is very slow and restricted to desert areas with high natural calcium levels in soil parent material. Most soil calcium carbonate is believed to be derived from old ocean formations. The current and potential carbon sequestration of oceans is roughly equal to terrestrial systems in total. There have been some recent proposals to increase ocean carbon storage through ocean fertilization. However, most biological carbon sequestration projects have focused upon terrestrial systems, predominately forests.

Productive forests can accumulate considerable amounts of carbon in tree stems, woody roots, and duff (slowly decomposing needles, leaves, and shed bark). Removal of live trees, disturbance associated with harvest, and increased temperatures near the soil surface generally increase total respiration and reduce photosynthesis, making newly logged stands or cleared forests net sources of carbon. As the stand regenerates and recaptures site resources, net photosynthesis generally exceeds respiration within 15 years, and rapidly growing tree stands become strong carbon sinks that sequester carbon[9]. This change from source to sink reflects the natural tendency of systems to return to balance after disturbance. The carbon lost following harvest is restored as the forest ages. There is some disagreement among ecologists about whether mature forests continue to accumulate carbon or if they gradually become carbon neutral as increased respiration catches up with photosynthesis in older forests. Since both respiration and photosynthesis strongly reflect site characteristics, the tendency for carbon accumulation to slow as the forest ages is very site specific. Silviculturalists sometimes argue that “decadent” mature forests could be replaced with younger rapidly growing forests that would be stronger carbon sinks. However, this argument generally focuses on the middle, carbon sink, portion of the timber rotation and often underrates the early carbon emission stage. Forest carbon inventories frequently also undervalue stored soil carbon. It is unclear if replacing old mature forests with new young forests will actually store more carbon over the entire timber rotation. Clearly, the length of time the forest is in place (timber rotation) will affect its carbon status. It is generally assumed that longer timber rotations will accumulate more carbon. There is generally more total carbon present in old forests than young forests. Carbon accumulates over time as coarse wood debris in the form of dead logs on the forest floor, dead stumps, organic debris in the forest floor (duff), and soil organic matter, as well as standing woody stems in older forests. The more interesting question is whether the rate at which additional carbon is added to storage decreases over time as forests age. A recent study of forests around the world[9] estimated that forests over 200 years old continued to sequester approximately 2.4 tons/ha/year of carbon, of which about 1.1 tons was stored aboveground as vegetation and woody debris and 1.3 tons was belowground in roots and soil organic matter.

Afforestation is planting trees onto areas that recently did not support forest, such as crop and grazing lands). Reforestation is replacing trees that were recently harvested. Afforestation is more attractive as a carbon sequestering mechanism than is reforestation because it lacks the early carbon source stage of a recently harvested timber rotation. Afforestation projects such as agroforestry (producing crops or pasture together with trees) often involve converting croplands or pastures into open canopied forests. Since croplands are often net sources of carbon, agroforests can be very effective carbon sequestration projects.

Grasslands and planted pastures are widely underrated as carbon sinks compared to forests. This is probably because the accumulation of woody material in forests is easily seen and measured. Although grasslands often store as much total carbon as forests do, they store less in aboveground vegetation and much more in the soil where it is less apparent. Many carbon inventories do not adequately consider soil organic matter. This bias makes forests and shrub lands appear to be more superior to grassland as carbon sinks than they really are. For example, a recent study near Corvallis, Oregon[10] compared carbon inventories for pastures, forests, and agroforests (pasture+forest) growing on the same site.

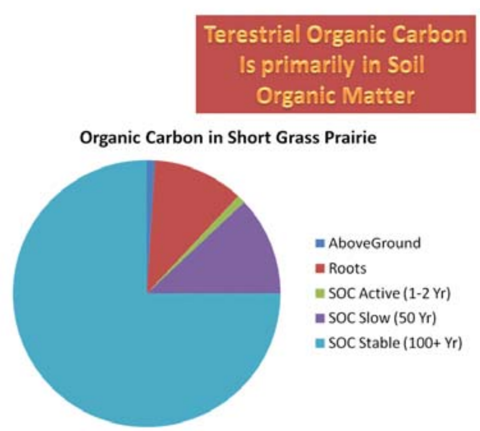
Nitrogen Stored in System Compartments in August 2000 (kg/ha)

Corvallis, Oregon USA

Compartment*	Pasture	Agroforest	Forest	SE
Tree	0	83^{a}	50^{b}	7
Understory	54^{a}	62^{a}	59^{b}	5.5
Soil	$8,879^{a}$	$8,097^{a}$	$7,600^{a}$	635
TOTAL	$8,933^{a}$	$8,242^{ab}$	$7,709^{ab}$	442

- Tree & understory include both above and belowground biomass
- Soil is the top 45 cm depth
- ^{ab} Means in a line differ ((p<05)
- SE is standard error

After 11 years, pastures and forests had roughly the same total amount of stored carbon. However, carbon stored above ground was higher in forests while carbon stored belowground was higher in pastures. Agroforests had both forests' above ground storage plus grasslands belowground storage. So, they accumulated about 500 kg/ha/year more total carbon. Mixed grass and shrub communities, common on western rangelands, will probably have similar carbon storage patterns as agroforests. In all cases, most carbon was stored as soil organic matter. To a large extent, carbon management in terrestrial ecosystems is soil organic matter management! Besides containing carbon, soil organic matter is a primary storage site for soil nutrients, feeds useful soil organisms, holds soil water, and improves soil structure so that rainfall may more readily enter the soil. So, good soil carbon management leads to good soil quality that supports land productivity and stability. Managing for carbon sequestration can be quite compatible with other land management objectives. This appears to offer numerous opportunities to develop win-win land management options.

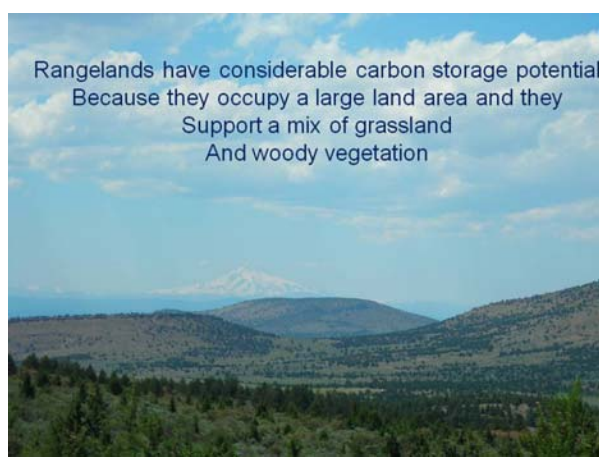


It is important to realize that not all soil organic carbon is the same. Some soil organic matter is readily decomposable and will turn over rapidly, while some recalcitrant organic matter is very stable and will remain in the soil for half a decade or more[11]. Most of the soil organic carbon is contained in fairly stable humic compounds that are very slow to decompose. In a short grass prairie, for example, approximately 87% of the total soil organic matter is either slow decomposition or stable compounds with an expected residency time of over 50 years. As we add organic matter, the readily decomposable material rapidly passes through the system, leaving a small stable proportion behind as recalcitrant organic matter. This means that it takes many years to really sequester carbon as stable organic matter and that most of the initial increases in soil organic carbon can be quickly lost if environmental conditions or land management change. Such loss of previously stored carbon is sometimes referred to as "leakage". In order to really sequester carbon in soils, a long enough time frame to contribute to stable soil organic matter is highly desirable. Otherwise, considerable carbon leakage can occur once sequestration contracts expire.

To be honest, it is very hard to predict how changing land management will affect net carbon storage on a particular site. For example, when grassland is plowed and planted to crops such as corn, the net productivity per hectare may increase because of fertilization and other farming practices. Relatively little of the crop biomass is removed as grain. So, it seems reasonable that soil organic matter should increase. However, we know from experience that it decreases because of increased soil respiration and oxidation of soil organic matter. That said, here is a brief list from the U.S. Environmental Protection Agency of some land practices that are likely to increase carbon storage[12]:

1] Rehabilitation of degraded pastures and rangelands
2] Riparian shelter belts
3] Windbreaks
4] Conservation tillage
5] Wetland restoration
6] Afforestation
7] Increased length of timber rotations
8] Returning cropland to grassland or forest

Many of the above practices have benefits beyond carbon storage alone. Most of them may also reduce soil erosion, increase wildlife habitat values, and improve watershed function. Reduction of soil carbon lost to wind and water by soil erosion is sometimes listed as a form of carbon mitigation. However, most of this carbon is not returned to the atmosphere, it is merely moved to a new site. So, most erosion is not carbon loss, it is merely carbon redistribution. The rate at which this redistributed carbon decomposes and is converted to CO_2 depends upon conditions at its new location. Organic matter deposited in lakes or streambeds probably decompose at a relatively slow rate, while those deposited on the surface of may decay rapidly. In general, only about 20% of carbon present in soil moved by wind or water erosion probably is released by increased decomposition[13]. Even though reducing erosion is a laudable goal, it is often not included as a way to offset other carbon releases when considering carbon sequestration.



Obviously, the ability of any terrestrial ecosystem to accumulate carbon will be related to its climate, soils, and other factors that affect its ability to produce vegetation, as well as its present carbon status. Simply stated, more productive sites and carbon depleted sites have potentially greater carbon sequestration rates and storage capacity. Rangelands often occupy lower potential sites, but their large area makes them a potentially significant carbon sink in total. Grazing lands have been estimated to store approximately 10-30% of world's total soil carbon[14]. Rangeland productivity often varies substantially with weather from year to year. We do not have a lot of reliable site-specific carbon storage data from rangelands, but what we do have[15], clearly shows this variability with the same site often being a net source of carbon one year and a net sink for carbon the next year. Clearly, carbon credit trading on rangelands will have to take a long-term view of carbon storage and monitoring that averages over these yearly climate variations. Most current carbon credit projects use a 5 to 10-year-average project projection of carbon sequestered, while forestry contracts are often for 10-15 years. It is unclear how longer-term systematic climate patterns such as periodic droughts will be dealt with in carbon accounting.

Improved management is assumed to increase the carbon storing ability of range and pasture lands. Carbon credits generated by implementing "improved practices" may be sold on the Chicago Climate exchange. Because forest and pasture sites are typically more inherently productive than rangelands, their potential to produce vegetation, and to sequester carbon, is higher. While forests may store considerable carbon as woody biomass, increasing carbon stored by pastures or rangelands is most directly related to the quantity and quality of vegetation available to support soil organic matter accumulation. In general, more fibrous plants such as warm season grasses decompose more slowly and contribute more to soil organic matter than do cool season grasses or leafy forbs. Plants that are chemically protected with tannins, oils, or other anti-quality compounds to deter herbivores also are less readily decomposable in the soil and contribute more to increasing soil organic matter. So, to some extent, the higher value a plant has as a feed for livestock, the lower its effectiveness in promoting soil carbon accumulation. Individual practices such as burning, fertilization, rotational grazing, reseeding, or draining wet meadows change the balance of plant growth vs. respiration in plant communities through a complex set of interactions. It is very hard to predict their net outcomes on carbon storage on a specific site or even within a specific region. However, some general tendencies are evident in the literature[16].

1] The more degraded (impacted) a site is, the higher its potential for carbon sequestration. Presumably, soil carbon was lost during disturbance. This carbon can now be replenished. This is the "half full glass" opportunity. Land that is already in good condition is a full glass. There is little room for additional carbon.

2] Improved grazing practices often increase plant production and soil organic carbon.

3] Controlled (prescription) burning often increases soil organic carbon in the long term.

4] Converting cropland to permanent grassland substantially increases soil organic carbon.

5] Fertilization generally increases plant growth and soil organic carbon.

6] Increasing the length of forest tree rotations should increase stored carbon (both in woody biomass and in soil carbon)

7] Converting cropland to forest (afforestation) should increase total stored carbon

The actual amount paid for carbon sequestration services and the responsibilities of those selling carbon credits in the United States is largely dependent upon political and regulatory decisions that have yet to be made. It is possible, at this point however, to examine the European Economic Community as an example of an existing carbon credit trading system, to examine local western U.S. carbon sequestration projects, and to use current discussions underway in the U.S., to make some educated guesses about the nature of a U.S. National trading system that is most likely to emerge and the price range that carbon credits are likely to trade within.

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