WILHELM FARM
FACTSHEET

Climate Change, Agroforestry and Carbon Sequestration

The scientific evidence is that (1) the global climate is changing, and (2) human actions are the primary cause. We continue to burn carbon fuels in our vehicles, power plants and industrial manufacturing, and that is unlikely to change dramatically in the short term. It is more important than ever to understand how different ecosystems absorb carbon. Even on the scale of small farm and forest ownerships, Agroforestry can increase the sequestering of carbon. Further, it is usually more efficient at carbon capture than the annual and single crop perennial systems it replaces.

Global Measurements of Climate Change

The most well known measures of CO^2 concentrations in the atmosphere are taken on Mona Loa.[1] Fifty years of data illustrates the definite upward trend of CO^2 in the atmosphere (Figure 1A). The up and down swings within each year reflect the seasonal growth of north temperate forests and grasslands, and their increased ability to absorb carbon and reduce the ambient CO^2 in the atmosphere. More recent monthly average CO^2 data from Mauna Loa (Figure 2A) illustrate the same seasonal swings, but now with concentrations above 400 parts per million (NOAA 2018).

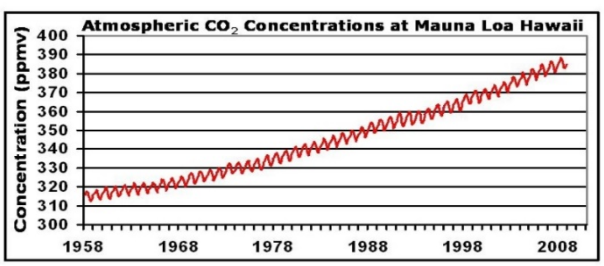

Figure 1: ***CO2 parts per million measured on Mona Loa, 1958-2008***

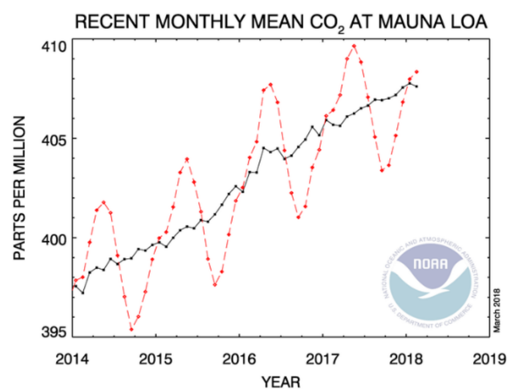

Figure 2: ***Monthly Means CO2 parts per million measured on Mona Loa, 2014-2018***

Theory of Greenhouse Gases and Global Warming Is Not New[2]

While our data for CO2 measurements may only go back 50 years, the understanding of how CO2 concentration Earth's temperatures goes back much further. In 1824, Joseph Fourier described what we now call the greenhouse effect – *how certain atmospheric gases trap heat*. Fourier, a famous French mathematician and physicist, asked a simple question: *why doesn't the planet keep heating up as it receives sunlight.* Fourier reasoned that the Earth would emit radiation absorbed from the Sun back into space, but 100% reflection would result in an icy

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[1] R.F. Keeling, S.C. Piper, A.F. Bollenbacher and J.S. Walker. Carbon Dioxide Research Group, Scripps Institution of Oceanography, University of California, La Jolla, California 92093-0444

[2] Adapted from David Wogan. 2013. *Why we know about the greenhouse gas effect*. *Scientific American*, May 16, 2013.

planet. *What was the temperature regulating mechanism that … keep[s] the planet from freezing or overheating?* Fourier's work prompted the discoveries that water and carbon dioxide in the atmosphere trap heat from escaping the atmosphere.

Climate Change in Southern New England[3]

New England's climate changed during the 20th century. Average annual temperatures increased by 0.08ºC (0.14^{o}F) per decade while average winter temperatures have increased by 0.12ºC (0.22^{o}F). The rate of temperature increases accelerated during 1970 to 2000 with average annual temperatures increasing by 0.25ºC (0.45^{o}F) per decade and average winter temperatures increasing by 0.70ºC (1.26^{o}F). The consequences of this change in temperatures include:

- Longer growing seasons, including fewer days with snow on the ground and earlier timing of peak spring stream flow.
- Significant increases in 1948-2007 rainfall data, including both the occurrence and intensity of extreme precipitation, with the most significant increases occurring recently.
- Projected increases in frequency and severity of heat waves and heavy precipitation events, plus predicted coastal sea level rise of 1.5 to 6 feet by 2100.

On April 26, 2019, The University of Connecticut Law School hosted a day-long conference on *Food & Our Changing Climate*, which integrated science and law. Two UConn professors highlighted the impact of these changes in the state.

Mark Urban, Ecology and Evolutionary Biology, notes that …*February 1985 was the last date we observed temperatures [that]were in the "normal" range*. It took 165 years of industrialization to raise the average global temperature 2°F. It only took 30 more years to raise the temperature another 4°F. This pathway will lead to dramatic changes across the globe.

Guiling Wang, Civil and Environmental Engineering, presented the results UConn Geography's Climate Lab work translating global trends into the impacts we will see on our local region. While much of the globe will become drier – including much of US – the Northeast will become wetter. Overall, Connecticut's annual mean temperature is rising:

1970 – 50.1°F

2050 – +5.1°F

2095 – +8.3°F

We expect more heat-waves of 6 consecutive 90°F days going from about 4 to 40 heat waves mid-century to 95 heat waves late in the 21st century. We also will have fewer frost days, with a predicted change in consecutive days without frost of 124 to 190 by end of century (with the largest decrease on the coast and the Connecticut river valley). These changes will lead to a longer growing season with more rain – 10% more by end of century. However, more rain will

[3] See *manomet.org/sites/default/files/publications_and_tools/Forestry_fact_sheet%205-13.pdf* for references to the data underlying this summary.

also lead to higher rates of transpiration, so actual water availability may not increase without storage facilities.

The panels following each speaker amplified these findings. The panel predicts that Connecticut farmers will move animals and crops north from the mid-Atlantic and Southeast. Pest and pathogen problems will increase. Also noted was that trees species will migrate north over time, which will influence silvicultural and agroforestry decisions.

Forest types (mixes of tree species) in the Northeast are likely to change significantly in the next 100 years under every climate change scenario. Predicted changes include less sugar maple, red maple, eastern hemlock, balsam fir, northern birches, and other northern hardwoods. Red and white oak probably will extend their ranges northward and upslope, and white pine will be less common in southern New England. Change in species distribution will be slow because canopy trees are long lived, can tolerate environmental stress, and are slow to spread seed. More rapid transformations may occur in disturbed areas where storms, fires, extreme heat, drought, or insect or disease outbreaks damage canopy trees. New non-native plants, pests, and pathogens will be introduced as climate change makes their growth and spread more likely, and will also intensify the negative effects of existing invasives.

Adaptive forest strategies include maintaining species, structural, and age class diversity. These sustainable management strategies for dealing with climate change are important because they:

- Create mosaics of habitats for existing and new wildlife species.
- Diversify stands – more species and age classes are less vulnerable to stress and disturbance.
- Reduce risk of loss and create economic opportunities by managing for species suited to changing climatic conditions
- Promote regeneration of native tree species.
- Adopt harvest strategies that retain some mature trees and create cohorts of younger.[4]
- Invasive plants thrive with warmer climate and require new control strategies.[5]

Agriculture is vulnerable to climate change.[6] New England farmers are faced with rising temperatures, shifting plant hardiness zones, more heat stress for livestock and crops, new invasive species and pests, increased water limitations, and more weather volatility. Along with challenges, however, will come opportunities, such as a longer growing season and evolving agriculture markets and crop options.

Rising temperatures increasingly will have negative impacts on animal agriculture in New England, including increasing heat stress in livestock. Heat stress can decrease animal health and productivity and will increase their water requirements. Dairy cattle are particularly sensitive because of their lower temperature thresholds

[4] **Note:** Shortened winter logging period, extended mud season, and increasingly frequent and severe storm events will reduce the number of days with conditions favorable for low-impact logging, increase logging costs as machinery sits idle, and increase pressure on managers to operate during marginal or unfavorable conditions.

[5] Track existing and emerging threats of invasive species. The US Forest Service's *Alien Forest Pest Explorer* supports tracking the range and determining forest susceptibility of over 70 pest species. Develop an effective monitoring program for invasive species.

[6] Facts from Grund, S., Walberg, e., 2013. Climate Change Adaptation for Agriculture in New England. Manomet Center for Conservation Sciences, Plymouth MA.

Higher temperatures will reduce water availability during summer months because transpiration from plants and evaporation from soil will increase. A general rise in drought frequency in the Northeast is likely, along with increased variability of weather. Changing weather patterns in New England may affect some of the region's staple crops. Uncertainty surrounds the "specific effects" of climate change on New England crops. A warmer growing season may provide opportunities for new crops in New England, and could even produce higher yields for some crops. Warmer temperatures will make for a longer growing season, and the higher levels of carbon dioxide in the air could potentially increase plant growth. However, increased growing season temperatures could also decrease yields in certain crops, for example cool-season grains. Apple production in the Northeast could benefit from the changing environment, but will also have increased risk and management requirements.

Several possible changes in farm strategies may mitigate losses from climate change:

- Explore different crop varieties.
- Update water management for increasing water needs of crops, including water conservation measures, maintenance of current irrigation systems and expansion of irrigation capacity.
- Alter harvesting schedule to take advantage of longer growing season or avoid adverse weather affecting crops; e.g., maple syrup farmers can tap trees earlier to avoid loss of sap flow days.
- Monitor for pest pressures for changing pest pressure (e.g., fungi, insects) and incorporate associated management techniques as necessary.
- Consider shifting marginal crop, pasture, orchard and woodlands to silvopasture or alley cropping.

Agroforestry Systems Add to Carbon Sequestration

Soil carbon plays a key role in the carbon cycle and carbon storage in soils is important in global climate models. The capacity of Earth's soil carbon storage exceeds the amount of carbon in the form of CO^2 contained in our atmosphere and all the carbon in the biosphere (biomass) combined. The tremendous ability for soil to store carbon, means that agriculture, forestry and agroforestry can play a lead mitigation role in reducing climate change.

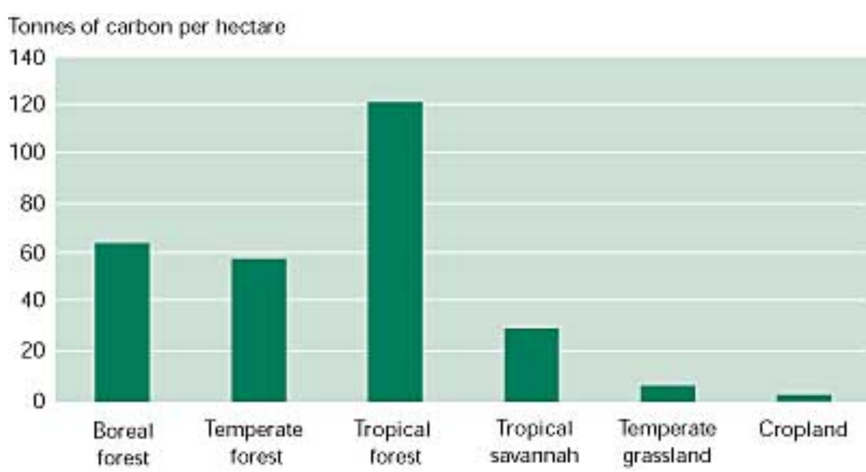

Figure 3: *Distribution on stored carbon by world regions*
(note: a metric tonne is 2200 pounds – 10% more than the US ton).

A shift toward an agroforestry system serves several purposes is the southern New England, including potentially reducing climate change. Our WF Factsheet No. 1 defines agroforestry systems: *Agroforestry is a mix of systems that take advantage of complexity to produce an integrated set of values. They are important illustrations of perennial plant mixes and are considered more today because we are taking a holistic view of our landscapes and their management.*[7]

Land management systems generally provide more financial and environmental benefits and incur lower costs if they imitate the original natural ecosystem. The most important biophysical benefits are improved soil health and productivity, which improves land conservation, but other benefits include:[8]

- Agroforestry utilizes solar energy more efficiently than monoculture systems because different heights, leaf shapes and alignments capture more energy for photosynthesis.
- Mixed species systems often lead to reduced insect pests and associated diseases.
- Agroforestry provides more diverse farm household economies and stimulates rural economies, leading to more stability and lower risks by producing multiple products.

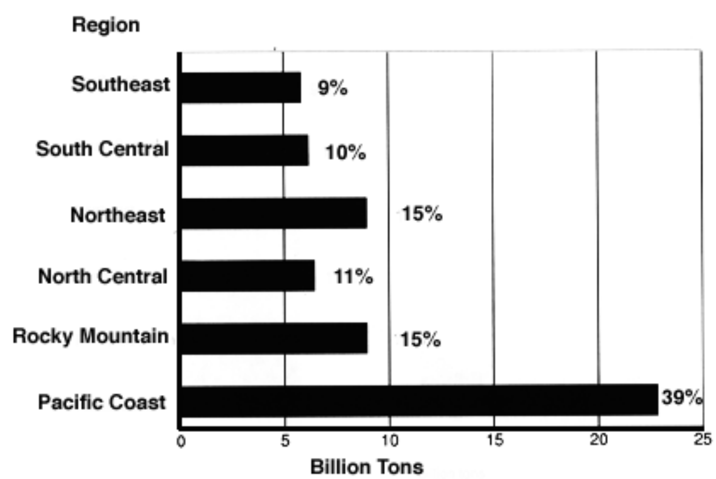

Figure 4 - Total carbon storage in U.S. forest ecosystems by region. Total storage in the United States is 57.8 billion tons.

Figure 4: *The Northeast contains about 15 percent of U.S. forest carbon.*

Moving from crop agriculture to perennial grass or trees increases the stored carbon in soils. Crop soils store 30% to 40% less below-ground carbon compared to natural grasslands or forests.[9] Natural grasslands and forests have more photosynthesis per acre, which means more capture of CO^2 per acre. This advantage is amplified by the long-term storage of carbon in the root systems of both perennial grasses and trees, plus tree's long-term storage of carbon in above-ground stems and branches. These factors make agroforestry, in many soil and ecological settings, a sensible strategy for reducing the impact of climate change.

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[7] WF Factsheet No 1. *Agroforestry Systems – A Summary*.

[8] See WF Factsheet No 1. *Agroforestry Systems* for more details and references.

[9] Poeplau, Christopher; Don, Axel. *Carbon sequestration in agricultural soils via cultivation of cover crops – A meta-analysis. Agriculture, Ecosystems & Environment.* ***200*** *(Supplement C): 33–41.*

The largest proportion of carbon in the average U.S. forest is found in the soil. Soil contains 59 percent of the carbon in the forest ecosystem, or approximately 93 thousand pounds per acre (10.4 kg/m2). About 9 percent of all carbon is found in litter, humus, and coarse woody debris on the forest floor, and about 1 percent is found in the understory vegetation. When one adds the carbon in tree roots to the carbon in the soil, the average proportion of carbon below the ground in the US forests is estimated to be 64 percent.

An acre of established temperate forest can sequester 2,000 pounds to 6,000 or more pounds of carbon per year, depending on the age of the trees and other conditions. Mature grasslands sequester 2,400-3,600 lbs. per acre each year. From a global perspective, grasslands store approximately 34% of the global terrestrial stock of carbon while forests store approximately 39%, agro-ecosystems approximately 17 percent with the remaining 10 percent in other ecosystems.[10] Unlike forests, where the above-ground vegetation represents an important carbon storage component, most grassland carbon is stored in the soil.[11]

Intuitively it makes sense that forest-like agriculture will sequester carbon somewhat like a "real" forest. Broadly speaking this appears to be the case. In their excellent 2004 review of the subject, Nair and Montagnini state that agroforestry systems generally sequester somewhat less carbon than forests, but much more than most annual cropping systems[12] Many agroforestry systems integrate functional trees, like nitrogen fixing legumes, with annual crops and production of non-timber forest products, like nuts, fruits, and other perennial crops (forest farming can include perennial crops like ramps and fiddle heads.

With more focused design, Eric Toensmeier argues integrated agroforestry systems could come much closer to the amounts of carbon sequestered in managed forests, and he advocates Carbon Farming: *There are several, sometimes conflicting, definitions of carbon farming currently in circulation. Most definitions agree that the term refers to farming practices that sequester carbon.*[13]

Beyond that agreement, many definitions focus on creation of carbon offsets. A carbon offset is the sequestering of a specific amount of CO^2, usually one-metric tonne (MT). Carbon credits are purchased by emitters of CO^2 to demonstrate compliance with some formal or informal rules. Markets currently exist for trading of carbon offsets; e.g., European Union, China, and California/Quebec and EU carbon prices/MT are listed like stock or bond prices. Toensmeier is not favorably disposed to carbon offset markets because:

> *... even when they're functioning optimally, they don't reduce the total amount of greenhouse gases and instead just maintain their current dangerous level (unless a "shrinking cap" is built in, which has not yet happened anywhere to my knowledge). Two, and more important, is that they have largely failed to work and have also been vulnerable to corruption.*

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[10] World Resources Institute 2000

[11] Janzen et al 2002

[12] P.K. Nair and Francesca Montagnini. 2004. *Carbon sequestration: An underexploited environmental benefit of agroforestry systems*, in Agroforestry Systems 61:281-295. Most annual systems are net releasers of soil carbon to the atmosphere, and the mechanized practice add CO^2 emissions because of heavy fossil fuel use.

[13]Eric Toensmeier. 2016. The Carbon Farming Solution: *A Global Toolkit of Perennial Crops and Regenerative Agricultural Practices for Climate Change Mitigation and Food Security*. Chelsea Green Publishing. 512 p.

This may change if the US and Canada join a global cap and trade system that includes Europe, China and India. For such a system to work, cap values would have to shrink, making carbon credits more valuable. Functioning markets would encourage enforcement of carbon property rights if effective measurement and monitoring systems are used.[14]

[14] See proposed simple, inexpensive monitoring system based on simple metrics in ***Biophysical Metrics for Agroforestry*** (Wilhelm Farm Factsheet No. 4). Precise systems necessary for cap and trade or other carbon credit schemes would be expensive