Estimating the Environmental Footprint of New York Apple Orchards

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There is currently a great and growing awareness of the importance of the environmental consequences of each of our activities. Growers also wish to know the environmental footprint of their operations since, as stewards of the land with plants that absorb carbon dioxide (CO_2), they have a potentially greater impact than the average citizen. Consumers and retail outlets are beginning to request information on grower's environmental impacts and purchase products from those they feel are most environmentally sound. Growers in other states are beginning to conduct environmental footprint studies to both understand and improve their environmental effects, but also to inform and assure their customers about them.

"The environmental footprint of an apple orchard is both positive and negative. Some CO_2 is released to the atmosphere in the production of the crop (making and using the fuel, fertilizers, and pesticides), but we estimate that an acre of orchard fixes about 20 tons of CO_2 from the air each season, releases 15 tons of oxygen, and provides over 5 billion BTU's of cooling power. In addition, some carbon is sequestered in the new wood and roots of the trees."

Unfortunately, growers have been limited in their ability to estimate the full environmental footprint for their operation. Reasonable estimates are available for energy costs and environmental impacts of the energy and greenhouse gas emissions related to making and using fuel, fertilizer and chemicals used in orchards, fruit storage, costs of fruit storage, machinery used in the orchard and storage, transportation, etc. An excellent web site for these farm-scale greenhouse gas emissions calculations is http://www2.cplan.org.uk/. The site provides a downloadable review of the topic as well as a calculator itself. However, quantitative estimates of the positive effect of trees' carbon dioxide (CO_2) uptake and other environmental effects, cooling effects, oxygen generation, are rare and preliminary at best.

There are both positive and negative aspects to an environmental footprint. Besides the negatives of energy use, and possible environmental degradation (erosion, pesticide drift), orchards have many positive effects. They fix CO_2 from the air rather than give it off. Plants in the process also give off oxygen, and when they evaporate water, they cool the environment. These factors are real but are often not discussed.

Models of apple tree carbohydrate relationships and water use have been developed in our lab that can provide some initial estimates of these environmental impacts. The carbohydrate model can estimate seasonal tree and orchard CO_2 fixation, and the distribution of carbon to the crop and the rest of the tree for a range of orchard configurations and for apple-producing regions of NY by using weather data from each region. The model has been validated for dry matter production against studies in several climates with very good results.

This project focused on estimation of these processes as affected by long-term climates of Western NY (represented by Geneva weather), the Hudson Valley (Poughkeepsie) and the Champlain Valley (Peru).

Objectives of the Research

- Refine and utilize the apple tree carbohydrate model to develop the best estimates of apple tree and orchard carbon fixation and oxygen evolution from apple orchards in different regions of NY.
- Utilize NY-specific data and models of water use to estimate evaporative cooling effects of apple orchards in the NY climate.
- Evaluate methods to integrate these estimates into broader models for the entire orchard (trees, soil and cover crops) and orchard operations.

Procedures Used

Estimating Carbon Relationships: These estimates were generated by the "MaluSim" apple carbon model of Lakso, et al. (2001 and later modifications) that is a simplified, but adequately comprehensive model of apple tree sunlight capture, photosynthesis, respiration and carbohydrate distribution to the parts of the trees. The model has been used successfully to estimate total dry matter production by apple orchards checked against measurements taken in different orchards and in different climates. It is the same model being currently used by Terence Robinson to integrate weather and tree sensitivity to chemical thinners for refining thinning practices.

The model was run with average NY weather data (max and min temperatures and sunlight radiation) from the primary production areas of Western NY, the Hudson Valley and the Champlain Valley. Geneva weather was used for Western NY as we have a long history of this kind of needed data, especially sunlight radiation. Although long-term temperature data is plentiful for the Hudson and Champlain Valleys, there is very little sunlight radiation data. So we worked with Art DeGaetano, the Director

of the NE Climate center at Cornell who used a proven method to estimate sunlight radiation averages for 10 years from airport sky observations in Poughkeepsie and Burlington, VT. The data were used with 30-year temperature averages from Poughkeepsie and Peru. Note that the model calculations assume a mature cropping orchard that is average for sunlight interception.

Oxygen Production: When a molecule of CO_2 from the air enters a leaf and is fixed by photosynthesis, a molecule of oxygen (O_2) is released. Since O_2 is lighter than CO_2, about 73% as much weight is released. So, if 1 ton/acre of CO_2 is fixed, about ¾ ton/acre of oxygen is released.

Water Use and Evaporative Cooling: In previous studies in our lab, we measured and modeled the water use by an apple orchard in NY weather conditions. In general it appears that over a season, 15-18 acre-inches of water (400,000 to 500,000 gallons/acre at about 27,000 gallons per acre-inch) is used by the trees in a typical NY orchard. The evaporative cooling was calculated from standard physics of energy for this amount of water loss by the trees. The cover crops in the alleyways also evaporatively cool by using water. Our previous study of cover crop water use in vineyards provided estimates that the cover crops would use about 50-60% as much as the trees.

Results

The estimates of CO_2 fixation for Geneva are better than for Peru or Poughkeepsie due to the accurate sunlight data. Nevertheless in general the results for CO_2 fixation were quite similar for all regions. On average, an acre of apple trees fixes about 11-12 tons of CO_2 per acre per season, producing 7-8 tons/acre of dry matter (Table 1). For the Hudson Valley, the models suggest that although it is a sunnier and longer season than Geneva so there is more potential to capture CO_2, it is also warmer so higher respiration for growth will burn up more CO_2. These tend to counteract one another, giving similar but slightly higher final values compared to Geneva. For the Champlain Valley, it is similarly sunnier, but cooler, which is best for net photosynthesis per day. However, the season is shorter in the Fall. So, again similar values were found.

Estimates of oxygen released by an acre of trees are roughly 8-9 tons of oxygen/season (Table 1). Again, regional differences were minor.

Role of Cover Crops in Alleyways Although the cover crops in the alleyways vary in species composition and thus may vary somewhat in CO_2 fixation and dry matter production, in general, it is estimated that they produce similar amounts of dry matter to the trees. This is estimated to be due to their somewhat higher photosynthesis rates than apples, but somewhat less sunlight interception (40-45%) versus the trees (50-55%). The combined CO_2 fixation of the trees and the cover crops was estimated to be about 20 tons of CO_2 per acre per season producing about 13 tons/acre of dry matter with little difference between locations (Table 2).

Cooling Effects The cooling effects of orchards were estimated to be:

Trees – 3.5-4 billion BTU's per acre per season (equivalent to about 85-90 air conditioners of 10,000 BTU capacity running 24/7 for 6 months).

Whole Orchard including cover crops – 5-5.5 billion BTU's/acre (equivalent to 120-125 air conditioners of 10,000 BTU capacity running 24/7 for 6 months). These are substantial cooling effects per acre.

Table 1. Estimates of carbon dioxide fixation per acre per season - trees only

Location	Net CO_2 Fixed (tons per acre per season)	Total Dry Matter (tons per acre per season)	Oxygen Released (tons/acre per season)
Geneva	11.6	7.3	8.5
Poughkeepsie	11.8	8.0	8.6
Peru	11.0	7.0	8.0

Table 2. Estimates of carbon dioxide fixation per acre per season whole orchard (trees + cover crops).

Location	Net CO_2 Fixed (tons per acre per season)	Total Dry Matter (tons per acre per season)	Oxygen Released (tons/acre per season)
Geneva	20	13	15
Poughkeepsie	21	14	16
Peru	19	12	14

Can We Estimate Carbon Sequestration of Orchards?

Sequestration of carbon is a key issue in relation to reducing the increases in atmospheric CO_2 and is the basis of possible carbon credits for growers. Sequestration means to trap and hold something (carbon in this case) for long periods (though how long is not always agreed upon). The crop sequesters carbon but only for a short time until the fruit is eaten. We can estimate how much carbon is sequestered in the structure of trees but all too often trees are burned when they are grubbed, thus releasing all the sequestered carbon. Evaluation of several soil and whole system models to estimate carbon sequestration is continuing but these models are very complex and being run with too little data.

We unfortunately have scarce data on key issues of how dry matter such as apple prunings and roots add to sequestered carbon. A major limitation is understanding the fate of carbon that goes to and through roots. A key in this aspect is to improve soil organic matter (OM). However, soil OM values tend to level out at higher percentages. In arid climates where they have done clean cultivation, their soils are often low in OM and they can sequester C via increased OM additions. In general, in NY we have quite high soil organic matter, so our potential to sequester more is somewhat limited (we have already been doing a good job for decades!).

Dry matter produced per tree that could be sequestered depends on the weather and is relatively consistent from year to year. But the heavier the crop, the more dry matter goes into the crop and less into structure (Figures 1 and 2). So the heavier the crop, the lower the potential to sequester carbon. Overall, with our modern orchards that produce good yields on dwarf trees on heavier soils with generally high organic matter we probably have limited opportunity to sequester much more carbon that we do now, unless we produce lower crops (not recommended). Leaves fall to the ground and can add to the soil carbon, but microbial action will release CO_2 during degradation. The wood of the tree is the best place to sequester carbon as it is held without microbial degradation.

These values of carbon sequestered for different orchards will differ primarily by how much sunlight they capture, since sun energy drives carbon fixation. Sparse orchards with low light interception will fix less carbon though the alleyways will fix more.

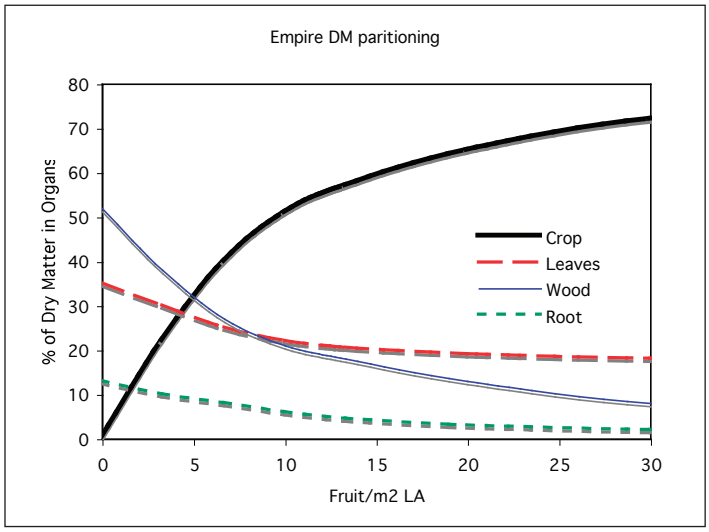

Figure 1. General relationship of total dry matter per acre distributed to parts of the tree with increasing crop on the tree. As crop goes up, less dry matter goes into structure and potential C sequestration. Relationships were averaged over the course of several studies by Hansen, Heim and Landsberg, Palmer and Lakso.

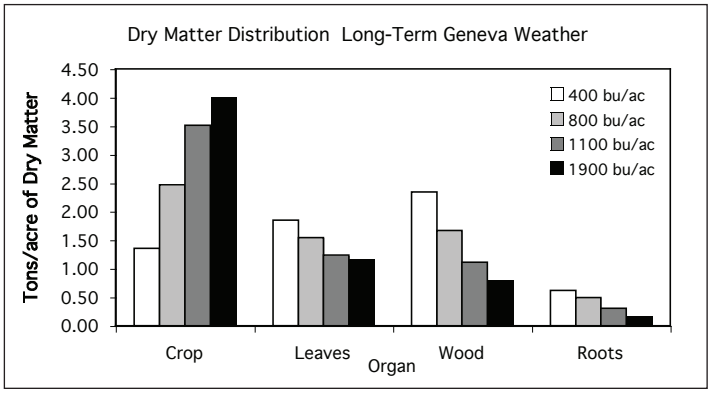

Figure 2. Estimates of total dry matter per acre distributed to parts of the tree (tons/acre).

With the compensation of trees vs. cover crops the total CO_2 fixed will be similar; however, the potential to sequester carbon may differ if the mix of grass to trees changes.

Summary

Apple orchards in NY have several positive environmental impacts. An acre of orchard each season fixes about 20 tons of CO2 from the air, releases 15 tons of oxygen, and provides over 5 billion BTU's of cooling power. Carbon is sequestered by trees, though estimates are hard to make at this time due to lack of key knowledge.

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