# ONLINE TOOL FOR ESTIMATING CARBON STORAGE IN AGROFORESTRY PRACTICES

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**Abstract:** The CarbOn Management Evaluation Tool for Voluntary Reporting (COMET-VR) is an online tool developed by the USDA Natural Resources Conservation Service and Colorado State University to estimate carbon sequestration in farm and rangeland soils under user-specified management scenarios. Development is underway to expand the capabilities of COMET-VR so users will be able to estimate changes over time in carbon storage (CS) in above- and below-ground components of agroforestry practices. Individual tree biomass is calculated using diameter-based allometric equations generalized for species groups. The Century soil carbon model, linked to COMET-VR, is used to estimate CS in soil for agroforestry plantings established within the last 20 years. Estimates of biomass growth and therefore reportable CS flux over the next 10 years are based on inventory data from both windbreak and forest plots in different regions of the US. The tool output will be an estimate of the annual change in CS suitable for use in the US Dept. of Energy voluntary greenhouse gas reporting program. It will also allow users to compare potential CS in agroforestry and other agricultural practices.

**Key Words**: carbon sequestration, biomass, allometric equations, soil carbon, greenhouse gas reporting

**Mots clés**: agroforesterie, flux de carbone, biomasse, modèle allométrique, carbone du sol, comptabilité de carbone

## INTRODUCTION

Agroforestry practices contribute to the storage of carbon in temperate-zone agricultural landscapes while maintaining food and forage production (Brandle et al. 1992, Montagnini and Nair 2004, Oelbermann et al. 2004). Planting woody vegetation on farm and rangelands not previously forested, i.e. afforestation, can significantly increase carbon storage (CS) in soils, vegetation and other components therein.

Practical methods have recently been developed to estimate CS on cropland, pasture and forests. Examples of carbon accounting methods for forest stands include the use of look-up tables generalized by forest type and region (Smith et al. 2006), computerized models of tree biomass growth that reflect stand conditions and silvicultural practices (e.g., the carbon submodel of Forest Vegetation Simulator, http://www.fs.fed.us/fmsc/fvs/index.shtml), and periodic direct measurement of the structural components of forests in which carbon is stored (Brown et al. 2004).

For farm and range lands, the online Carbon Management Evaluation Tool for Voluntary Reporting (COMET-VR) enables landowners to rapidly estimate potential CS in agricultural

soils under various land management practices in the conterminous U.S. It uses the Century Soil Organic Matter model, a generalized biogeochemical ecosystem model that simulates changes in soil carbon, nitrogen and other elements (Parton et al. 1993). COMET-VR is designed to comply with the requirements for voluntary reporting of carbon emissions under the US Dept. of Energy's 1605(b) program (http://www.eia.doe.gov/oiaf/1605/frntvrgg.html). It is publicly available at www.cometvr.colostate.edu.

Since agroforestry by definition includes elements of both agricultural and forest landscapes, an appropriate carbon accounting system will include methods from both land uses. This paper describes the development of methods for estimating changes in CS in agroforestry practices that will be incorporated into COMET-VR, along with an example of its use to compare carbon values under different agricultural practices.

## MATERIALS AND METHODS

Work to incorporate agroforestry practices into COMET-VR began at the USDA Natural Resources Conservation Service's (NRCS) West National Technology Support Center (WNTSC) in 2006. The agroforestry extension will enable users to estimate CS in the five most common temperate-zone practices, i.e., Windbreaks, Alley Cropping, Silvopasture, Riparian Forest Buffers, Multi-Story Cropping (also known as Forest Farming), as well as an additional category, Farm Forests and Woodlands. In keeping with the design criteria for COMET-VR, the agroforestry extension is designed for relative ease of use, national-scale (conterminous US) applicability, and reasonable estimation across a wide range of site factors.

Carbon can exist within various pools in agroforestry systems depending on their structure and management, including live trees, standing and down dead trees, understory shrubs, annual crops, leaf litter, and soil. However, most of the change in CS occurs as result of growth, and thus biomass accumulation, of live trees. Other pools such as down deadwood, understory and litter change relatively slowly (Smith et al. 2006). Technical guidelines for forestry reporting of greenhouse gases recommend measuring and monitoring of carbon in the live trees (above and below-ground) and soil pools of agroforestry projects (US DOE 2006a).

Although soil is an important reservoir of organic carbon, short-term change is significant only following afforestation of previously cultivated land (Guo and Gifford 2002, Post and Kwon 2000). Due to the 10-year reporting period for the US DOE 1605(b) program, changes in soil carbon are only estimated by COMET-VR for agroforestry plantings less than 20 years old. Otherwise, live trees are the only carbon pool in agroforestry systems for which fluxes are estimated by COMET-VR.

To calculate biomass and thus carbon content at the baseline (current) age, COMET-VR will use a series of diameter-based allometric equations developed by the US Forest Service (Jenkins et al 2003). They predict total (above- and below-ground) dry weight biomass of individual trees from diameter at breast height (dbh) for all US tree species divided into ten different groups by genera (Table 1). The meta-analysis performed by the authors produced a set of equations designed to be used at the national scale over all sites, slopes, aspects, elevations, etc.

Table 1. Tree genera groups for biomass equations (adapted from Jenkins et al. 2003)

| | **Genera Group** | **Representative Genera** |
|---|---|---|
| **Hardwood** | Aspen/alder/cottonwood/willow | *Alnus, Populus, Salix* |
| | Soft maple/birch | *Acer, Betula* |
| | Mixed hardwood | various |
| | Hard maple/oak/hickory/beech | *Acer, Carya, Fagus, Quercus* |
| **Softwood** | Cedar/larch | *Calocedrus, Larix, Sequoia* |
| | Douglar-fir | *Pseudotsuga* |
| | True fir/hemlock | *Abies, Tsuga* |
| | Pine | *Pinus* |
| | Spruce | *Picea* |
| **Woodland** | Juniper/oak/mesquite | various |

Before one can begin using the COMET-VR tool, they must first perform an inventory of the standing live trees within the parcel of land for which they wish to estimate CS. Basic inventory information required will include the tree genera present, average dbh of the sampled trees in each genera group, and the estimated number or percentage of trees of that group on the parcel. For landowners who do not already have inventory data available, two different sampling methods are suggested. For linear plantings such as windbreaks and alley cropping, strip sampling within row segments is recommended, and for other agroforestry types, the zig-zag transect method is suggested (NRCS 2004). Guidelines and documentation for sampling methods will be provided in the COMET-VR online help file.

Once the COMET-VR tool is accessed online, the user will first be asked to enter some general information about the parcel they're reporting, including state, county, parcel size, and the average age of the agroforestry planting. From inputs of state and county, the parcel's location at two regional scales will be identified: Major Land Resource Area (MLRA) and the larger-scale Land Resource Region (LRR) (NRCS 2006a).

If the agroforestry planting is either new or less than 20 years old, the user will then be asked a series of questions leading to a description of conditions and a history of land management:

1. The predominant soil texture of the parcel, and whether or not the soil is hydric.
2. The land management applied during four time periods (pre-1970's, 1970 to mid-1990's, mid-1990's to current year, and next 10 years) from choices of irrigated and dryland crop rotations that are common in the MLRA of the parcel being assessed.
3. For the time periods from 1970 and later, the intensity of tillage utilized, e.g. intensive, reduced or no-till.

All these inputs are then transmitted by COMET-VR to the Century model which estimates the annual change in soil carbon over the next 10 years. This soil carbon calculation will be skipped for plantings established more than 20 years before present.

The next step will be to calculate the biomass of live trees on the parcel at the present (baseline) year. The user is asked to supply the information collected from their inventory sample (see

above), along with the average age of trees in each genera group. Landowners in the Northwest growing Douglas-fir and those in the Southeast growing pine species may also specify the site productivity of their parcel, if known. Based on user input, COMET-VR then calculates total individual tree biomass for each genera group using the appropriate allometric equation coefficients.

Once the baseline biomass of an average tree in each genera group is estimated, the next step will be to predict how much that tree will likely grow over the next 10 years in the geographic region where the parcel is located. Recent data collected from permanent inventory plots both in forest stands (US Forest Service, Forest Inventory and Analysis, http://fia.fs.fed.us) and windbreaks (NRCS Ecological Site Inventory, http://esis.sc.egov.usda.gov/Welcome/ pgFSWelcome.aspx) in each state for which data are available were accessed online. Because FIA inventory data are collected over a range of stand conditions from dense, closed-canopy forest to sparsely-stocked stands, it was necessary to filter the data to select only those from relatively young, open stands which would more closely match the conditions found in agroforestry practices. Data were selected for the following criteria: All-live stocking class less than 59%; tree crown class co-dominant, dominant or open-grown; and age (corrected to "breast height" age) less than 126 years. For NRCS windbreak plots, it was not necessary to filter the ESI data.

Using the filtered FIA and unfiltered ESI datasets, coefficients were calculated for nonlinear regressions of age versus dbh for each genera group in each state, LRR and productivity class. Where data for genera groups were insufficient at the state level, data were combined by LRR and those regional values were used instead. In the few cases where both FIA and ESI data were available for the same genera group and location, the source that produced the higher $r^2$ was used. The difference between baseline and future (10 year) individual tree biomass, predicted by the appropriate growth equation, will then be used as the growth increment for trees in that genera group.

The final calculation step will be to expand the estimated 10-year biomass growth of an individual tree by the number or percentage of trees in that genera group over the whole parcel. Predicted growth values for all genera groups present are summed to give a total biomass flux for the parcel. This value is converted to carbon assuming a factor of 50% of dry-weight biomass. For new plantings (< 20 years) only, the annual soil carbon flux predicted by Century is added to the total. The final result reported to the user is the annual change in carbon mass (and $CO_2$ equivalent) for the parcel. If soil CS was estimated by Century, an uncertainty value will also be reported for that pool. However, due to the scarcity of long-term, well-documented agroforestry experiments, uncertainty values will not be estimated for carbon flux in live tree biomass.

## RESULTS AND DISCUSSION

The alpha-version of the COMET-VR agroforestry extension and version 1.1 of the COMET-VR tool for agriculture were used to compare predicted CS values for a hypothetical parcel of cropland versus the same parcel with a field windbreak.

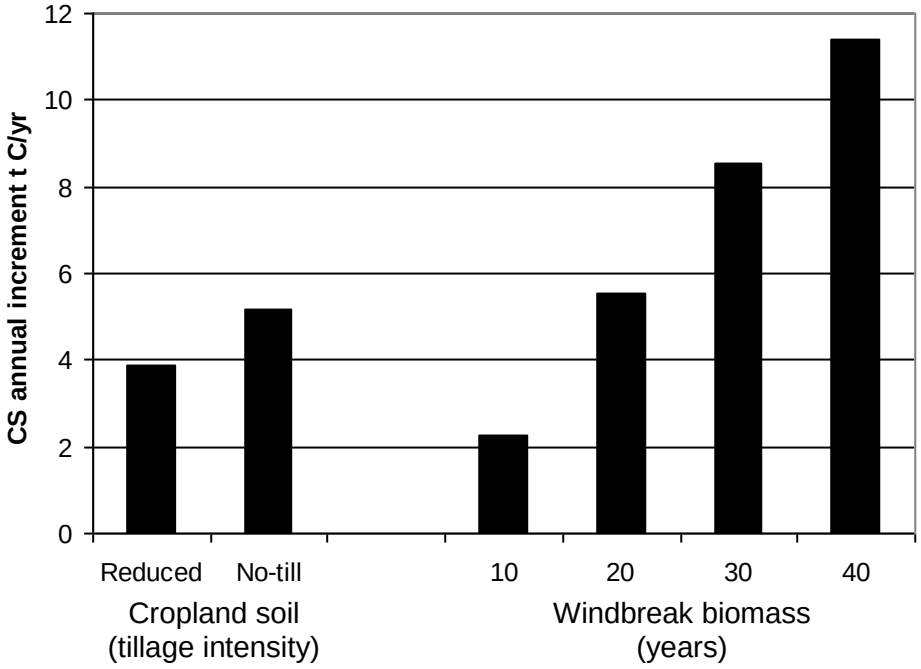
The example is a 50 ha parcel of non-irrigated cropland (non-hydric silty clay loam soil) in Lancaster County, Nebraska cropped with a corn (maize)-soybean rotation using conservation

tillage. Based on past and current use of conservation tillage practices on the example parcel, COMET-VR estimated the annual CS increment for the next 10 year period under reduced tillage at 3.9 t C $yr^{-1}$ and under no-till at 5.2 t C $yr^{-1}$ (Fig. 1).

To compare estimated CS with an agroforestry practice, a four-row field windbreak planted along two sides of the same cropland parcel was modeled. The windbreak consisted of two rows each of pine and mixed hardwood trees. Trees occupied 1.7 ha, approximately three percent of the total land area.

Using the agroforestry extension of COMET-VR, CS of the windbreak trees was estimated over time (Fig. 1). From 10 to 40 years, the periodic annual increment in CS for the windbreak increased from 2.3 to 11.4 t C $yr^{-1}$. The steady increase in CS from the windbreak mirrors the growth of the trees predicted using the methods described above and assumes that site factors are not limiting. At some older age, the annual increment would reach a plateau according to the biological growth potential of the trees. In contrast, annual CS from cropland soil under conservation tillage will remain at a steady, but lower rate for the next 10 year period and will likely decline thereafer. For the whole parcel, annual CS accrual rate for the cropland soil with conservation tillage exceeds that for the windbreak biomass until about 15 years after the trees were planted. However, it appears that more C will be stored in the parcel over the long term by adding a windbreak compared to only using conservation tillage on the cropland.

Fig.1. Annual increment in CS for the example 50 ha parcel for windbreak biomass over time and for cropland soil for ten years under a corn-soybean rotation with conservation tillage.




COMET-VR's estimate of biomass growth, and thus carbon flux, is based on the use of allometric equations, i.e. from Jenkins et al. 2003, that were originally derived from data collected in forest stands where stocking levels are likely higher than would be found in

agroforestry practices. Therefore, it is possible that the use of forest-derived biomass equations may underestimate biomass in more open-grown agroforests. Recent studies involving destructive sampling of trees growing in windbreaks in the U.S. Great Plains suggest that forest-derived equations may underestimate biomass of individual trees by at least 22% (Zhou, X., Brandle, J.R., Schoeneberger, M.M., Awada, T. and Mize, C.W. unpublished data). Since similar studies have not been performed on other genera in other locations, it is not possible at present to correct the values calculated by COMET-VR using the forest-derived biomass equations. However, filtering the forest inventory data to mimic the more open-grown conditions found in agroforestry, as described above, will help reduce this potential over-estimation.

## CONCLUSIONS

COMET-VR is a first attempt to develop a user-friendly carbon accounting system for agroforestry practices in the contiguous US. The intended audience includes private landowners, farmers, ranchers, non-industrial private forest owners, NRCS field staff, and technical service providers. Public release of agroforestry extension of COMET-VR is expected in the later half of 2007. It will be available at same URL (see above).

Because it is based on allometric equations and growth estimates derived from regional datasets, the estimates produced by COMET-VR are generalized estimates for a site-specific location. More accurate accounting of biomass growth, and thus carbon flux, would require more site-based information, e.g. site index or localized growth curve formulae. This would be possible only for those genera groups and locations where large inventory plot datasets are available.

Woody shrubs or multi-stemmed trees are often used in agroforestry practices, e.g. windbreaks, and they contribute some amount of CS, although less than larger trees. Two relatively simple methods have been developed to estimate biomass of shrubs in windbreaks, based either on “shelterbelt volume” of the shrub row (Kort and Turnock, 1999) or on diameter measurements of the three largest stems in the shrub crown (Zhou et al. 2007). Although insufficient data are available at present to derive equation coefficients for either method for all shrub genera in all potential locations, it is possible that a future release of COMET-VR could include a procedure for estimating biomass, and thus CS, of shrubs in agroforestry plantings.

Another potential future improvement for COMET-VR would involve further parameterization of the Century model to better predict soil carbon dynamics under agroforestry systems. Some field studies have been conducted to quantify changes in soil carbon in temperate-zone agroforestry practices, including alley cropping (Oelbermann and Voroney 2007, Peichl et al. 2006), riparian buffers (Tufekcioglu et al. 2003), silvopasture (Sharrow and Ismail 2004) and windbreaks (Kort and Turnock 1999, Sauer et al. 2005). Results of these and future studies in other locations would help parameterize the Century model for agroforestry.

We expect the agroforestry extension of COMET-VR to be used for a variety of purposes. It will be used under the DOE 1605(b) program for voluntary reporting. Landowners can already receive a subsidy for testing COMET-VR under the Conservation Security Program (NRCS 2006b). It is possible that other conservation provisions of the forthcoming Farm Bill in the US

will encourage farmers to adopt practices such as agroforestry that increase CS and to monitor carbon fluxes with COMET-VR.

If it is accredited for such use, COMET-VR could also be used to monitor and report CS in agroforestry practices which are established as carbon offset projects under contracts with state programs (e.g., Regional Greenhouse Gas Initiative, http://www.rggi.org) or private companies (e.g., Chicago Climate Exchange [CCX], http://www.chicagoclimatex.com). For example, some private organizations, acting as aggregators of forestry carbon offset projects for CCX, are currently offering contracts for new riparian buffers and other widely-spaced (<625 stems ha) tree plantings (e.g. Iowa Farm Bureau, http://www.iowafarmbureau.com/carbon). The availability of an accredited, user-friendly tool for CS estimation will help landowners wishing to enroll their agroforestry plantings as carbon offset projects.

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## LITERATURE CITED

Brandle, J.R., Wardle, T.D. and Bratton, G.F. 1992. Opportunities to increase tree plantings in shelterbelts and the potential impacts on carbon storage and conservation. *In* Forests and Global Change. Edited by R.N. Sampson and D. Hair. American Forests, Washington, D.C. pp. 157-175.

Brown, S., Shoch, D., Pearson, T. and Delaney, M. 2004. Methods for measuring and monitoring forestry carbon projects in California. Winrock International, for the California Energy Commission, PIER Energy-Related Environmental Research, 500-04-072F, 40 p.

Guo, L.B. and Gifford, R.M. 2002. Soil carbon stocks and land use change: a meta analysis. Global Change Biology 8:345-360.

Jenkins, J.C., Chojnacky, D.C., Heath, L.S. and Birdsey, R.A. 2003. National-scale biomass estimators for United States tree species. Forest Science 49(1):12-35.

Kort, J. and Turnock, R. 1999. Carbon reservoir and biomass in Canadian prairie shelterbelts. Agroforestry Systems 44:175–186

Montagnini, F. and Nair, P.K.R. 2004. Carbon sequestration: an underexploited environmental benefit of agroforestry systems. Agroforestry Systems 61:281-295.

Natural Resources Conservation Service. 2004. National Forestry Handbook, title 190. PDF document accessed 4 April 2007 at http://soils.usda.gov/technical/nfhandbook.

Natural Resources Conservation Service. 2006a. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean and the Pacific Basin. Agriculture Handbook 296.

Natural Resources Conservation Service. 2006b. Air Quality Enhancement Activities: Carbon Sequestration Scenario Examination. CSP Worksheet. Word document accessed 18 April 2007 at http://www.airquality.nrcs.usda.gov/programs/CSP%20Documents/Official%202006%20COMET-VR%20Enhancement%20EAM-40.doc

Oelbermann, M. and Voroney, R.P. 2007. Carbon and nitrogen in a temperate agroforestry system: Using stable isotopes as a tool to understand soil dynamics. Ecological Engineering 29: 342–349.

Oelbermann, M., Voroney, R.P. and Gordon, A.M. 2004. Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and southern Canada. Agriculture, Ecosystems and Environment 104:359-377.

Parton, W. J., Scurlock, J. M. O., Ojima, D. S., Gilmanov, T. G., Scholes, R. J., Schimel, D. S., Kirchner, T., Menaut, J.-C., Seastedt, T., Moya, E. Garcia, Kamnalrut, A. and Kinyamario, J. I. 1993. Observations and modeling of biomass and soil organic matter dynamics for the grassland biome worldwide. Global Biogeochemical Cycles 7(4):785-810.

Peichl, M., Thevathasan, N.V., Gordon, A.M., Huss, J. and Abohassan, R.A. 2006. Carbon sequestration potentials in temperate tree-based intercropping systems, southern Ontario, Canada. Agroforestry Systems 66:243–257.

Post, W.M. and Kwon, K.C. 2000. Soil carbon sequestration and land-use change: processes and potential. Global Change Biology 6:317-328.

Sauer, T.J., Cambaradella, C.A. and Brandle, J.R. 2005. Soil carbon content within a red cedar-Scotch pine shelterbelt. *In* Moving Agroforestry into the Mainstream. Proc. Ninth North American Agroforestry Conference, Rochester, MN. 12-15 June 2005. Edited by K. Brooks and P. Ffolliott. PDF document accessed 4 April 2007 at http://cinram.umn.edu/afta2005/pdf/Sauer.PDF.

Sharrow, S.H. and Ismail, S. 2004. Carbon and nitrogen storage in agroforests, tree plantations, and pastures in western Oregon, USA. Agroforestry Systems 60:123–130.

Smith, J.E., Heath, L.S., Skog, K.E. and Birdsey, R.A. 2006. Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States. Publ. GTR-NE-343, U.S. Forest Service, 216 p.

Tufekcioglu, A., Raich, J.W., Isenhart, T.M. and Schultz, R.C. 2003. Biomass, carbon and nitrogen dynamics of multi-species riparian buffers within an agricultural watershed in Iowa, USA. Agroforestry Systems 57:187–198.

US Dept. of Energy. 2006a. Technical Guidelines for Voluntary Reporting of Greenhouse Gas Program, Chapter 1, Emission Inventories, Part I Appendix: Forestry. PDF document accessed 2 April 2007 at http://www.eia.doe.gov/oiaf/1605/aboutcurrent.html.

US Dept. of Energy. 2006b. Technical Guidelines for Voluntary Reporting of Greenhouse Gas Program Chapter 1, Emission Inventories, Part H Appendix: Estimating Carbon Fluxes from Agricultural Lands Using the CarbOn Management Evaluation Tool for Voluntary Reporting (COMET-VR). PDF document accessed 2 April 2007 at http://www.eia.doe.gov/oiaf/1605/aboutcurrent.html

Zhou, X., Brandle, J.R., Schoeneberger, M.M. and Awada, T. 2007. Developing above-ground woody biomass equations for open-grown, multiple-stemmed tree species: Shelterbelt-grown Russian-olive. Ecological Modelling 202:311–323.