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ESTIMATING CARBON STOCK CHANGE IN AGROFORESTRY AND FAMILY FORESTRY PRACTICES

Miles L. Merwin[1], Mark Easter[2], Lyn R. Townsend[1], Roel C. Vining[1] and Greg L. Johnson[1]

[1]USDA Natural Resources Conservation Service, 1201 NE Lloyd Blvd., Portland, OR 97232
[2]Natural Resource Ecology Laboratory, Colorado State University, Ft. Collins, CO
Contact: Roel.Vining@por.usda.gov

Abstract: The Carbon Management Evaluation Tool for Voluntary Reporting (COMET-VR) is an online tool that estimates short-term carbon stock (CS) changes under different farm or forest land management systems, including temperate agroforestry practices. It was developed by the USDA Natural Resources Conservation Service in conjunction with Colorado State University. The intended audience includes private farm and forest landowners, NRCS field staff, and technical service providers. Through the online interface, users identify their location, parcel size, surface soil texture, crop rotation history and tillage intensity. The user can choose either of two methods to estimate CS change for their agroforestry practice: 1) for new or future plantings, by using standard prescriptions common to their geographic region, or 2) for a more accurate estimate of an existing planting, by using a summary of live-tree stand inventory data collected from their parcel. Above and below-ground individual tree biomass is calculated using diameter-based allometric equations generalized for tree genera groups. For existing agroforestry plantings, growth estimates are based on empirical models developed from forest inventory data specific to species and region. For new or future plantings, growth estimates were derived for standard agroforestry prescriptions using the Forest Vegetation Simulator. COMET-VR uses the Century soil carbon model to estimate CS change in soil. The output of the tool is a report estimating CS changes over the forthcoming 10 years in the above and below-ground portions of live trees and in the soil. Although specifically designed to meet the requirements of the US Dept. of Energy voluntary greenhouse gas reporting program, COMET-VR may also be applicable to other private and public sector carbon offset programs.

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

INTRODUCTION

A new version of the online Carbon Management Evaluation Tool for Voluntary Reporting (COMET-VR) tool enables landowners to rapidly estimate potential changes in live tree and soil carbon stocks (CS) under different temperate agroforestry management practices in the conterminous US. These include the row-type agroforestry practices Alley Cropping (including nut orchards) and Windbreaks, and the forest-like practices Multi-Story Cropping, Riparian Buffers and Silvopasture. An additional practice, Farm Woodlots, is also included for non-industrial family forest plantings. It uses the Century Soil Organic Matter model (Century), 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 short-term changes in CS under the US Dept. of Energy's 1605(b) program.

Work to add the reporting of agroforestry practices to COMET-VR, which was previously calibrated only for annual crop rotations and grazing on farm and range lands, began in early 2006. Merwin and Townsend (2007) described methods and expected results during an earlier stage of its development. This paper describes changes incorporated in the current (2009) version of COMET-VR that includes the agroforestry/family forestry extension.

MATERIALS AND METHODS

Carbon Pools and Tree Biomass Estimation

Since the DOE 1605(b) reporting period is only ten years, the COMET-VR agroforestry extension focuses on those components that account for most of the short-term change in CS. Smith and Heath (2008) estimated that 85% of the total net annual CS change in all US forests from 1987 to 2001 was in the live tree (66%) and forest soil (19%) pools. The remainder occurred in other pools that change more slowly: shrubs and herbaceous understory (2%), forest floor (4%) and down dead wood (8%). Technical guidelines for reporting of greenhouse gases from agroforestry projects under the DOE 1605(b) program recommend measuring and monitoring of carbon in the live tree (above and below-ground) and soil pools (US DOE 2007a). Guidelines for forest carbon sequestration projects also recommend monitoring only these three pools for agroforestry, afforestation and forest restoration projects (Pearson et al. 2007). These pools are the only ones estimated by the COMET-VR agroforestry/family forestry extension.

To estimate live tree biomass in agroforestry practices, COMET-VR uses a generalized, diameter-based allometric equation developed by the US Forest Service that predicts total above-ground and component (roots, branches, etc.) dry weight biomass of individual trees from diameter at breast height (dbh) for all US tree species divided into ten genera groups (Jenkins et al. 2003, 2004). It is designed for use at the national scale over all sites, slopes, aspects, elevations, etc.

Tree Growth Estimation

No "universal" model to predict the growth of trees in agroforestry practices in all regions of the US exists. However, it is possible to develop empirical models of individual tree growth by species from periodic inventory data collected from a large number of field plots (Lessard 2001).

The first attempt to develop an empirical growth model was to try to relate tree age with dbh (Merwin and Townsend 2007). Published data from the Forest Inventory and Analysis (FIA) program was obtained from US Forest Service. Site trees of known age and size were selected. However, due to a high level of site and genetic variation, the resulting plots of age versus dbh by species and location failed to produce realistic or useable models of tree growth. The data had too wide a scatter to fit a non-linear equation that could represent an expected (sigmoidal) tree growth pattern.

The second method tested and the one ultimately used in COMET-VR was relative diameter increment. This method relies on data from individual trees whose diameters are measured at two different points in time. It's not necessary to know the age of the tree, only its current dbh, which is a more easily-measured and accurate variable. The growth metric is diameter change over time (standardized to 10 years) relative to the starting diameter, i.e.

$RI = ((DBH_1 - DBH_0) / DBH_0) * (10 / RemYrs)$

where RI is relative increment, DBH_0 is the dbh at the first measurement time, DBH_1 is the dbh at the second measurement time, and RemYrs is the time intervals between measurements in years. Relative diameter increment is a common measure of tree growth (Bragg 2001, Lessard et al. 2001, Westfall 2006).

Development of growth models based on relative diameter increment for COMET-VR followed the work of Lessard et al. (2000, 2001). They created growth models using state-level FIA data that have two terms: average dbh increment and a modifier. For COMET-VR, only the average growth term was used because the modifier term requires collection of more detailed information than was deemed practical for COMET-VR users, e.g. crown ratio, basal area, etc. Therefore, the growth equation predicts growth of "average" trees on an "average" site.

The form of the growth equation used for COMET-VR is as follows,

ARI = a*exp(-b*x)*(x^c)

where ARI is average relative increment, x is average dbh at the current age, and a, b, and c are coefficients.

Because of the relatively short, 10-year reporting period for the 1605(b) program, the tree growth estimates produced by COMET-VR assume no mortality, harvest, or significant change in growth potential due to management, microclimate or inter-tree competition during the interval.

Inventory Data and Analyses

Both published and unpublished data from FIA inventories in which trees were remeasured at least 10 years apart were obtained from FIA National Spatial Data Services for all but one of the conterminous states. The data were mainly from older periodic inventories, since the newer annual inventories conducted by FIA since 2000 only allow comparisons over short remeasurement intervals. Only live trees that were not overtopped by adjacent trees were selected. Geographic locations of tree records were identified at the level of Land Resource Region (LRR) and Major Land Resource Area (MLRA) (USDA 2006). (For COMET-VR, alphabetical subdivisions within an MLRA, e.g. 43A, B and C, were combined into one.) Data were then fit by nonlinear regression to the ARI growth equation to derive coefficients for each combination of species by MLRA and species by LRR.

In addition to the FIA forest inventory plot data available from USFS, data from windbreak trial plots are published by the Natural Resources Conservation Service (NRCS). The data are from windbreak species evaluations monitored under the Ecological Site Inventory System (ESIS) and located in the central states. The original idea was to use FIA data to derive growth models for the forest-like agroforestry practices and Ecological Site Inventory (ESI) data to derive growth models for the row-type practices in COMET-VR (Merwin and Townsend 2007).

ESI data on tree species and dbh were accessed online (http://esis.sc.egov.usda.gov/). The data are averages of 10-tree row plots and can be differentiated on the availability of supplemental moisture. However, no remeasurement data are available for the same trees on the same plots over time. Therefore, it was not possible to calculate relative diameter increment. Instead, an attempt was made to correlate tree age with dbh for species by LRR combinations, using the Chapman-Richards tree growth model (Richards 1959). However, there was too much variability in the ESI data to produce a good fit to the Chapman-Richards equation. Therefore, it was decided to use only the ARI method outlined above for tree growth equations regardless of agroforestry practice.

Site Productivity Class

Potential growth of trees in agroforestry practices depends not only on genetics and microclimate, but also on site factors such as soil moisture holding capacity, slope, aspect, etc. Some of the state-level FIA files used for COMET-VR contain a rating of the Site Productivity Class of the inventory plot, which is a measure of the site's inherent capacity to grow stemwood, expressed as cubic feet/acre/year.

An attempt was made to correlate ARI with site productivity class for selected commercial species in some regions, e.g. Loblolly pine in the Southeast (Merwin and Townsend 2007). However, the analysis did not result in a consistent relationship between growth (ARI) and site class code. Also, it was decided that it would be difficult for the average COMET user to obtain their site productivity class code. Therefore, site class is not used in the current version of COMET-VR.

Agroforestry Prescriptions

Predictions of soil CS change for annual crops on farm and range lands calculated by the Century model under COMET-VR are based on agronomic crop rotations commonly used in each MLRA. These crop rotations were parameterized with the Century model to estimate soil C changes. It was therefore necessary to develop a set of standardized prescriptions for common agroforestry practices in all regions (LRRs) of the US.

From a telephone survey of NRCS foresters and a literature review, a set of 84 agroforestry prescriptions was developed for all LRRs that include different combinations of hardwood and softwood species and planting densities derived from recommended tree spacings. Using the Jenkins biomass equation and the ARI growth equation described above, the live-tree biomass growth of each prescription was modeled over a range of starting diameters (1-50 inches). These values are used to predict the change during the 10-year reporting period in dry-weight above- and below-ground biomass per tree for the standard prescriptions in each LRR.

The change in soil C during the same period is estimated by Century following parameterization of each prescription to the model. Parameterization was done by LRR and Jenkins biomass group rather than by species.

To help validate the parameterization of these prescriptions with Century, biomass growth was also modeled using selected regional variants of the Forest Vegetation Simulator (FVS) (http://www.fs.fed.us/fmsc/fvs/index.shtml). All but one of the FVS variants used contain the Fire and Fuels Extension (FFE) which estimates CS changes over time in different forest components; only above and below ground portions of live trees were modeled in this instance.

The interface program Suppose with the database extension was used to run FVS. A stand initiation file was constructed using National Forest sites, average site indices and potential vegetation codes that were deemed to be generally representative of each LRR. For some LRRs, e.g. DN and E, prescriptions were modeled with more than one FVS variant. Tree growth in each prescription was simulated for 60 years in 10 year cycles, starting from planting 2-year old seedlings on bare ground. The carbon submodel of FFE (based on the Jenkins biomass equation) was used to model total above and below-ground C for all live trees in the stand at each cycle end. These values were converted to dry biomass assuming that woody biomass is 50% C by weight.

RESULTS AND DISCUSSION

The inputs and outputs of an earlier version of the COMET-VR user interface were previously described by Merwin and Townsend (2007). Through the online interface, users identify their location, parcel size, surface soil texture, crop rotation history and tillage intensity.

One important change in the current released version is on the land management information page. Here the user is asked to select the agroforestry or family forestry prescription(s) which most closely match(es) their own current or future plantings from a list of regionally-appropriate choices. A choice of agroforestry practices is available for the two most recent time periods, i.e., pre-1970s to the forthcoming 10 years.

After choosing the appropriate prescription, the user is asked if they have data to enter from an inventory of their agroforestry planting. This choice-point determines which of two methods is used to estimate CS change on their parcel for the reporting period. If the user does not have inventory data, the agroforestry practice is not yet established, or the average dbh of the trees is currently less than 1 inch (25 mm), then CS estimates are based solely on pre-calculated values for the agroforestry prescription they selected for the reporting period in the previous step.

On the other hand, if they have data collected from a current inventory of their planting and wish a more accurate estimate, then the CS estimate is predicted from calculations using the biomass and growth equations for their tree species and geographic region.

For either method used to calculate CS change for an agroforestry parcel, the results are reported to the user in the form of a table. The carbon storage report presents the annual change in C for the entire parcel subtotaled by above-ground live tree, below-ground live tree and soil. For each pool, values are given in tons C per year, tons CO_2 equivalent (CO_2e) per year and uncertainty. The uncertainty estimates for these annual CS change values are based on long-term experiments of agronomic rotations.

To guide the user through the COMET-VR interface, extensive online Help is available. This includes detailed instructions and worksheets for performing field inventories in both row-type and forest-like agroforestry practices; descriptions, photos and references for the five common agroforestry practices plus family forestry; and step by step instructions for navigating the COMET-VR interface.

CONCLUSIONS

The latest version of COMET-VR is a first attempt to provide a user-friendly carbon estimation tool for agroforestry and family forestry practices in the conterminous US. The intended audience includes private landowners, farmers, ranchers, non-industrial private forest owners, NRCS field staff, and technical service providers. In keeping with the design criteria for COMET-VR, the agroforestry extension is designed for relative ease of use, national-scale applicability, and reasonable accuracy across a wide range of site factors.

Research conducted at University of Nebraska Lincoln (UNL) on windbreak trees in some central states suggests that the Jenkins biomass equation may significantly under-estimate biomass in widely-spaced trees growing in windbreaks (Zhou et al. 2002). More research is needed on this question, involving species and regions beyond the UNL study.

FIA data used to develop the ARI growth equation was collected mainly from forest stands that may not include the lower planting densities often found in widely-spaced or linear agroforestry practices, i.e., windbreaks and alley cropping. It has been suggested that FIA incorporate more inventory plots of “working trees” on agricultural lands (Perry et al. 2009). That would allow the development of more accurate models of tree growth in row-type agroforestry plantings. Nevertheless, tree growth models derived from FIA data collected in forest stands should be a good predictor of growth in family forests and forest-like agroforestry practices, i.e., multi-story cropping, silvopasture (except widely-spaced tree rows), and riparian buffers.

Furthermore, the FIA plot data used are from older periodic inventories dating back to the 1970s in some cases. USFS has since changed to an annual program of data collection. For a future version of COMET-VR, it would be worthwhile to compile a new dataset from annual inventory data with remeasurement intervals of 10 or more years. Using more recently collected inventory data would better reflect potential tree growth responses to changing microclimates.

As mentioned above, site quality is a strong predictor of tree growth. More work is recommended to try to differentiate potential growth of selected tree species by site index or site productivity class. That would improve the accuracy of CS change estimates for users able to assess the relative site quality of their land.

COMET-VR is currently accredited for voluntary reporting of CS changes in soil under agronomic practices for the DOE 1605(b) program (US DOE 2007a). Guidelines for the use of models for reporting of CS changes in forestry projects under 1605(b) give higher ratings for models that produce estimates close to the actual values, e.g. an A rating for 90% or higher accuracy (US DOE 2007b). The latest release of COMET-VR has not yet been approved or rated by US DOE for reporting of CS changes in agroforestry or family forestry projects, and field studies are needed to compare model estimates with values obtained through direct measurements. The use of site-specific inventory data should earn the user an A or B rating, whereas estimates based only on standard prescriptions may earn a C rating.

Although it was originally designed to be used for voluntary reporting under the 1605(b) program, COMET-VR could potentially be used in existing or future greenhouse gas (GHG) trading systems. For example, Chicago Climate Exchange (CCX) protocols for monitoring of carbon pools in managed forests allow the use of models such as FVS. Field testing would be required to determine if the current release of COMET-VR could be used for monitoring and verification of agroforestry / family forestry carbon offset projects under CCX. Nevertheless, COMET-VR is useful now for planning purposes since it enables landowners to compare potential CS changes that may result from applying different agronomic, grazing, agroforestry and family forestry practices on their land.

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