

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[®])

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1. Introduction

This appendix describes how to use the CarbOn Management Evaluation Tool for Voluntary Reporting (COMET-VR)¹ to estimate carbon flux in mineral soils. COMET-VR was developed by the Natural Resources Conservation Service (NRCS) of USDA in collaboration with researchers at the Natural Resources Ecology Laboratory at Colorado State University for the purposes of reporting under the revised 1605(b) program.

COMET-VR is a web-based calculation tool that allows users to estimate changes in mineral soil carbon storage on cultivated lands for most regions and cropping systems prevalent in the United States. The COMET-VR system has a simple interface where users provide basic information about a parcel of land including soil characteristics and land management and COMET-VR provides estimates of annual soil carbon flux. Specific information requirements and guidance on using the tool for reporting in the 1605(b) program are discussed below.

The primary function of COMET-VR is to estimate soil carbon flux. It can also provide data on fuel use and nitrogen fertilizer applications to facilitate reporting for other agricultural greenhouse gas emissions sources. The output data for fuel and nitrogen fertilizer can be applied to methods in the Technical Guidelines for Transportation and Agriculture sectors to generate additional emissions estimates.

2. Using COMET-VR

This section provides guidance on using COMET-VR to estimate soil carbon flux for an entity. The section provides a general overview of information required, step-by-step instructions for inputting information into COMET-VR, and guidance on using COMET-VR output for reporting in 1605(b).

2.1. Information Requirements

COMET-VR uses a simple web interface to initiate a run of the Century model.¹ Each run is based on users inputs for a unique parcel of land within their entity or sub-entity. A parcel is defined as an area of land that has uniform soils and common historical and present day drainage, crop rotations, and grazing or tillage management. Users input data as they are guided through seven screens Data inputs include: parcel location and size; soil characteristics; and past and present crop rotations and tillage or rangeland practices. For most of these inputs, users choose among menu options, with menus based on regional characteristics. Users will keep records of individual parcel estimates and sum these to make entity or sub-entity level estimate

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2.2 Step-by-Step Instructions for Using COMET-VR

2.2.1. Logging into the system

COMET-VR can be accessed at <http://www.cometvr.colostate.edu>. Users will launch COMETVR from this site and will be guided through seven input screens. COMET-VR then provides a Carbon Report with estimates of carbon flux on the parcel of land. An optional report on fuel and fertilizer use will also be available. For the sake of privacy, each run using COMET-VR will be made available only to the user and will not be stored on the main server. Users will have the option of printing and/or downloading the output report to a local drive.

2.2.2. Getting Help

A Help Manual with instructions for inputting data is provided at the website under the Help button.

2.2.3. State Selection Screen

The user selects the State in which the parcel is located.

2.2.4. County Selection Screen

The user selects the County in which the parcel is located

2.2.5. Parcel Selection Screen

Users will designate a name for the parcel, English or metric output units, and the size of the parcel in the units selected.

2.2.6. Soil Selection Screen

Users have a choice of six different soil types (Table 1). Resources for determining soil type for a parcel of land are provided in the help menu.²

Table 1. Definition of COMET-VR Soil Types

Soil Type	Sand	Silt	Clay	Includes soil types:
clay loam	28%	41%	31%	
loam	40%	41%	19%	
loamy sand	81%	14%	5%	fine sand, loamy coarse sand, loamy fine sand, loamy very fine sand, sand
sandy loam	61%	27%	12%	fine sandy loam, very fine sandy loam, coarse sandy loam, sandy clay loam
silty clay loam	7%	60%	33%	silty clay, clay
silt loam	12%	68%	20%	silt

² Details on the model are provided in the supplemental materials in section 3.

Most soil types vary within their texture classification, so users should define the soil type that best describes the texture of the soil in the parcel. Parcels should be defined so that a single soil type dominates.

Hydric Soil

Users must specify whether or note the soil is hydric. "Hydric" generally means that the soil developed under moderate to poor drainage conditions such that some or all of the soil became anaerobic for some portion of the year. If the soil in the parcel has been artificially drained at some point during its history, it is likely to be hydric.

2.2.7. Rotation Selection Screen

Specifying Management History

The final steps involve defining the general cropping and tillage history for the parcel, as follows:

Selecting Rotations

Landscape Position and Historical Management: Defined as the time immediately following land conversion to agriculture up to the mid-1970's. This period establishes the agricultural history of the parcel based on dominant trends of the era. Land use histories are assumed based on general land form or land management and defined by either the landscape position (upland vs. lowland) or other long-term management for the parcel prior to the mid-1970s. Users choose one of four options:

- Upland for parcels located on hill slopes, mesas, or table land above valley floors, which were generally cropped as continuous annual grains, cotton, or other crops.
- Lowland for parcels in valley floors that were generally cropped as cash grains or cotton rotated with hay or pasture.
- Irrigated refers for parcels in upland or lowland areas that came under irrigation some time prior to the 1970s, and were generally cropped as high-value cash crops. This entry should be chosen over upland or lowland if applicable.
- Livestock Grazing refers to parcels that have been grazed more or less continuously since settlement up until the 1970s.

1970's to 1990's: This period is defined generally as the mid-1970's to mid-1990's and establishes likely impacts of agricultural uses during this time period drawing on data collected in the Carbon Sequestration Rural Appraisal (CSRA) about rotations and other management practices. Estimated present and future soil carbon sequestration rates are sensitive to the management and tillage practices used during this time period. Users will select the cropping rotation that most accurately describes the cropping system grown on the parcel from the mid 1970s to the mid 1990s. If more than one rotation was grown during this time, select the system that was grown for the longest time during that period.

Base (Current Management): The time period immediately prior to the reporting period and generally covering the mid-1990's to present. Information provided for the Base Period establishes soil conditions immediately prior to the reporting period. Estimated present and future soil carbon sequestration rates are sensitive to the management and tillage practices used during this time period. Users will select the cropping rotation that most accurately describes the cropping system grown on the parcel over approximately the last decade. If more than one rotation was grown during this time, users should select the system that was grown for the longest time during that period.

Management Over Report Period (next decade): Refers to cropping rotation that you will be growing on the parcel for the reporting period and assumes that conditions are maintained for ten years into the future. By definition, the Report Period begins with the Reporting Year designated by COMET-VR and continues for 10 years. Select the cropping rotation that will be used in the reporting period.

2.2.8. Tillage Selection Screen

Users will choose one of three tillage practices for the later three time periods described above. The tillage choices are intensive, reduced, or none (i.e., no till).

2.2.9. Review Screen

Before submitting data for a Century run, users will be encouraged to review their data inputs and make any corrections. The submit button is provided on this screen.

2.2.10. Carbon Flux Report

Upon submission data, the web interface will run the Century model to generate a soil carbon flux estimate and return a report to the user through their web browser. The report will summarize input data and provide an estimate of soil carbon flux for the parcel, as well as an associated percent uncertainty. The uncertainty designates a range around the estimate defined by +/- the percentage of the value, within which the true value is 95% likely to fall.

2.2.11. Fuel and Fertilizer Use Screen (optional)

Fuel and Fertilizer Nitrogen Changes

In addition, the database can calculate associated annual amounts of fuel use (No. 2 diesel) and in-organic nitrogen fertilizer amendments for the parcel in the base and report period. These estimates are based on data collected in the CSRA and reflect default parcel-level application rates. The user may also input parcel level information on fuel, electricity and nitrogen fertilizer (actual N applied) based on their records. This provides a single parcel-report with information on soil carbon flux together with the associated fuel, energy and nitrogen changes, which can be saved to a local computer for use in generating entity level estimates.

2.3 Reporting Carbon Flux with COMET-VR

Users will run COMET-VR to generate parcel-level estimates of soil carbon flux and will keep their own records of these values. Entity estimates are derived separately by the reporter from their records. This section provides the basic steps for developing entity level carbon flux estimates.

General Procedures for Developing and Entity Estimate:

1. Divide the entity into parcels following guidance above.
2. Prepare records for each parcel by collecting information such as area, location, soil type, etc. to use as inputs to COMET-VR. An entity or sub-entity may contain a single or multiple parcels depending on the diversity of cropping systems and land features.
3. Use COMET-VR to estimate and record annual soil carbon flux values for each parcel.
4. Sum individual parcel estimates for an entity or sub-entity total carbon flux estimate.

Soil carbon flux rates are based on long-term soil dynamics. Therefore, parcel estimates provided by COMET-VR are valid for up to 10 years. Unless the rotation or tillage practices chosen for the Report- Period change, users may use the same carbon flux for a parcel of land for up to 10 years. When changes occur in rotations or tillage practices on a parcel of land, a new query of COMET-VR must be initiated. All inputs will remain the same, except for entries for the Report Period rotation and tillage.

Whenever no-till practices are ceased and intensive or reduced tillage is implemented the majority of carbon stored in soils will be lost to the atmosphere. Therefore, switching from no-till to intensive/reduced till results in soil carbon losses that equal the sum of all reported soil carbon sequestration for that parcel. Under these circumstances users will not use COMET-VR to estimate soil carbon losses; rather they will refer to their own records to estimate soil carbon losses.

3. Summary of Supporting Information

This section contains details on the development of COMET-VR. It goes into depth on research related issues that users do not need to familiarize themselves with in order to use COMET-VR. It is provided for background information only.

This section provides a rationale for, and detailed description of, the methods used to estimate soil carbon flux for different agricultural practices and regions in the US. The estimates are designed to be applicable for the major cropping regions of the US, where land use data are based on information aggregated for relatively large regions (Land Resource Regions [LRR]), while climate and soils are based on information at a

somewhat finer scale (i.e., Major Land Resource Areas, MLRAs), which delineate major agroecological zones (>200) in the US.

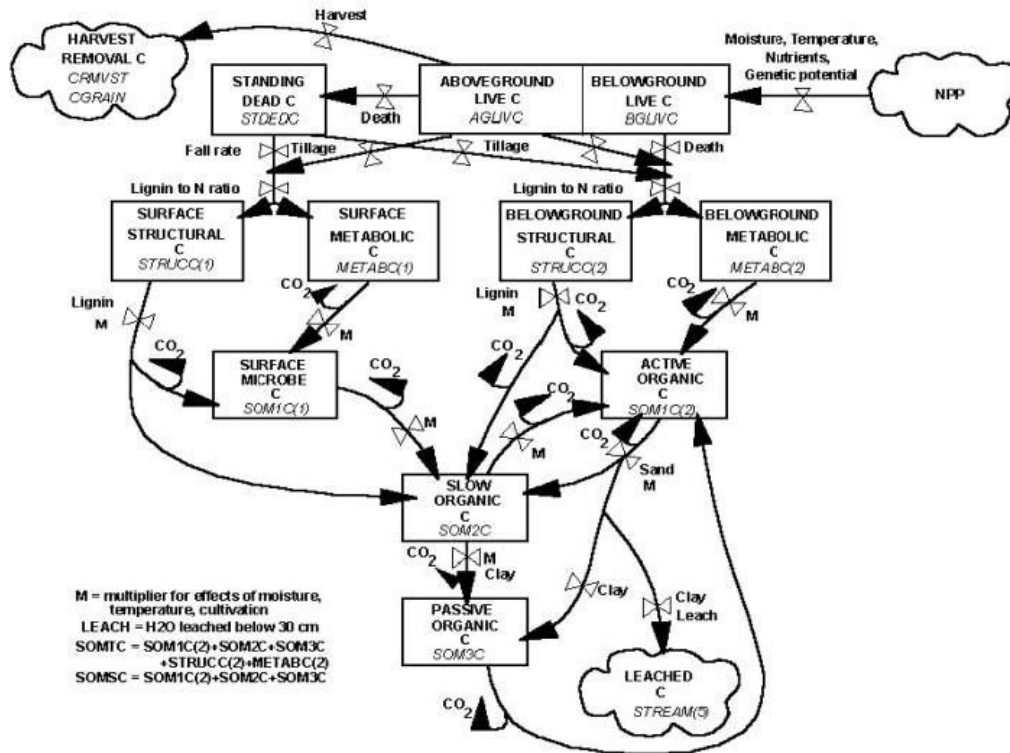
The Century ecosystem/soil organic matter turnover model (Metherell et al. 1993, Parton et al. 1994) was used to compute estimates for soil carbon emissions and sequestration for US agricultural soils. Century is a generalized biogeochemical ecosystem model, developed in the US, that simulates carbon (i.e., biomass), nitrogen and other nutrient dynamics. The model can be used to simulate cropland, grassland, forest and savanna ecosystems and land use changes between these different systems. The model is used by a number of researchers worldwide and is also used for national soil C and greenhouse gas inventories in the US and Canada (EPA 2003, Smith et al. 2000). The model has been used previously in several regional studies of soil organic matter dynamics (e.g., Burke et al. 1989, Cole et al. 1987, Ojima et al., 1993; Parton et al., 1995; Paustian et al., 1996, 1997) and in state- and county-level assessments of agricultural practices and soil C sequestration (Brenner et al. 2001, 2002, Paustian et al. 2002, Smith et al. 2002).

The model consists of four main subsystems: a plant process submodel, a soil organic matter and nutrient cycling submodel, a soil water balance and temperature model and subroutines that manage I/O and scheduling of land use and management practices. For cropland and grassland systems, a wide range of different management practices can be simulated including all major crop types and crop rotations, planting, harvest, differential residue removal, fertilization, tillage, irrigation, drainage, manure application, grazing and fire.

The model runs on a monthly time step, using monthly temperature and precipitation data and hence management practices are also ‘scheduled’ on a monthly basis. Other model input variables include soil physical characteristics, i.e. soil texture, soil depth and soil drainage status. Soil physical parameters controlling soil water balance (e.g. water contents at field capacity and wilting point) can be specified from measured or estimated internally in the model from soil texture and organic matter content.

The soil organic matter and nutrient submodel is summarized in Figure 2.1. Plant residues (from plant and root senescence during the growing season and at harvest) are apportioned into two ‘litter’ pools (metabolic and structural), representing easily and more recalcitrant plant components. Litter can be deposited both on the soil surface and within the soil and the placement of litter impacts its decomposition rate. As litter is decomposed it is transformed into soil organic matter, which is represented by three pools – active, slow and passive – representing easily degradable to highly recalcitrant organic matter compounds. A full description and documentation of the model are provided in Metherell et al. (1993).

Fig. 2.1: Diagram of major organic C state variable and C flows in Century.



CENTURY Model Validation and Verification

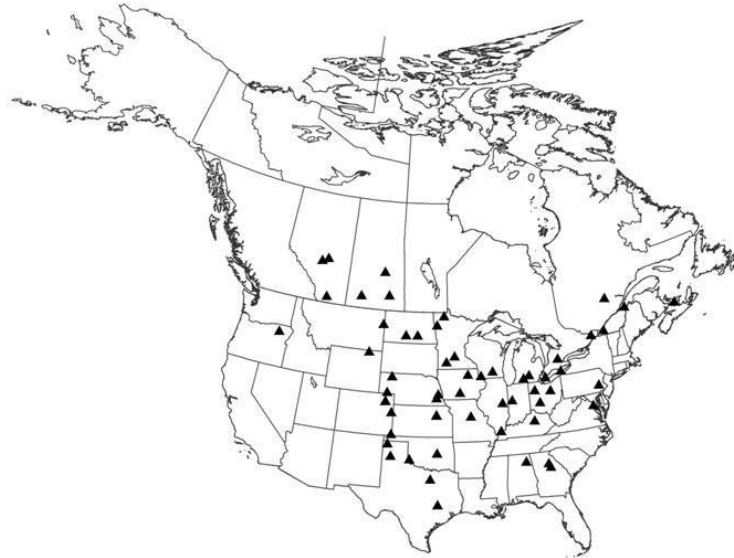
The CENTURY model and the crop parameters used to drive this study have been validated through analysis of more than 800 long term crop production experiments at more than 60 different experiment stations throughout North America. Research personnel at the Natural Resources Ecology Laboratory (NREL) of Colorado State University collected published and unpublished research data from studies that combined soil carbon and crop production measurements, in order to verify the plant growth and soil carbon decomposition submodels within CENTURY. Findings from this approach were used to improve the crop production parameters used as inputs to the CENTURY model, and improved various aspects of the CENTURY model related to plant growth and decomposition.

Synthesis of Existing Literature and Data

The Agroecosystem Soil database was developed at the NREL and currently contains about 1200 peer-reviewed journal articles, representing 65 countries. Locations for studies in the US and Canada are shown in Figure 2.2. The database stores studies from agro forestry lands, cultivated lands, wetlands, organic soils, native lands, pasture and urban lands. Research articles were chosen from the database for this study according to certain criteria. Long-term experiments providing detailed management, site information

and total soil carbon data, were selected for model validation. Experiments that improved the geographic coverage of this study were prioritized, as were studies that evaluated crop rotations, tillage effects, fertilizer rates, cover crops, organic amendments, Conservation Reserve Program enrollment and grazing practices.

Figure 2.2: Locations of long term field experiments in US and Canada



Utilization of Geographic Information Systems for the Development of a Conterminous U.S. Land Cover Dataset for Land Resource Region Analysis

Several geographic data layers are needed for Century model input. One of the critical dataset layers is a conterminous U.S. Land cover dataset with irrigated agriculture as one of the land-use classes. Geographic Information Systems (GIS) were used to analyze and assimilate several land-use layers into the final conterminous U.S. land cover coverage.

- The following datasets were used in combination to create the final land cover data used as input for the Century model:
- Twenty-one individual 1000-meter National Land Cover Data (NLCD) grids were obtained from the EROS Data Center, U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (USEPA) for the conterminous U.S. The NLCD data were reclassified from the original 21 classes into 10 land cover classes (Table 2.1).
- Irrigation information from the U.S. Geological Survey “National Atlas North America Seasonal Land Cover Characteristics” Arc/INFO grid map was extracted for the study.
- The Urban Areas of the United States from U.S. Geological Survey data set, updated in 2001, was provided by ESRI as data layer “urban.shp.”
- U.S. Roads (Generalized) represents interstate highways and major roads within the United States from ESRI “roads.shp” data layer.

Table 2.1: NLCD reclassified LRR land cover

Original NLCD Classifications & (GRID Layer)	New LRR Classification & (GRID Layer)
82 Row Crops (lc82)	1=crop (crop)
83 Small Grains (lc83)	2=fallow (lc84)
84 Fallow (lc84)	3=pasture/hay/grass (phg)
71 Grasslands/Herbaceous (lc71)	4=shrubland (lc51)
81 Pasture/Hay (lc81)	5=orchards/vineyards (lc61)
51 Shrubland (lc51)	6=forest (lc_forest)
61 Orchards/Vineyards/Other (lc61)	7=barren (barren)
41 Deciduous Forest (lc41)	8=bottomland (bottom)
42 Evergreen Forest (lc42)	9=water (water)
43 Mixed Forest (lc43)	10=urban (urban)
31 Bare Rock/Sand/Clay (lc31)	
33 Transitional (lc33)	
91 Woody Wetlands (lc91)	
92 Emergent Herbaceous Wetlands (lc92)	
11 Open Water (lc11)	
2 Perennial Ice/Snow (lc12)	
121 Low Intensity Residential (lc21)	
22 High Intensity Residential (lc22)	
23 Commercial/Industrial/Transportation (lc23)	
32 Quarries/Strip Mines/Gravel Pits (lc32)	
85 Urban/Recreational Grasses (lc85)	

- Major Stream data was extracted from ESRI “hydroln” arc coverage. The data is part of the National Atlas of the United States and was developed by the United States Geological Survey.
- Water body data was extracted from U.S. National Atlas Water Features of the United States from ESRI “hydroply” coverage.
- Bottomland coverage data was derived using the ESRI “hydroply” layer by extracting features labeled “Swamp or Marsh”.
- State Parks and Forest data, derived from ESRI “parks.shp” layer, represents National Parks, National Forests, State and local parks and forests within United States.
- U.S. National Atlas of Federal and Indian Land Areas data, derived from ESRI “fedland.shp” layer, represents the federal and Indian owned land areas (e.g., Bureau of Indian Affairs, Department of Defense, and Tennessee Valley Authority) of the United States.

The final land cover classifications are: cropland, fallow, pasture/hay/grass, shrubland, orchards/vineyards, forest, barren, bottomland, water, urban, Irrigated cropland, irrigated fallow, irrigated pasture/hay/grass, irrigated shrubland, irrigated orchards/vineyards, and state/federal land.

Carbon Sequestration Rural Appraisal (CSRA) Data Gathering

The CSRA consists of a series of data sheets detailing historical land-use and dominant management practices (drainage, irrigation, crop rotations, tillage and fertilization, grazing) over time compiled by local experts in each LRR. This procedure was successfully used in Iowa, Indiana and Nebraska to gather data from conservation districts (Brenner et al., 2001, 2002, Smith et al., 2002). CSRA used an Excel spreadsheet containing a series of work sheets. To assist in completing the CSRA, individual LRR maps were developed using GIS techniques as described in the 'Utilization of Geographic Information Systems for the Development of a Conterminous U.S. Land Cover Dataset for Land Resource Region Analysis' section. The 20 LRR's in the conterminous U.S. are defined by NRCS in Ag Handbook 296 (USDA-NRCS, 2003). USDA-NRCS collected land use data for each of the LRR's using the CSRA process. To assist in the data collection, individual LRR maps detailing the specific land cover including irrigated and non-irrigated cropland and the area within each category were developed.

Additional information was gathered at the county level to address management decisions necessary for crop production including irrigated or non-irrigated crop rotations including fallow periods, fertilizer rates and timing, tillage events and timing, crop yields, grassland type, fire frequency, fertilizer rates and timing, and grazing intensity and duration. CSRA data were verified against other published data where appropriate.

Representation of Land use History

To represent the influence of land use history and previous management practices, information from the literature and from the CSRA were used to divide the model simulations into four periods corresponding to regionally typical management practices. Those periods consist of:

- *Historic Period:* Plowout to mid-1970's. The model simulations were divided into pre1880 (if European agricultural methods were practiced during this time), 1881-1920, 1921-1950, and 1951-mid 1970's. The model simulations for these periods reflected changes in crop genetics, soil drainage, irrigation practices, tillage, and fertilizer application. They are divided into four basic land use history types, consolidated by basic landform and management categories: 1) *Upland* (generally consisting of continuous cash grains), 2) *Lowland* (generally consisting of alternating cash grains and hay/pasture), 3) *Irrigated* (generally consisting of highest-value, high-producing cash grain or hay crops), and 4) *Long-term grazing*.
- *Mid-1970's to mid-1990's.* Up to four dominant grain, hay, or grain/hay rotations and up to five dominant grazing practices were simulated for this time period, as specified by NRCS soil conservationists familiar with growing practices in each particular region of the country. Three tillage management systems (intensive tillage, reduced/mulch tillage, and no tillage) were simulated for each tillage agriculture rotation. Two CRP systems (100% grass, or a grass-legume mixture) may be selected as a management practice starting in 1985.
- *Base :* Mid-1990's to present time. Up to five dominant grain, hay, or grain/hay rotations, CRP systems (100% grass, or a grass-legume mixture), and up to four

dominant grazing practices were simulated for this time period, as specified by NRCS soil conservationists familiar with growing practices in each particular region of the country. Three tillage management systems (intensive tillage, reduced/mulch tillage, and no tillage) were simulated for each tillage agriculture rotation.

- *Report Period:* Present time into the future for one decade. Up to five dominant grain, hay, or grain/hay rotations, CRP systems (100% grass, or a grass-legume mixture), and up to four dominant grazing practices were simulated for this time period, as specified by NRCS soil conservationists familiar with growing practices in each particular region of the country. Three tillage management systems (intensive tillage, reduced/mulch tillage, and no tillage) were simulated for each tillage agriculture rotation.

Sensitivity and Uncertainty Analysis

Model uncertainties are often assessed using a Monte Carlo procedure (e.g., Ogle et al. 2003), in which probability distribution functions are constructed for the inputs and parameters in a model, as well as their shared dependencies, and then values are randomly selected from those distributions in an iterative manner to simulate a range of carbon sequestration values. However, the Century Agroecosystem Model is highly complex with several hundred parameters and inputs (Metherell et al. 1993), and so the Monte Carlo approach is less effective for evaluating uncertainty in carbon sequestration values from this model. Consequently, an alternative method has been used in this analysis with uncertainties quantified using an empirically-based approach (Monte et al. 1996), in which model results are compared to field data.

Results from over 50 long-term agricultural experiments were used for the comparison between modeled estimates and field data, representing a variety of tillage, cropping and land use practices. Differences between model output and field measurements were statistically analyzed using linear-mixed effect models. Uncertainty was applied to the carbon sequestration values based on the predictions from the statistical models and these estimates varied by management system and LRR.

Land Use Database Development

A relational database was developed to manage the data provided by the various LRR's for these assessments. This database was necessary to define the relationships between the various crops, non-irrigated and irrigated rotations, tillage operations, and cropping histories. CSRA data was checked to assure consistent terminology, definitions, and units between LRR's. Quality control of the CSRA responses is completed using existing data from national, regional and state databases. Complete details of study methods and results are available in the 'Supporting Documentation for the LRR National Study.